IDEA

Innovations Deserving
Exploratory Analysis Programs

INTELLIGENT
TRANSPORTATION
SYSTEMS

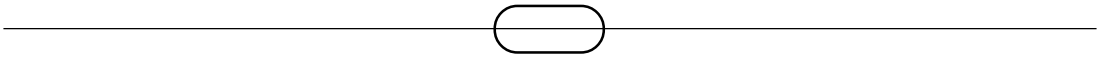
New IDEAs for ITS

Annual Progress Report
July 1998 — June 1999

TRANSPORTATION RESEARCH BOARD • NATIONAL RESEARCH COUNCIL

TRANSPORTATION RESEARCH BOARD

NEW IDEAS FOR INTELLIGENT TRANSPORTATION SYSTEMS



An Annual Progress Report of the
ITS IDEA Program

JULY 1998 – JUNE 1999

Transportation Research Board

National Research Council

ITS IDEA PROGRAM COMMITTEE

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INTRODUCTION

IDEA Programs explore promising but unproven concepts with potential to advance surface transportation systems. The ITS-IDEA Program is jointly supported by the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration (NHTSA), and the Federal Railroad Administration (FRA) and is one of the four integrated IDEA Programs managed by TRB. The other three IDEA programs are

- NCHRP Highway-IDEA, which focuses on concepts for advancing the design, construction, safety, and maintenance of highways;
- Transit-IDEA, which supports innovative approaches for improving transit operations and safety; and
- High-Speed Rail (HSR)-IDEA, which brings together ITS and structural/material advances to upgrade existing rail infrastructure for high-speed train operations.

Since 1993, ITS-IDEA has received $10.5 million in support from our DOT sponsors. An additional $2 million has gone to HSR-IDEA which was spun off of ITS-IDEA in March of 1997 with the formation of the HSR-IDEA Program Committee to manage railroad-related projects. The two programs remain closely associated since they are administered jointly by IDEA and have members who sit on both Program Committees. Together the programs have funded 91 projects (21 are administered through HSR and are not reported here). The average value of all the ITS-IDEA awards is close to $85,000. They have ranged in value from $29,000 to $240,000. From 8 to 15 ITS-IDEA awards have been made each year.

In October of 1999, IDEA sponsors at the U.S. Department of Transportation informed TRB that they will not provide funds to continue the ITS-IDEA Program in FY2000 and beyond.

Accordingly, TRB will not be making new ITS-IDEA awards beyond those selected from the September 1999 submittals. These new awards, and our currently active projects, will run to completion even if new funding for the program does not materialize. Our sponsors and investigators can be confident that these projects will be properly managed.

Although the ITS-IDEA Program is not accepting new proposals we continue to encourage researchers to submit proposals with ITS content to the "modal" IDEA programs (HSR-IDEA, Transit-IDEA, and NCHRP Highway-IDEA). IDEA staff will guide ITS proposals to the most appropriate programs but it is recommended that proposal writers keep one of the other programs in mind as they formulate their concepts.

ITS IDEA was designed to serve the federal multimodal ITS program. As ITS technology matures, it will inevitably be incorporated into the mainstream operations of the individual modes. We hope to facilitate this process by accepting as many ITS projects as we can in the modal IDEA programs.

This report is organized by project number. Brief reports on the results of projects completed before July 1998 appear first. Projects that were active between then and June 1999 are more fully described and illustrated and appear in the mid-section of the report. Projects in negotiation but not begun by June 1999 appear last. A table classifying projects by general ITS inter-

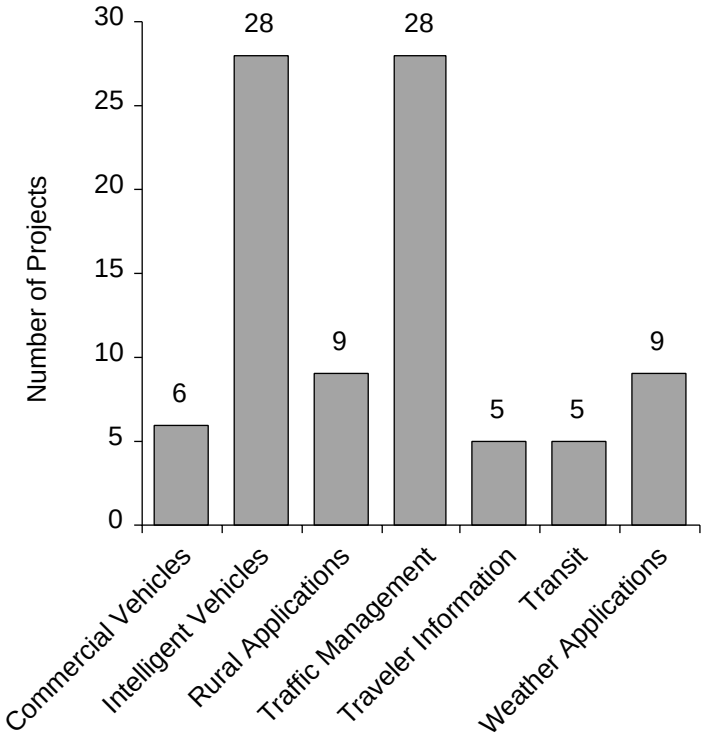


Figure 1

ITS area distribution of ITS-IDEA projects

est areas is included at the end of the report. Figure 1, taken from that table, shows the interest area representation of ITS-IDEA projects.

Figure 1 shows that ITS-IDEA projects have contributed in all areas of the federal ITS program. Intelligent vehicles and Traffic Management applications make up much of the program, as they should since they encompass the critical areas of vehicular safety devices, incident response, traffic control, and traffic surveillance. The other ITS areas, however, are also represented by more than just a token number of projects.

IDEA has a number of projects that were not high enough on anyone's list of funding priorities to otherwise find support. IDEA was an early source of support for rural ITS projects and for railroad grade crossing projects and continues to look for good projects in neglected corners of the ITS marketplace. This includes "social, behavioral, and institutional" projects where they can contribute to ITS deployment and the general safety and efficiency of the ground transportation modes. Projects that enhance intermodal connectivity are also encouraged.

Since July of 1998, ITS-IDEA award distribution between small companies, universities, and others remains about the same as it has been in the past. Universities received seven awards and small (all very small) companies received 6 awards. In the "other" category, two awards went to relatively large companies, one went to a large non-profit, and one went to the Minnesota DOT. ITS IDEA makes awards to about 10 percent of the proposals it receives.

PROJECTS COMPLETED BEFORE JULY 1998

ITS Type 1: Commercial Vehicle Operations and Fleet Management
IDEA Projects 13, 25

ITS Type 2: Intelligent Vehicle Systems
IDEA Projects 1, 5, 7, 9, 11, 12, 14, 16, 18, 21, 23, 24, 28, 41, 42, 48

ITS Type 3: Advanced Rural Transportation Systems
IDEA Projects 32, 34, 38

ITS Type 4: Improved Traffic Management and Analysis
IDEA Projects 2, 4, 6, 9, 15, 17, 19, 26, 27, 34, 35, 49, 52

ITS Type 5: Advanced Traveler Information
IDEA Projects 3, 8, 20, 49

ITS Type 6: Advanced Transit Systems and Operations
IDEA Projects: 3, 20, 36, 40, 49

ITS Type 7: Advanced Weather Applications
IDEA Projects 34, 38

PROJECTS COMPLETED PRIOR TO JUNE 1998

ITS-1: Collision Avoidance and Improved Traffic Flow Using Vehicle-to-Vehicle Communication

Bernard Galler and Harry Asher (313-763-4427)
University of Michigan, Ann Arbor

This project developed an onboard processing system based on short-range vehicle-to-vehicle communication that can predict potential intervehicular collisions and provide drivers with advance collision warnings using information from nearby vehicles. This project examines the feasibility of an intermediate level of communication that collects data from multiple vehicles in the local area.

The impact of the proposed advisory system is potentially large. Some 20 percent of all accidents are rear-end collisions that result in injuries and loss of life. Research results show that 60 percent of all rear-end collisions could be avoided if the driver were given an additional one-half second of warning before an incident.

The approach taken in this project is unique in that the proposed warning system allows vehicles to operate independently by using data from several vehicles ahead. It differs from two-vehicle interaction systems (such as distance warning systems) that focus only on the interaction between the driver's vehicle and the vehicle immediately ahead of it.

ITS-2: Models for Real-Time Incident Prediction

Samer Madanat and Pen-Chi Liu (317-494-3954)
Purdue University, West Lafayette, IN

The ITS-IDEA product is a proactive freeway-incident management system. It incorporates incident likelihood prediction models, with a Bayesian updating algorithm, into a traffic simulator. The simulator (INTRAS) is used to generate traffic characteristics that serve as inputs to the incident-likelihood prediction models. Environmental conditions are specified by the user. New predictions are produced according to a regular schedule and are used to update the freeway-incident likelihood. This sequential fusion of incident detection and prediction probabilities produces better estimates of incident likelihood because both traffic and environmental factors are taken into account.

State-of-the-art incident-detection algorithms use only traffic information. By considering both traffic and environmental variables, it is possible to achieve a more accurate estimate. The incident-likelihood models can be used as part of a proactive warning system for freeway motorists, or they can be combined with incident-detection outputs to improve the accuracy of the estimated incident probabilities.

ITS-3: Computerized Dispatching of Car Pooling Vehicles as Part of an Improved Metropolitan Area Transportation System

John Chisholm (702-972-8305)
CF International, Reno, NV

The intelligent metropolitan transportation system (IMATS) uses central computer management to provide services to a continuum of urban transportation modes with the goal of attracting a higher percentage of travelers to multiple-occupancy vehicles. As a part of the IMATS project, instant rent-a-car (IRAC) technology was developed to augment the mobility of people who would commute by carpool or transit if they had access to personal vehicles once they reached their destinations.

IRAC fleet management is based on radio communications between the vehicle and a central management facility. A user may reserve a vehicle or use a credit card to rent one on the spot. The transaction is verified and processed from the vehicle so that the user does not need to talk to a rental agent.

A potential near-term use of IRAC vehicles in transit practice as part of the Bay Area Rapid Transit (BART) Station Car Program was tested as part of IDEA project ITS-48 described below. Station cars are vehicles specifically targeted to serve as an adjunct to transit use. BART is incorporating IRAC rental procedures with the objective of renting each vehicle to several customers per day.

ITS-4: Distributed Input/Output Subsystem for Traffic Signal Control

Darcy Bullock (765-494-2226)
Purdue University, West Lafayette, IN

John Broemmelsiek
Louisiana Department of Transportation

This work, performed while the investigator was at Louisiana State University, applies off-the-shelf communications network components to simplify the electrical interface between a controller, its sensors (typically loop detectors), and its actuators (typically signal lamps). The product is unique in that spread-spectrum signals from the controller are carried over a pair of alternating current (110-VAC) wires that supply power to all the devices. Control modules at the actuators decode these signals and implement only the commands that are addressed to their devices. The process works in reverse for sensors, using the same hardware. This novel interface greatly reduces the quantity of wiring required for traffic signals and can easily be expanded to accommodate additional sensors and actuators. This can produce considerable savings by reducing labor and material costs.

The project applies LONWORKS network technology, which was originally developed to enhance system integration in the industrial control sector. This commercially available open-architecture technology is a prime candidate to replace the current 24-V logic used in traffic control systems with the goal of substantially simplifying cabinet wiring. Fundamental components make this technology possible.

As part of its “smart diamond” intersection controller project, the Texas Transportation Institute funded Louisiana State University to develop and install fiber-optic variable lane-assignment signs with the LonTalk interface. In addition, CalTrans has supported further development of this technology.

ITS-5: Feasibility Study of ITS Drifting-Out-of-Lane Alert System

Ed Ramey (334-844-4320)
Auburn University, AL

This project investigated two possible designs for low-cost automated systems that can alert drivers when their vehicle drifts out of its lane. Prototype vehicle-mounted infrared (IR) and radio frequency (RF) sensors that detect painted stripes on highway lane boundaries were developed. They sense when the vehicle passes over lane boundaries painted with paint that has been doped with ferromagnetic particles (for the RF sensors) or mixed to be IR reflective (for the IR sensors). The paint modifications and the vehicle-mounted sensors are not expensive and could form the basis for a cost-effective system.

Most lane-position-sensing concepts attempt to satisfy the fairly strict requirements needed for true automatic vehicle control. This calls for sophisticated and costly modifications to vehicles, roadways, or both. The potentially unique aspect of this IDEA product is that by focusing on aiding drivers instead of trying to replace them, the modifications to the vehicle and roadway can be simpler and less expensive. The goal here was limited to alerting an inattentive driver when the vehicle drifts out of its lane.

The results showed that operational conditions impose several limitations on applications of this low-cost technology to ITS practice. The IDEA concept, however, yielded a new application in automated maintenance operations for tracking and restriping painted lane markings.

ITS-6: Laser-Based Vehicle Detector/Classifier

Richard Wangler, Robert Gustavson, and Robert Olson (407-298-1802)
Schwartz Electro-Optics Corporation, Orlando, FL

A diode-laser-based vehicle detector/classifier (VDC) using a scanning laser rangefinder measures three-dimensional vehicle profiles for accurate vehicle classification. The narrow laser beam-width permits detection of closely spaced vehicles moving at high speed (even a 2-in.-wide tow bar can be detected). The VDC shows great promise for application in electronic toll collection from vehicles at freeway speeds, which require high detection and classification accuracy.

The VDC sensor scans two narrow laser beams at a fixed angular separation across a lane at a rate of up to 720 scans/sec. Pulsed time-of-flight range measurements provide an accurate (±3 in.) transverse vehicle-height profile on each scan. The vehicle speed, determined from the interval between the interception of the two laser beams by the vehicle, is used to space the transverse profiles appropriately to obtain the full three-dimensional vehicle profile. An algorithm similar to those developed for military target recognition is applied to the three-dimensional profile to classify vehicles.

More than 300 of these IDEA sensors, marketed under the “Autosense” trade name, have been installed by Hughes Traffic Management Systems on the Toronto Highway I-407 toll road project. They are also used in Korea to monitor bus lanes and are being evaluated at several locations in the United States for electronic toll collection applications similar to the I-407 installation. IDEA is currently funding development of axle-counting capabilities for this device (see ITS-65).

ITS-7: Driver-Adaptive Warning System

Christopher A. Miller (612-951-7390)
Honeywell Technology Center, Minneapolis, MN

The driver-adaptive warning system (DAWS) concept seeks to advance automobile safety with an intelligent collision warning system specifically designed to adjust itself to individual driving styles. Adaptive warning system technology has the potential to reduce dramatically the false-alarm rates of sensor systems that alert vehicle operators of hazardous situations. User acceptance of these systems can be greatly increased by taking the driver's unique behind-the-wheel style into account when setting warning thresholds for the vehicle.

The traditional approach to collision warning system design is to compare measurements of vehicle parameters, such as lane deviation, from on-board sensors with fixed warning thresholds derived for "average" driving scenarios. Because of the variability of the driving population, warnings provided by such systems correlate poorly with actual hazard for many, perhaps even most, drivers. Systems that can monitor data over time and adapt warning thresholds to individual driving styles will deliver much more reliable hazard assessments.

DAWS includes an on-board adaptive maneuver assessment module that analyzes the driver's actions (measured by on-board sensors) and, in only minutes, develops a set of models of a specific driver's characteristic behavior in making different driving maneuvers, such as lane changing, lane following, and traffic avoidance. A decision module compares the current driver behavior data with the modeled "norm" for that driver to detect altered driver states, such as fatigue and intoxication or the presence of an unauthorized driver. Specific hazardous events (e.g., a change into a nonexistent or occupied lane) can be detected in their early stages, and a warning can be delivered by the system's driver interface.

ITS-8: Laser Optics Open-Air Communication System

Sheldon Chang (516-632-8408)
State University of New York at Stony Brook.

The laser optics open-air communication (LOOC) system concept offers reliable, high-rate data communications between moving vehicles and the highway system. The concept applied the use of mechanically scanned laser technology that substantially reduces the required signal power and potential interference. As much as a megabyte of data can theoretically be exchanged in less than a second during each passage of a vehicle past an LOOC highway communication station under all weather and traffic conditions, without the vehicle stopping or slowing down. This amount of information is more than sufficient to cover high-volume ITS data transfer needs.

An automated highway system using reflective markers placed along the lane edges that could be sensed by scanning lasers mounted on each vehicle was also proposed so that vehicles could automatically follow the roadway curvature and remain centered within the lane. Both concepts were explored analytically. A later attempt at fabricating a prototype, funded through the High-Speed Rail Idea Program, failed due to an overwhelming number of operational complications that were not anticipated in the analysis.

ITS-9:
Decision-Theoretic Reasoning for Traffic Monitoring and Vehicle Control

Michael Wellman (313-764-6894)
University of Michigan, Ann Arbor

This project was the first to apply dynamic probabilistic networks to problems in traffic monitoring. The project builds on previous work on visual processing of real and simulated traffic images capable of identifying and tracking individual vehicles accurately. From these inputs and general traffic knowledge, IDEA algorithms generate and evaluate probabilistic models to assess the overall traffic situation for traffic management, emergency response, near-accident detection for intersection safety analysis, and intelligent traffic signal control, among other applications.

Recent advances in probabilistic modeling technology by artificial intelligence researchers have led to significant improvements in the flexibility of specifications of probabilistic knowledge. The standard probabilistic network framework has been extended to handle reasoning over time by adding nodes to represent state variables at progressive time slices.

The Indiana Department of Transportation is incorporating algorithms developed under this IDEA project into the traffic management center for the Borman Expressway corridor.

ITS-11:
Scale-Model Automated Highway System Research Facility

Randal Galijan (650-859-3217)
SRI International, Menlo Park, CA

The IDEA concept was intended to be an innovative scale-model test bed for automated vehicle control systems. An integral part of the investigation was the development of scaling laws designed to allow engineers to translate small-scale vehicle results to full-scale vehicles. The system was to have the dynamic realism necessary to perform scale-model testing of automated highway systems to reduce development cost and time while increasing safety and offering repeatability and accuracy of test scenarios.

The project developed two 1/4-scale test vehicles that were used as platforms for testing automated vehicle control systems. Most of the vehicle chassis was available off-the-shelf, but radar clutter problems were encountered in modeling the longitudinal control sensor. Developers of intelligent cruise control radars for full-scale vehicles have experienced similar problems. Operation at realistic speeds was found to require automatic lateral and longitudinal control. The timing involved in the maneuvering and cornering at scale AHS speeds is too demanding for manual operator control.

To further develop this concept for AHS research and development, SRI is integrating carrier phase Global Positioning System (GPS) equipment and algorithms onto the scale-model cars. The results show maximum GPS-measured excursions of less than 2 cm and an RMS deviation of 0.5 cm. These results indicate that carrier phase GPS can provide the position accuracy needed for vehicle control. The next step is to use this high-quality data for real-time lateral and longitudinal control of the scale-model vehicles. SRI is currently developing an automatic controller using fuzzy logic control techniques. See ITS-77 for related work by this investigator.

ITS-12: Vehicle Lane Control System

ITS-IDEA Project 12
William Bush (619-454-6513)
QST Electronics, Inc., La Jolla, CA

This new vehicle lane control system uses an innovative and cost-effective approach to determine a vehicle's position within its lane. A sensor in the vehicle establishes vehicle position relative to small resonant coils embedded down the center of the lane. Tests made on a straight course indicate that a coil spacing of 13 ft provides a signal suitable for automatic servo-control steering or lane departure warnings.

The lane-position sensor uses a simple electronic continuous-wave phase comparison module in the vehicle to detect the wire coils. The coils consist of a capacitor and a single-wire loop 4.5 in. wide and 14 in. long. They are completely passive and appear to sustain performance in a simulated highway environment. Because the link between the road and the vehicle uses radio frequency (RF) propagation, visibility impediments either in the air or on the road surface have no net impact on system performance. Tests have shown that system operation is not affected when the road coils are buried in 2 in. of asphalt, concrete, or salt water. The simplicity of the coils results in a system with low infrastructure cost.

A follow-up project was awarded to perform field trials of the IDEA concept (see ITS-41).

ITS-13: Development of an Intelligent Air Brake Warning System for Commercial Vehicles

Per Reinhall and Robert Scheibe (425-556-5555)
University of Washington, Seattle

Malfunctioning brakes are the leading mechanical cause of commercial vehicle accidents, and they constitute the most common safety violation. This IDEA project focuses on developing an on-board intelligent brake warning device (IBWD) for air brake–equipped commercial vehicles. The low-cost IBWD can be mounted in the cab or tractor of a truck or bus and will warn the driver of brake degradation or impending failure from any mechanical cause. It continually assesses vehicle brake performance in real time by monitoring a relatively small number of on-board parameters as well as relevant environmental information, such as grade severity and the presence of precipitation. The concept consists of an on-board microprocessor that measures brake air pressures, vehicle weight, speed, deceleration, and roadway environment information. The driver will not have to calibrate the device or manually enter any information related to the vehicle, road, or load. An empirically determined algorithm evaluates the measured data and identifies situations indicating impending loss of brake effectiveness. Because the IBWD will assess braking performance from the standpoint of the total vehicle system, it will be sensitive to brake degradation from any cause. The IBWD will require only a few sensors and systems not already carried on modern vehicles and will be complementary to other on-board systems, including the antilock brake system (ABS). The ITS communication system can also be incorporated to allow information flow to and from the vehicle.

Discussions are under way with several potential partners about implementation of the IBWD concept. PACCAR, Inc., has already demonstrated a commitment by subsidizing extensive full-scale testing and is interested in commercialization of the product. Various brake component manufacturers have expressed interest to the investigators for potential collaboration. The Washington State Department of Transportation has provided collaborative funding for this IDEA research and will continue its participation in IBWD field tests and verification. IDEA has recently negotiated a contract that will support more work on this technology (see ITS-75).

ITS-14: Adaptive Filtering for ITS and Advanced Vehicle Control

Laura R. Ray (603-646-1243)
Dartmouth College, Hanover, NH

This project developed adaptive filtering algorithms that provide high-quality information for vehicle decision making and automated control. A crucial parameter governing vehicle motion is the tire/road-surface coefficient of friction. All decision information for maintaining safety, such as vehicle stopping distance, safe following distance, safe speed, and lateral maneuverability, depends on this uncontrollable parameter. Road friction governs tire forces, which cause deceleration and traction and prevent a vehicle from spinning during a panic maneuver. Other important parameters governing vehicle motion can be measured using transducers, but there is currently no non-contact method to determine road friction. A sensor that measures road friction directly would be difficult at best to design, because friction depends on interactions occurring at the contact surface between a rolling tire and the road.

In the absence of a "road friction sensor," this project estimated road friction from measurements of vehicle motion. The major components of this project include a set of onboard transducers, an Extended Kalman Filter (EKF), a Bayesian Hypothesis Selection algorithm, and a Vehicle Parameter Determination block. The EKF provides coefficient of friction estimates that can act as feedback signals for braking and throttle inputs to improve vehicle control systems. A major automobile manufacturer is continuing to support this work.

ITS-15: Efficient Use of Narrowband Radio Channels for Mobile Digital Communication

Michael Fitz (614-292-8039)
Ohio State University, Columbus, OH

The IDEA project developed a communication architecture that efficiently uses narrowband land mobile radio channels for digital communications. The system will have 12 kbits/s transmission capacity on the 4-kHz channels in the 220-MHz band currently available to ITS applications. The results provide a resource for application to data communications in traffic management systems, travelers' information systems, and commercial vehicle operations. A prototype was developed, tested, and field verified.

The best wireline modems currently achieve efficiencies of about 9 bits/s/Hz, but narrowband wireless modems seldom achieve efficiency greater than 1 bit/s/Hz. Although the wireless channel presents a greater challenge due to its location dependence and multipath characteristics, the gap in bandwidth efficiency need not be so large. This project combines standard telephone modem techniques (e.g., large signal sets and complex coding schemes) with techniques specifically designed for wireless mobile data communications (e.g., time and spatial diversity). This approach provides a potential for a dramatic increase in the bandwidth efficiency of land mobile data transmission over narrowband (< 7 kHz) radio channels.

This work was performed at Purdue University, and IDEA funded additional work there on this concept (see ITS-47). Dr. Fitz has since moved to Ohio State and is collaborating with an equipment manufacturer, Welkin Systems of San Diego, on another IDEA contract for final development of this product (see ITS-86).

ITS-16: Vision-Engineered In-Vehicle Warning Signals Improve Driver Response to Hazards Detected by ITS Sensors

Theodore Cohn (510-642-5076)
University of California, Berkeley

An in-vehicle warning signal display concept was developed and tested through the application of vision-engineering principles. The design is based on the long-standing observation that moving or flickering objects are more likely to be noticed. By refining this insight with contemporary knowledge of the visual system, this IDEA project developed a system in which warning signals are noticed more rapidly and are more readily identified. The signals are arranged around a simple line drawing of a vehicle and, when actuated, are set in "apparent motion" by alternately illuminating adjacent images so that the signals oscillate. Tests show that these signals improve driver time to react and warning signal detectability when compared with static signals.

Various proof-of-concept tests were conducted to measure warning signal characteristics. In one test, an observer was given the task of pushing a button when he or she detected the signal, and the time to respond was measured for each trial. Two interesting features of the response time distributions were observed. First, moving signals had the lowest observed response times. Second, more extra-long response times occurred for stationary signals. Comparison of the average times does not fully convey this significant point. However, at 60 mph, the 276 msec of difference in the average delay observed for the off-axis detection task (most typical of dashboard warnings) would put a driver 24 ft further down the road before reacting to a warning signal. This test suggested that the difference in response times is due solely to the motion in the warning signal.

The U.S. Patent Office has granted initial approval for coverage of the proprietary features of the warning signal design. The Office of Technology Licensing at the University of California is currently negotiating licensing agreements with potential commercial partners.

ITS-17: A Sequential Hypothesis Testing–Based Decision-Making System for Freeway Incident Response

Samer M. Madanat (317-494-3954)
Purdue University, West Lafayette, IN

The product of this IDEA research is a decision-making system for integrated freeway traffic incident-detection and response activities. This system employs sequential hypothesis testing techniques to dynamically optimize incident-response decisions by systematically considering the trade-off between the possible costs of a delayed incident-response decision and the improved decision-making capabilities that result from delaying action until additional measurements are taken.

Inputs to this system include traffic parameters and their distributions under different conditions, traffic delay costs due to incidents, costs of implementing response measures, incident frequencies in time and space, and distribution of incident duration. The outputs are optimal incident-response policies for each time period. In real-time operations, the derived optimal policies can be used to select incident-response decisions, given various traffic conditions.

This decision-making system explicitly accounts for the presence of traffic-stream interpretation errors and simultaneously considers incident-detection decisions and possible response actions such as traffic diversion to alternative routes.

ITS-18: Three-in-One Vehicle Operator Sensor

Richard P. Hamlin (310-948-6070)
Northrop Grumman Corporation, Pico Rivera, CA

The three-in-one vehicle operator sensor tested by Northrop Grumman uses nonintrusive eye tracking and analysis to perform the following functions: (1) drowsy driver recognition, (2) antitheft protection, and (3) alcohol-impaired driver recognition. The results showed significant short-term potential for drowsy driver recognition. Northrop Grumman has, however, decided not to pursue this project since it does not fit into their business plans.

The three-in-one vehicle operator sensor is unique in that it can nonintrusively perform its three functions in a single integrated package. The drowsy driver recognition subsystem continuously monitors the driver's state of alertness and triggers an alarm when there is a significant decline in the state of alertness of the driver. This subsystem used algorithms that optically track eyes and eyelids to accumulate evidence of drowsiness over time. The drowsy driver recognition function relied on facial imagery for primary determinants of drowsiness, with steering wheel motion data used as a corroboratory indicator.

The antitheft subsystem proposed to optically inspect the iris of the vehicle operator's eye during the engine start sequence. Iris patterns are unique for each individual, just as fingerprints are. The system could thus disable the start if the iris pattern does not match one from a stored set of authorized-operator iris patterns.

The alcohol-impaired driver recognition subsystem optically monitors the vehicle operator's eye during the engine start sequence, concurrent with the driver identification process described above, and disables the start if signs of alcohol consumption in excess of predetermined thresholds are detected. This configuration eliminates many of the deficiencies of the current technology, including the possibility of a sober passenger providing the critical breath input.

ITS-19: AutoAlert — Automated Acoustic Detection of Traffic Incidents

David A. Whitney (617-942-2000, x323)
The Analytic Sciences Corporation, Reading, MA

The AutoAlert automated classification system prototype provides an all-weather, automated acoustic incident-detection system. Using sophisticated "acoustic fingerprinting," the AutoAlert system provides direct incident detection, identification, and alerts by capturing dynamic characteristics of time-varying acoustic patterns. Although it employs existing conventional acoustic sensors, the key to AutoAlert's improved performance is a new signal-processing algorithm, Hyperstate analysis, that uses adaptive signal modeling to remove variable background noise.

The problem of rapid and reliable acoustic incident detection is more complex and difficult than the problems of freeway traffic flow monitoring or vehicle type identification. AutoAlert's hyperstate classification algorithms can accurately characterize the short- and long-term dynamic behavior of acoustic signals. This has the potential to provide a new level of detection timeliness and reliability, with fewer false alarms. It relies on sophisticated statistical models, such as nested hidden Markov models and canonical variates analysis.

Although the feasibility of this technique was demonstrated in theory, limited data availability hindered full development of the concept. Additional work is needed.

ITS-20: Real-Time Computer-Matched Ridesharing Using Cellular or Personal Communications Services

Edward W. Walbridge (708-445-0117)
National-Louis University, Evanston, IL

This IDEA project evaluates the use of cellular telephones to access a computer that does rideshare matching in real time. The project has developed a ride-matching algorithm optimized for wireless access methods, has identified three candidate demonstration projects, and has assessed the potential of this application through simulation and analysis.

The problems with using the standard home phone to access a rideshare matching system are obvious. The persons seeking a ride match are not always available. A driver cannot inform the ride seeker of an unanticipated delay, and a potential rider cannot be informed of a driver who calls in with a good match after the rider has departed.

This IDEA project has three key innovations: the use of wireless pocket phones, the provision of ride-rider matches in real time, and a focus on single-trip (as opposed to commuter) ridesharing. This study has established requirements that the interval required for the computer to present one or more candidate matches to the ride seeker should be less than 3 min and the total time to rider pickup should be less than 10 min.

ITS-21: Interference-Resistant Signals for Collision-Avoidance Radar

Mark Hischke (847-259-9600, x478)
Northrop Grumman Corp., Rolling Meadows, IL

The key element of this IDEA concept was its focus on reducing, through a good understanding of the electromagnetic environment, vehicle radar blinding and false triggering caused by other radars. The IDEA project investigated the use of frequency multiplexing, time multiplexing, and code division multiplexing to minimize interference in collision-warning radar applications, including collision-warning radars used for "smart" cruise control. Correct operation in the presence of interference can be achieved by proper design of the radar architecture and signal structure.

Currently, only a small number of collision-warning radars have been fielded. As the number of these radars increases, the likelihood of signals from one automobile's radar adversely interfering with another automobile's radar will increase. This interference can result in blinding, in which the radar cannot see potential collisions, or in false alarms, in which a collision is signaled when there is no real problem. Study results show that as many as several hundred potential interference sources could exist during rush hour conditions on a large freeway if most vehicles start to use radar.

ITS-23: Precise Navigation for Vehicle-Collision Avoidance Using the GPS/DRAIN System

Mark S. Asher (240-228-5327)
The Johns Hopkins University Applied Physics Laboratory, Laurel, MD

Global Positioning System and Distributed Redundant Accelerometer-only Inertial Navigation (GPS/DRAIN) is a demonstration system for high-precision terrestrial navigation for collision avoidance using inertially aided GPS carrier-phase tracking. The goal of the project was to demonstrate navigation of a vehicle with an accuracy of 10 cm with respect to a reference receiver in an operational environment. To be useful for collision avoidance, vehicle orientation is also required. This information can be provided by combining the inertial data with phase data from an array of four GPS antennas. The DRAIN inertial instrument system consisted of 15 QA-700 accelerometers, which were spatially separated so that a full three-dimensional navigation solution could be obtained without gyros. The GPS instrumentation consists of an array of four vehicle-mounted antennas, which are fed into a wideband recording device. A stationary receiver provided the reference for differential GPS.

A field test of the system was performed on September 30, 1996. The inertial instruments were mounted in a plywood box with the GPS antenna array and groundplane on top. The complete instrument suite, wideband recording equipment, and a personal computer were placed in the back of a small pickup truck and driven around the Applied Physics Laboratory facility in Howard County, Maryland.

The test lasted for approximately 15 min and covered a closed course of about a mile. The course contained a large number of metal buildings and sheds, which provided a stressful multipath environment.

The project work successfully resolved the initial difficulties and collected a large amount of data. Processing problems, particularly involving instrument calibration, prevented the investigators from achieving the accuracy to support collision avoidance effectively. No additional IDEA project work is planned on this concept.

ITS-24: Passive Optical Lane-Position Monitor

Joseph Geary (205-890-6030, x473)
Swales and Associates, Inc., Beltsville, MD

In this IDEA project, a passive optical lane-position monitor, consisting of a small lens/detector assembly and a compact electronics module, was designed, built, and tested. The sensor consists of a cylindrical lens and a position-sensitive detector that tracks vehicle position relative to any well-delineated lane-marking lines. It can be mounted behind the rearview mirror, on the vehicle's hood, or anywhere with a view of the roadway 15 to 20 ft ahead of the vehicle. This lane position monitor could function as a lane departure warning sensor on well-marked roads. A prototype unit was tested in the lab and in limited field conditions. Results showed some promise but more work is necessary.

ITS-25: Automated Roadside Brake Inspection

Thomas Wissing (810-354-2720)
Eaton Corp., Southfield, MI

The automated roadside brake inspection system (ARBIS) concept involves automating the brake performance inspection process to achieve rapid brake inspections in a roll-by mode. At minimum, it is expected to be a viable screening process to inspect trucks with likely problems before making a conventional "crawl-under" inspection.

Algorithms were developed to analyze measurements of air brake parameters taken during a single standardized deceleration task and to identify potential problems in a vehicle's braking system. This IDEA project was canceled at the first milestone due to technical problems experienced in developing appropriate software to account for all operational braking conditions. The results indicated that it would not be productive for the IDEA Program to continue the product development cycle with the resources available. A decision was therefore made to discontinue the project after the first stage activity.

ITS-26: Fuzzy Inference–Based Driver Decision and Traffic Flow Simulation Models

Shinya Kikuchi (302-831-2657)
University of Delaware, Newark

The IDEA concept explored a new way of modeling driver behavior in congested traffic flow and tested its validity using data collected in real driving conditions by a vehicle equipped with state-of-the-art measurement equipment. A traffic flow simulation package using the new model has been incorporated into the NETSIM testbed. The IDEA model can now be selected as an option when running NETSIM traffic flow calculations. In this IDEA project, fuzzy inference logic is used to model individual drivers' perception, decision, and reaction processes. Fuzzy inference recognizes the fact that vagueness exists in human decision making and that the outcome of the decision-making process has a degree of freedom as a result.

This IDEA product is useful as a new technique for microscopic modeling of traffic flows consisting of drivers with different characteristics. Previously, this was limited to a deterministic or probabilistic approach. The inference mechanism behind this product has potential for application to intelligent cruise control logic, automated vehicle speed control, and driver warning systems.

ITS-27: Application of Neural Networks to Data Fusion

Peter Nelson (312-996-3259)
University of Illinois at Chicago

This project explored the use of artificial intelligence techniques to improve the efficiency and accuracy of arterial data fusion. In a typical data fusion process, screening of data from multiple sources is essential to ensure that the data are meaningful, pertinent, and free from any troublesome outlying data points, before they are combined to compute the system output. Outlying and erroneous data may be the result of problems in the transmission of data, errors in probe vehicle reports, detector malfunctions, and so forth. Results of the arterial data fusion process are critical inputs to Advanced Traffic Management Systems (ATMSs) and Advanced Traveler Information Systems (ATISs).

A data fusion system for arterial roadway segments was developed. This neural network system processes available traffic data and produces synthesized traffic information that can be integrated into ATIS and ATMS architectures. The IDEA product includes a neural network architecture tailored for the arterial data fusion process and a supporting object-oriented C++ class library. This class library should be a valuable tool for other ITS developers and researchers who are interested in using neural networks in ITS data processing applications.

This research focused on processing actual field data derived from ADVANCE, an ITS dynamic route guidance project in the Chicago metropolitan area.

ITS-28: Evaluation of Low-Cost, Network-Based Driving Simulators for ITS Safety Research

Paul Green (313-763-3795)
University of Michigan Transportation Research Institute, Ann Arbor

Driving simulators are used to evaluate the human factor characteristics of ITS products such as road hazard warning systems, adaptive cruise control, and impairment monitoring systems. This project developed and implemented architecture for a low-cost driver interface research simulator (DIRS) consisting of four Macintosh computers networked together. Each computer performs a unique task or collection of tasks (control the overall simulation, generate the road scene graphics, generate sound, update traffic, generate the instrument panel graphics, and so on).

The IDEA simulation has several unique features. It makes use of a network of affordable personal computers where most simulators use expensive high-powered graphic workstations. It uses a moderate-cost instrumentation program called LabView so that new instrument panel clusters can be created in about two days by personnel without specialized training. It uses traffic code and main simulator code that are modular so that any number of drivers and vehicles can be on the network at the same time. This allows for testing of multiple drivers in the same traffic scenario, something that has not been done to date.

All of the planned networking features have been added to the IDEA simulator. The simulator was used successfully for performing experiments on collision-avoidance warning projects and will continue to be used for other project research in UMTRI. A report is available describing the lessons learned in developing a network-based simulator, lessons that should guide others developing, enhancing, purchasing, or using driving simulators.

ITS-32: Emergency Mayday System for Rural and Urban Areas

David Richardson (847-259-9600, x4790)
Northrop Grumman Corporation, Rolling Meadows, IL

The proposed Mayday system is a small, rugged high-frequency (HF) communications unit that sends emergency messages from an automobile, truck, or bus. The system will use the Global Positioning System (GPS) and cellular radio, but it also includes an HF-band radio unit for use in rural areas of the United States where cellular radio is not available. The system will operate in situations in which cellular communication is not available, such as while the vehicle is in a rollover position or in a canyon. HF radio provides coverage of up to 500 mi in radius, low-cost electronics, and low-cost infrastructure. The project consisted of developing the parameters for the HF digital radio and making a proof-of-concept test. Cost is a major factor in consumer acceptance of Mayday programs, and the price of the mobile vehicle unit should be under $100.

The study analyzed radio frequency propagation paths and determined data message requirements. Analysis of ground and sky wave propagation modes using a computer-assisted drafting program showed that an HF sky wave radio can be designed with regional base stations that will cover a large geographical area. In the case of a Mayday radio with a 200-mi radius, the continental United States could be covered by 50 regional stations.

The regional station is expected to read the GPS information in the message, then route the message using phone lines to a local service center, such as a county police or fire unit. HF transmitter location technology was evaluated as a supplement to GPS data but does not appear to be a practical alternative.

The message will have a warning priority determined by the situation in the automobile. The highest priority would be a crash (i.e., the air bags have opened), an intermediate priority would be vehicle failure according to an engine sensor, and a low priority would be a test signal. The priority could be used by the automobile to determine transmission frequency and modulation to minimize potential message overlap from simultaneous access by multiple automobiles. The message will also contain a unique vehicle identifier such as license plate number and state.

Preproduction design and testing with further development would require joint funding by industry and the US Department of Transportation. There is no plan at this time by Northrop Grumman to conduct further tests or prepare refinements of the HF Mayday system.

ITS-34: Remote Passive Road Ice Sensor System (RPRISS)

Jack Reed (703-416-5010, x4171)
Nichols Research Corporation, Arlington, VA

The Remote Passive Road Ice Sensor System (RPRISS) is a remote, non-contact system that detects the presence of ice and snow on roadways and provides this information to the end user through video-type images in which the ice or snow is shown in red. RPRISS has the ability to detect very thin layers of ice, including "black ice," which is undetectable by other non-contact systems. It is built around an innovative passive infrared imaging system that does not require illumination and can accurately estimate road surface temperature. The infrared video image from RPRISS can be used as a supplement to existing video surveillance systems.

RPRISS may be implemented in a number of configurations. The test configuration was a fixed-location roadway monitoring system in which the sensor was mounted so that it viewed an ice-critical section of roadway. RPRISS may also have mobile application as an environmental sensor. This could be mounted on winter maintenance vehicles to alert the operator to adjust anti- or deicing treatment on the basis of real-time observed conditions.

The initial project work determined ice types and surface characteristics that are important to road system users and developed methods for identifying users, determining the amount of ice that is significant (both thickness and surface area) and the speed with which it must be detected, and for identifying the probability of detection versus the associated probability of false alarms. Discussions with operational users at the Minnesota Department of Transportation, the Metropolitan Washington Airports Authority, and the Virginia DOT Northern Virginia Traffic Management System helped establish the design goals.

Laboratory test data were collected on pavement samples provided by FHWA and the Minnesota DOT in icing and clear conditions. The results demonstrated proof of principle. This was followed by a limited winter field test in Minnesota along with developmental fieldwork in Colorado and Alabama.

ITS-35: Diagnostic Instrument for Maintenance of ITS Loop Sensors and Detector Systems

Boris Donskoy (301-670-9282)
DVP, Inc., Rockville, MD

This IDEA product is a flexible, portable instrumentation platform capable of diagnosing virtually any inductive loop (IL) vehicle sensor problem. It is innovative in that its real-time diagnostic system has intelligent functionality that can be altered by simply changing a software cartridge.

The project results have advanced the instrumentation diagnostic process by using an embedded expert system to dictate the data collection steps in the diagnostic process. As there are many different types of sensor applications, each requiring its own special set of diagnostic procedures, this functionality can be supported incrementally through the design of specialty "IL cards," all operating from the same base hardware platform. The IDEA project designed and built the base platform and a single, general-purpose IL diagnostic card for most conventional IL applications.

Maryland's Montgomery County Department of Transportation worked with the investigators to evaluate the IDEA product and has purchased several units. The project has received product transfer support from the IDEA Program to perform operational field testing and premarket evaluation of the IDEA product (see ITS-52)

ITS-36: Application of Decision Analysis to ITS Societal Issues

Barbara Richardson (313-763-5285)
University of Michigan Transportation Research Institute, Ann Arbor

Societal and institutional issues are pivotal concerns in the implementation of ITS technology. This project modified a widely used decision-support method called Decision Risk Analysis to include representatives of several organizations from the public and private sectors and applied it to the process of deciding on an example ITS implementation. The question was whether an individual community should upgrade the paratransit services already provided by a regional transit authority to include ITS technology such as vehicle location and route scheduling. The hypothetical community in which this decision was to be made was based on a typical community in southeast Michigan.

The modified decision-support method is called Multi-Organization Decision Analysis (MODA). Its objective is to facilitate consensus among the disparate public- and private-sector stakeholders in a decision process. The stakeholders are represented on a decision-making team, and are supported by a team of analysts. MODA meetings are aided by facilitators. The process includes developing of a shared vision statement, framing the problem, developing alternative solutions, analyzing the alternatives, and reaching a decision. Progression to the next step of the process does not occur until consensus is reached on the present step.

In the test case, the decision-making team reached consensus after two meetings. Through this demonstration, MODA was found to be a viable tool and is applicable to a variety of ITS technologies, geographic locations, and institutional and jurisdictional constituencies. A plan for nationwide application of the MODA process is being developed. MODA will be modified, if necessary, and offered to the ITS community as a tool for reaching decisions in an efficient way.

ITS-38: Low-Cost Fiber-Optic Visibility Monitoring and Information System

Richard Claus (540-231-7203)
Fiber and Sensor Technologies, Inc., Blacksburg, VA

Accurate and reliable measurement of visibility conditions is critical for achieving reliable weather advisory schemes in highway transportation. The IDEA fiber-optic-based visibility information system (FOVIS) uses a low-coherence light source to monitor quantitatively the effect of rain, fog, snow, smoke, or other visibility obscurants along the highway.

A high-accuracy and a lower-cost/lower-accuracy sensor configuration were fabricated and tested in the laboratory. The high-accuracy system used interferometric principles to measure visibility while the other system used an intensity-based approach. The intensity-based setup consisting of a light source, photodetectors, collimating lenses, and optical fiber was found to be more practical for this application. In this scheme, light from the source is split into two paths by an optical fiber coupler and the presence of visibility obscurants in one of the paths changes the intensity level of its optical energy.

The product will be field tested in cooperation with the Virginia Department of Transportation, the Virginia Transportation Research Council in Charlottesville, Virginia, and the Center for Transportation Research at Virginia Tech in Blacksburg, Virginia. The sensor's first implementation may be on Interstate 64 near Afton Mountain, Virginia, where visibility is often poor and accurate, reliable information would be very useful.

ITS-40: Application of Ergonomic Guidelines on Emerging ITS Technologies for Application to Advanced Public Transportation Systems Practice

Katharine Hunter-Zaworski (503-737-4982)
Oregon State University, Corvallis

The purpose of the project was to provide guidelines for transit agencies developing information systems that are accessible to persons with sensory and cognitive impairments. The ergonomic guidelines focus on a number of human factor issues that affect the use of variable message signs such as those on highways, in-vehicle navigation devices, and ATIS systems. Issues concerning color, font style, scroll rates, contrast sensitivity, and reflectivity were examined. Variable message signs are examples of dynamic signs and, therefore, must be designed and implemented in a new way that accounts for the fact that the flip disks and light-emitting diodes (LEDs) are discreet point sources of light and cannot be treated in the same way as static or painted signs. This requires a new set of design guidelines that consider the characteristics of the human operator.

The development of the ergonomic guidelines has been jointly supported by an international steering committee. The project results are under consideration for the development of standards by the International Standards Organization. Copies of the guidelines can be obtained from the investigator.

ITS-41: Pilot Testing of Lane Center Resonant Loops and Vehicle Sensor Modules for Automatic Vehicle Steering

E. William Bush (619-454-6513)
QST Electronics Corporation, La Jolla, CA

This IDEA lane control system uses a patented resonant-loop technique to sense a vehicle's position relative to the center of the roadway. This technique was originally developed in an earlier IDEA project (see ITS-12). The primary advantage of the resonant-loop sensor is its low cost. Small resonant loops consisting of a single wire and a capacitor are inexpensive to make and install. A simple continuous wave signal is inductively coupled both to and from passive road coils, providing an accurate indication of vehicle position. A phase-comparison electronic module in the vehicle provides an output proportional to the distance from the lane center. Road elements are completely passive and are either embedded or mounted on the surface. Tests have indicated satisfactory system performance in a highway environment.

Cost estimates were obtained from companies currently installing reflective markers for resonant loops embedded in the roadway or surface mounted. The cost of installing the road loops is estimated to be $5,000/lane-mi for the embedded installation and $3,000/lane-mi for the surface mount. The resonant loop's low profile and proven adhesion processes used for reflector markers make surface mounting a viable low-cost alternative for lane control anywhere in the country, particularly where snow removal is a factor.

The resonant-loop sensor is now ready for system integration. Testing to date has been limited to open-loop measurements of the sensor performance in static as well as dynamic operation environments. Under these conditions, the sensor output has been found to be linear, consistent, and entirely adequate for closed-loop servo-control. Field testing of this system was canceled because no servo-controlled test vehicle was available.

ITS-42: Antiglare Mirror and Visor Technology Development

George S. Levy (619-259-2226)
Quantics, Inc., San Diego, CA

At night, drivers are blinded by the glare from headlights reflected in their rearview mirrors. A simple antiglare device using a photochromic layer inserted in the focal plane of an optical system was developed and a test unit was fabricated. High-intensity rays originating from glare sources are focused on the photochromic layer, which responds to the increasing light intensity by becoming darker at those spots where light is intense. Therefore, high-intensity rays are attenuated while rays originating from dim objects do not create dark spots and can thus traverse the photochromic layer unaffected. This clips light intensity to a level defined by the photochromic layer.

This project developed a prototype photochromic system suitable for use as a component in an automotive anti-glare rearview mirror. A system analysis was first conducted to define the sensitivity requirements, given regulatory factors (NHTSA Standard 108), environmental parameters (solar spectrum), ergonomic factors (spectral sensitivity of the eye), and technical constraints (spectral response of candidate photoconductors). This led to the selection as candidates of two types of liquid crystal cells that were then assembled. Testing of these prototypes showed that limited functionality could be achieved. This work was very preliminary, while much remains to be done no additional investigation is planned at the present time.

ITS-48: Instant Rent-a-Car Technology for the Bay Area Rapid Transit Station Car Pilot Project

John Chisholm (702-972-8305)
C.F. International, Reno, NV

The instant rent-a-car (IRAC) fleet management concept provides a conveniently rented auto as an adjunct to transit stations. This “station car” concept is not new but the idea of developing an electronic package for the cars that facilitates efficient short-term rental transactions, as in this project, is. Estimates show that in a transit operation such as BART, ridership can be doubled by making IRAC vehicles available since they effectively increase the size of the area that can conveniently access the system. This could increase BART’s income by $100 million annually while it pays its own operating and capital expenses. IRACs are equally applicable to express buses and car pools and could provide a new market for the auto rental industry.

This project put together a fleet of 8 test vehicles and set up two different test scenarios at work sites near BART stations. Small electric vehicles were used and a group of commuters subscribed to the service. Tests were performed to determine the operational effectiveness and desirability of the shared-car arrangement. A general willingness and ability of commuters to share these vehicles was demonstrated. The requirements for an electronic package that would facilitate this sharing were not established since institutional and operational considerations took precedence. “Station Car” trials are continuing at BART in an unrelated investigation.

Large-scale implementation of the station car concept will require (1) the participation of transit agencies, (2) organizations capable of providing the in-vehicle electronics in volume and at low cost, (3) inexpensive wireless communication with the vehicles, and (4) efficient operation of the IRAC rental fleet.

ITS-49: Travel-Time Prediction in ITS

Andrzej Tarko (765-494-5027)
Purdue University, West Lafayette, IN

This IDEA project develops a method for making short-term predictions of travel times for vehicles moving along signalized arterials from knowledge of the traffic volumes along the considered route as provided either by a surveillance system or by a traffic assignment model. The Indiana Department of Transportation will implement the developed method in northern Indiana's Borman Expressway, where travel-time information will be disseminated through highway advisory radio and variable message signs to encourage diversions from the freeway onto the alternative surface routes when appropriate.

The product is useful in predicting travel times and reducing computational demands needed for advanced traveler information systems (ATIS), specifically when traffic movement volumes are known for each travel-link time horizon in a traffic assignment model or for a traffic surveillance system. In the simplest case, the recently recorded volumes can be applied to the current and future intervals. Missing values can be estimated on the basis of known values from upstream detectors and historical traffic patterns.

ITS-52: An Advanced Diagnostic Instrument for Inductive Loop System Maintenance

Boris Donskoy (301-670-9282)
DVP, Inc. Rockville, MD

This IDEA product, dubbed the ILT III, is a diagnostic instrument incorporating the latest portable instrumentation principles, which can be used for the qualification, troubleshooting, and preventive maintenance of the inductive loops used for vehicular traffic detection. It is a portable, handheld, battery-powered instrument incorporating a two-channel high-speed data acquisition subsystem, 1/4 VGA graphic display, digital signal processor, computer interface, rechargeable battery, and card programmability. It is a flexible, cost-effective addition to the traffic engineer's toolbox, providing powerful automated analysis, troubleshooting, and data collection functions.

The device measures inductance, quality factor, resistance, and leakage-to-ground (megaohm meter) of the loop in an easy-to-understand and automated fashion. The basic concept behind this instrument is that its two PCMCIA (PC card) slots allow the use of different software cards. The basic traffic card enables the user to measure all the parameters listed above and can walk an inexperienced user through various diagnostic procedures to help isolate a problem. Additional cards will be developed to provide extended test and data collection functions. A second card has software that allows the instrument to serve as a real-time data acquisition device, making it suitable for functions such as vehicle counting and data logging.

PROJECTS ACTIVE BETWEEN JULY 1998 AND JUNE 1999

ITS Type 1: Commercial Vehicle Operations and Fleet Management
IDEA Projects 33, 72, 75

ITS Type 2: Intelligent Vehicle Systems
IDEA Projects 33, 50, 51, 57, 61, 63, 66, 76, 81

ITS Type 3: Advanced Rural Transportation Systems
IDEA Projects 32, 34, 38

ITS Type 4: Improved Traffic Management and Analysis
IDEA Projects 2, 4, 6, 9, 15, 17, 19, 26, 27, 34, 35, 49, 52

ITS Type 5: Advanced Traveler Information
IDEA Projects 3, 8, 20, 49

ITS Type 6: Advanced Transit Systems and Operations
IDEA Projects: 3, 20, 36, 40, 49

ITS Type 7: Advanced Weather Applications
IDEA Projects 34, 38

PROJECTS ACTIVE BETWEEN JULY 1998 AND JUNE 1999

ITS-33:
Radar Reflective Patch-Based Convoying

Principal Investigator: Umit Özgüner (umit@ee.eng.ohio-state.edu 614-292-5940)
The Ohio State University ElectroScience Laboratory; Columbus, OH

Started: 11/95, Completed: 11/97, Final Report: 8/98

$108,781 total cost with an IDEA contribution of $86,867

Concept and Product

This project looked into the feasibility of using a radar-based convoying system for trucks. A lead truck is driven manually and is followed by autonomously controlled trucks. The autonomous operation will be based on a hardware/software system consisting of a radar sensor and a headway and steering controller. The radar system, which could also function as a collision-avoidance sensor, provides the range and azimuth difference between the leading and following trucks. Collision avoidance radars are now being deployed in truck fleets, and it is reasonable to consider convoying as a future dual use of such radars.

It has been shown that automated truck convoys could reduce fuel usage and provide relief to drivers. Attempts to perform convoying using vision-based systems have not been satisfactory, because of difficulties in identifying and tracking vehicles under diverse lighting and environmental conditions. In contrast, radar has the ability to perform accurate tracking irrespective of lighting or weather conditions, which makes it inherently appealing for convoying applications.

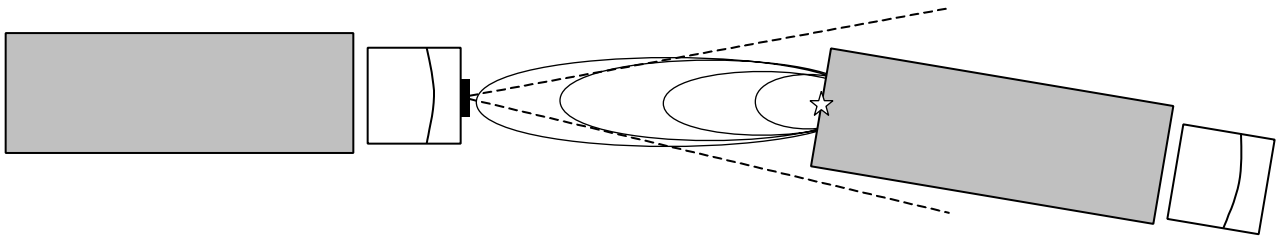


Figure 1

Concept for radar-reflective patch.

A key part of this convoying concept is an inexpensive, passive, radar retro-reflector patch. This patch is a planar antenna constructed from inexpensive rugged materials with roughly the shape of a license plate. The patch works in conjunction with the following vehicle's radar and headway and steering controllers. When illuminated by the following-vehicle radar, the patch produces a return distinct from other parts of the truck and from other roadway objects. Lateral and longitudinal control actions are based on this distinct reflected signal. Development of this device comprised a major part of the project effort.

Project Results

A novel patch reflector and headway and steering control algorithms were developed under this effort and a two-vehicle convoy was demonstrated. This experience indicated that, with a modest amount of additional development, a system of this type could be integrated with collision-avoidance radars now available on new trucks and passenger cars.

The chief technical challenge remaining in radar-based convoying is the large radar cross section of vehicles relative to that of the patch. Most features on a vehicle scatter co-polarized signals, while the patch produces a cross-polarized signature to increase its distinctiveness. Nonetheless, there exist strong, isolated scattering centers on some vehicles that can overwhelm the signature of the patch. The distinctiveness of the patch can be increased by several techniques, the most promising of which appears to be modifying the re-transmitted signal. If power is available to the patch (from, say, the same supply used for the brake or license plate lamps), then active devices can be used to modulate the reflected signal. Signal processing algorithms in the transmitting radar designed to detect this modulation can significantly reduce the vehicle clutter signal.

Longitudinal and lateral control issues have been thoroughly investigated. Further studies of control issues would be on specific application and equipment related variations.

ITS-43:
Feasibility Study for a Regional Traffic Surveillance Concept

Principal Investigator: Isaac Weissman (202-244-7200)
Weissman Science & Engineering Co.; Washington, DC

Other participants: Dunn Engineering Associates and XonTech, Inc.

Started: 7/96, Completed: 4/98, Final Report: 7/98

$192,105 total cost with an IDEA contribution of $77,933

Concept and Product

This concept, when fully developed, is expected to add significant and cost-effective enhancements to advanced traffic management systems by providing surveillance of commuter arteries in metropolitan regions from a single elevated site. Specifically, the operational implementation of this concept will employ unattended, low-power, non-hazardous microwave Doppler radar mounted atop existing FM or TV broadcasting towers. The radar design will be based on recently developed and proven techniques for military airborne surveillance and will include a phased-array antenna for electronic scene scanning and, simultaneously, rapid repositioning of several fixed radar beams. The absence of any moving parts, the all-solid-state design, and the unattended operation should result in extremely reliable performance over a long life span with low operating and maintenance costs. An individual radar will relay its automatically reformatted data to, and receive commands from, a traffic operations center via ordinary telephone lines. The use of the microwave portion of the electromagnetic spectrum will allow traffic monitoring through rain, fog, snow, haze, and smog.

The approach has a number of important advantages. First, a single radar can provide coverage of a highway network that would, equivalently, require a very large number of point sensors and their infrastructure. Second, the radar measures flow speed directly and instantaneously, thereby facilitating rapid incident detection, calculation of link travel times, and control of traffic signals and signs. Third, unlike visual or infrared sensors, the radar beams penetrate adverse weather and are unaffected by headlight reflections from wet roads. And fourth, the regional radar is remote and entirely avoids the installation and maintenance disruptions, deterioration, and vandalism that often attend point detectors.

Project Results

The experimental radar was located on the 82nd floor of the Empire State Building (figure 1) and measurements were made through a closed window under a variety of weather conditions. A military surplus “dish” antenna, with a single fixed beam, was employed in lieu of the aforementioned operational version. The following were successfully demonstrated:

- The ability of a small, low-power microwave radar to monitor vehicular traffic at long ranges and at low grazing angles. (12.5-km range capability was demonstrated.)

- The ability to measure speeds in either direction with great precision and to resolve vehicles with very slight velocity differences.

- The ability to resolve vehicles from much stronger ground-clutter echoes. Even very slow vehicles (e.g., about 1 meter/second) were resolvable.

- The ability to monitor traffic through very poor weather conditions, including those with zero visibility, without any noticeable degradation in performance.

The next step in bringing the regional radar surveillance concept to practice will be to form collaborations with one or more municipal or state traffic agencies. It is envisioned that a display depicting in real-time regional traffic data obtained by a radar will be installed at an appropriate traffic operations center as part of this collaborative effort.

Figure 1

Test location of regional traffic radar

ITS-44:
ITS Integration of Real-Time Emissions Data and Traffic Management Systems

Principal Investigator: Nagui Rophail (rouphail@eos.ncsu.edu 919-515-1154)
North Carolina State University, Raleigh

Other participants: National Institute of Statistical Sciences

Started: 8/97, Completed: 6/99

$125,484 total cost with an IDEA contribution of $83,356

Concept and Product

The objective of this project was to demonstrate a methodology for integrating data from vehicle emission sensors with operational traffic data available at advanced traffic management centers. Vehicle emissions were measured at selected sites with an infrared-based remote sensing device (figure 1). At the same time, a video image processing system for traffic data measurement and analysis, MOBILIZER, gathered data on vehicle behavior. The project team then developed and compared two types of emission models. A standard macro, or flow-based model, used fleet characteristics to predict fleet average CO and HC concentrations. A micro, or vehicle-based model, predicted individual vehicle CO and HC emissions based on the vehicle characteristics and traffic variables such as speed and acceleration.

Figure 1

Field set-up of RSD van for emissions data collection

An innovative instrumentation scheme that, for the first time, permits the integration of on-road emission measurements with real-time traffic variables was developed. Measurements of CO and HC emissions for each detected vehicle were gathered along with the detected vehicle speed, acceleration, and position in the traffic stream at two study sites. Traffic variables for the vehicles immediately before and after the detected vehicle were also gathered. This allowed the team to make a detailed study of the impact of microscopic traffic variables on vehicle emissions. Since traffic management applications manipulate such traffic variables to improve traffic flow, their collateral effect on emissions can be also assessed.

Project Results

The traffic parameter data and measured emission rates for CO and HC were analyzed using sophisticated statistical methods. In the most comprehensive case, 19 variables were considered including four traffic descriptors (vehicle speed, acceleration, time headway, and vehicle type), a site variable, and 14 vehicle specific variables (including model year, body type, and fuel delivery system type among others). This case represents an advanced traffic detection system in which license plate information might be decoded in real time to obtain the VIN, which in turn is decoded to obtain vehicle-specific variables.

By far the most significant variable explaining the difference in CO emission rates was the vehicle model year. The table below gives a brief summary of average CO emissions rates by model year for one analysis. This confirms expectations about the disproportionate impact of older vehicles on CO emission rates.

Mean CO Emissions Rate in grams/gal by Model Year

1985 or older	1986-1988	1989-1994	1995 or newer
615	439	266	163

It was found that traffic-related variables alone (e.g., headway) simply cannot explain the variability in vehicle emissions. They can be used to improve the individual vehicle emission estimate, but only after the vehicle-specific attributes are known. Both micro and macro models have been implemented in a spreadsheet environment. The user is prompted to select the type of model and to enter the appropriate input data for the selected model. By including supplemental information such as segment length, hourly or daily traffic volumes, and an estimate of fuel consumption by vehicle type, the models can generate aggregate CO and HC emissions rates in grams/hour or day.

ITS-45:
Development and Trial Deployment of an ITS Avalanche Hazard Management System

Principal Investigator: Rand Decker (rdecker@eng.utah.edu 801-581-3403)
University of Utah, Salt Lake City

Other participants: Consortium of 5 Western States

Started: 9/96, Completed: 3/98, Final Report: 6/99

$98,228 total cost with an IDEA contribution of $60,853

Concept and Product

Avalanche hazards on the alpine roads of the Western United States are currently managed by avalanche hazard forecasting, often coupled with explosive initiation of the avalanches while the road is temporarily closed. Operations of this style are carried out on roadways in Alaska, California, Colorado, Idaho, Montana, Nevada, Utah, Washington, and Wyoming, as well as in Canada and Europe. Delays due to such operations can be costly, the Washington State Department of Transportation (WSDOT) has determined that closure of I-90 for avalanche control during the peak hours of noon to 4:00 p.m. costs the State of Washington $40,000/hour. These costs and the desire for minimal delays have stressed the present method of avalanche hazard management to the point that many of our winter roads are now open even as the avalanche hazard is rapidly escalating. As a consequence, the growth in overall risk to motorists and highway maintenance personnel due to avalanches is increasing.

The purpose of this investigation was to integrate emerging technology in remote sensing of avalanche activity, micro-computing and control, and wireless communications, into a system that can reduce human exposure to avalanche hazards in a cost-effective manner. Two approaches were developed in which automated road closure systems are activated when an avalanche is sensed. In an approach based on time-of-descent management, a section of road is closed as soon as an avalanche event that threatens it is detected. This is possible since it typically takes a minute or so for the avalanche to reach the roadway. In the other approach, corridor management, access to the roadway by more vehicles is restricted once an avalanche has been detected on the road.

The cost of these systems compares quite favorably to the cost of installing permanent avalanche defense structures, which is typically in the millions of dollars. Furthermore, where snow supporting structures and avalanche sheds have been proposed for U.S. highways there has been considerable opposition from environmental and conservation groups. Hence, knowledge-based ITS avalanche hazard management systems also offer a cost-effective alternative to permanent avalanche defense structures.

Figure 1

Avalanche striking the Alta avalanche impact pylon facility

Project Results

Results indicate that knowledge-based ITS avalanche hazard reduction and management systems have the potential to improve safety for highway maintenance personnel and motorists in rural, often low-volume, alpine transportation corridors. These improvements may be realized if highway maintainers and emergency personnel can make more timely responses to avalanching as a consequence of having deployed ITS avalanche detection and alarm systems. Tests have shown that there will be a continuing need to improve the robustness and reliability of the field deployment hardware and communication interfaces of these systems. It will also be desirable to develop all-weather remote rural traffic surveillance systems that are capable of vehicle identification and tracking. These systems must be able to operate autonomously with little or no data communication (telephone hardwire) or power infrastructure.

As a result of the IDEA project, a follow-on 5-state pooled fund investigation, "Automated Avalanche Hazard Reduction on Highways," was initiated to continue this work and deploy the technology on additional sites. There has also been international interest in this technology from Canada and Chile.

ITS-47:
A Spectrally Efficient Wireless Modem for ITS Applications

Principal Investigator: Michael Fitz (fitz@ee.eng.ohio-state.edu 614-292-8039)
The Ohio State University, Columbus

Other participants: James Krogmeier
Purdue University, West Lafayette, IN

Started: 11/96, Completed: 2/99

$78,000 total cost with an IDEA contribution of $78,000

Concept and Product

The product produced by this IDEA project will be an extensively tested architecture for bandwidth efficient narrowband digital communications that can serve a variety of ITS applications. The modem architecture will be designed for the 4 kHz bandwidth ITS spectral allocations in the 220-222 MHz band and will be dual-mode in that it will support both point-to-point and mobile applications. The goals for the project are to achieve bandwidth efficiencies of 7 bits/s/Hz in stationary point-to-point applications and 4 bits/s/Hz in mobile applications.

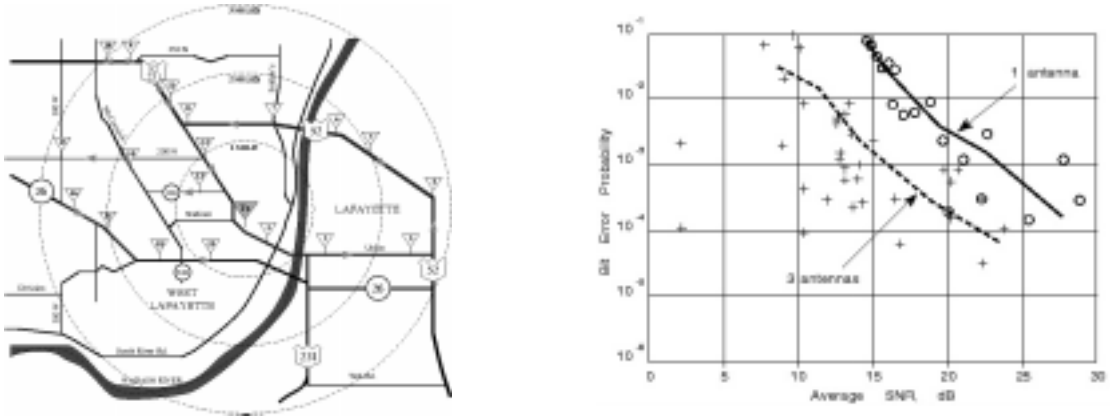
Because of the high value attached to radio spectrum in recent years, it is of the utmost importance to achieve high bandwidth efficiency in wireless communication systems. High bandwidth efficiency is thus the central technical goal of this IDEA project. This goal is best achieved with high-order constellations that transmit many bits per symbol, pilot symbol assisted modulation (PSAM), diversity, and forward error control coding. A complex architecture is necessary to ensure high reliability in the presence of deep fades in the received signal's power, which are commonly experienced in radio communication with a moving vehicle. However, in order to produce an economically viable product, the technical goals must be balanced against the cost of increased receiver complexity. In addition, a viable product in the ITS market must be adaptable to a variety of applications, such as data communications between highway infrastructure and moving vehicles, traffic sensor telemetry transmission, multiple access communications in adaptive traffic signal coordination, etc.

Project Results

Previous research by the principal investigators produced a design optimized for mobile applications. The system incorporated the following key features: 1) 3200 Hz symbol rate, 2) quadrature amplitude modulation (QAM), 3) pilot symbol assisted modulation (PSAM), 4) forward error control coding, and 5) transmit antenna diversity. This baseline modem architecture has the capability to easily support design modifications making the system an ideal testbed for future enhancements including the work of the present project.

The current project has significantly enhanced the previously developed wireless modem. The project has added dual-mode operation (mobile and stationary), optimized the design for low-cost production, and defined the wireless communications requirements for a variety of ITS applications of the 220 MHz spectral allocations. Figure 1 shows the some of the results of mobile-mode field testing performed in the Lafayette, IN vicinity. Hardware has been fabricated for this project at Ohio State University.

Extensive efforts are underway to define requirements for a wide variety of ITS modem applications. The stationary point-to-point modem is planned for use in the Borman Expressway ATMS in northwestern Indiana. The first planned application is remote video camera control for highway surveillance with a first deployment scheduled for late 1999. The Indiana Department of Transportation (INDOT) has also expressed interest in a more extensive deployment of the stationary mode modem as part of the Phase II Borman Expressway ATMS, which is currently under construction. Follow-on funding from the IDEA Program is now being negotiated.



(a) (b)

Figure 1:

Illustration of Mobile Field Testing. (a) A map of the Lafayette, IN area showing the path taken by the mobile receiver. Speeds ranged from 20 mph to 50 mph. (b) Plot of the bit error rates versus signal-to-noise ratio for the field test of (a).

ITS-50:
Road Surface Condition Detection and Monitoring Technology for a Vehicle-Mounted Hazard Warning System

Principal Investigator: Prakash Joshi (joshi@psicorp.com 508-689-0003-x231)
Physical Sciences Inc., Andover, MA

Started: 5/97, Completed: 3/98, Final Report: 9/98

$99,457 total cost with an IDEA contribution of $80,075

Concept and Product

This project investigated the feasibility of developing a vehicle-mounted device for sensing the presence of ice, water, snow, and other substances on road surfaces. This information could help winter road maintenance vehicle operators determine the type and amount of deicing or anti-icing treatment needed to keep the roadway driveable. In-vehicle information on road conditions that are not readily apparent to drivers, such as the presence of black ice, could help decrease the incidence of accidents due to drivers overestimating the traction available for maintaining vehicle control. There are also applications of this information where it could be gathered by fixed sensors, such as triggers for signs warning motorists of icing on bridges and control inputs for timing of yellow/green lights at intersections.

Present methods of determining the presence of surface contaminants on pavements includes remote infrared (IR) surface temperature sensors mounted on maintenance vehicles, in-situ deicing chemical sensors embedded in roadways, and passive ice/water sensors mounted alongside the road based on backscatter of sunlight from the road surface. This project developed a prototype for a compact, light-weight, vehicle-mounted sensor system. Such a device is now practical and potentially affordable on a commercial scale due to technological advances and cost breakthroughs in a number of areas. The detection concept involves illumination of the road surface with a broadband light source and measurement of scattered radiation from the

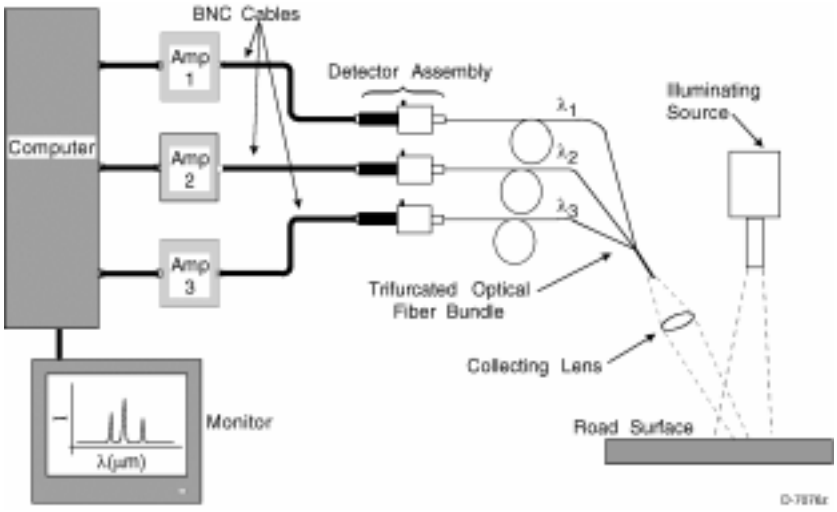


Figure 1

Sensor system schematic

road surface in three near-infrared wavelengths with filtered detectors. The ratios of measured intensities at the three wavelengths and the changes in absolute values of the individual intensities provide discrimination among ice, snow, water, and sand layers as well as moist and dry pavement surfaces.

Project Results

A proof-of-concept laboratory sensor system and a breadboard prototype system were fabricated. Sensor responses were characterized in the laboratory during transition of thin layers of ice and snow to water to demonstrate the feasibility of the detection concept. Preliminary low-speed tests of the vehicle-mounted prototype were conducted to characterize sensor response on asphalt with layers of ice, snow, water, and sand. These tests verified the laboratory observations and provided quantitative sensor data that enable discrimination among the various layers. Preliminary mechanical and optoelectronics designs of the sensor system were developed to prove the feasibility of a compact, light-weight vehicle-mounted system. A panel of experts from industry, government agencies, and academia was formed to guide the development of the sensor system and to identify its applications and commercial potential. Near-term applications as (1) an instrument on road maintenance vehicles during winter to detect black ice and to determine appropriate surface treatments, (2) a static sensor at bridges and other specific locations on the highways to monitor ice formation, and (3) a vehicle-mounted hazard warning system for highway trucks and tractor trailers were identified. A cooperative project, with partial IDEA funding, for development and field testing of an advanced prototype is being negotiated. Federal and state agencies, including the U.S. Army Cold Regions Research Laboratory, the Massachusetts Highway Department, and the Colorado Department of Transportation will also be contributing to the follow-on effort that should be starting this winter.

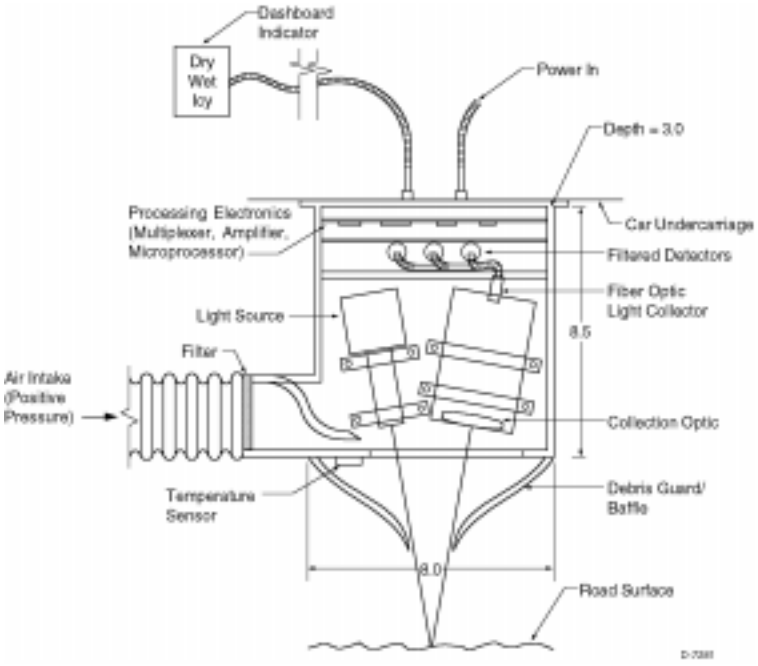


Figure 2

Preliminary sensor design

ITS-51:
Mitigating Litigation Barriers for Deployment of AHS and ETTM Innovations

Principal Investigators: John Bagby (jwb7@psu.edu 814-863-0520)

and Gary Gittings

Both from Pennsylvania State University, University Park

Started: 5/97, Completed: 8/98, Final Report: 8/98

$75,728 total cost with an IDEA contribution of $65,922

Concept and Product

The ITS community clearly perceives that legal constraints on ITS activities are among the most difficult institutional barriers to deployment. New and existing ITS technologies may not emerge until several legal and institutional issues become more widely understood. Some ITS advocates have downplayed the significance that tort liability may have in slowing the diffusion of this technology. The argument is advanced that the legal and institutional issues presented by the various ITS user services are not new but are wholly predictable extensions of current laws. Indeed, the few legal precedents to date concerning ITS related technologies have merely extended traditional tort and product liability law. However, major questions remain unresolved concerning the liability risk sharing among the public- and private-sector participants for injuries caused by ITS defects.

Part of the more novel aspects of ITS liability stems from the preference of many ITS participants to speak in terms of public-private "partnerships." Few if any, of such mixed participant projects will ever take the form of a true partnership. Instead, new forms of government procurement will be developed that break with traditional modes of procurement. Some early experiments may severely strain the existing procurement regimen. Considerable flexibility will be needed in these new relationships as the participants experiment by varying and introducing new legal contract variables that share, shift, or allocate control, cash flow, and legal responsibilities.

This ITS-IDEA project provides key analysis of this situation and the accompanying guidelines provide a better understanding of the allocation of these risks. ITS participants should be better able to design their relationships, allocate and spread their risks through insurance and other risk reduction techniques, control the remaining risks, and thereby avert catastrophes with their attendant financial losses. This project helps ITS participants to better predict the risks of liability exposure, for both the governmental and private sectors.

Project Results

This ITS-IDEA project examined existing tort principles to predict their likely evolution or reform when ultimately applied to deployed ITS systems. The well-established patterns for liability risk sharing in surface transportation systems will apply to ITS advances in vehicle control. Nevertheless, some ITS systems may induce new and potentially dangerous driver distraction problems. Among others these include the potential for misleading driver information and uncertain interactions among ITS subsystems. Quite different problems are raised as privacy concerns, such as uncertain security for the detailed dossiers possible covering individuals' movements. There is uncertainty in the reliability of significant new ITS systems software. Finally, the deployment of thousands of intellectual property innovations may considerably raise risk exposure. The close participation of governments, private contractors, and individuals in ITS user service systems will challenge traditional methods of allocating liability in the event of ITS system failure. The specter of catastrophic liability and a government's financial failure increase substantially if governments are exposed to such risks. Assemblers of completed ITS systems, e.g., automobile manufacturers, also face unknown and potentially huge legal liability.

ITS-53: A Real-Time Flow Estimation Model for Advanced Urban Traffic Control

Principal Investigator: Peter T. Martin (martin@civil.utah.edu 801-581-7144)
University of Utah, Salt Lake City

Started: 5/97, Completed: 8/98, Final Report: 4/99

$84,550 total cost with an IDEA contribution of $70,262

Concept and Product

This project demonstrates how a new model, Turning Movement Estimation in Real Time (TMERT) can infer unknown traffic flows from those measured in a network with relatively sparse detector implementation. The impact of this development is far reaching since it can eliminate the need for costly turning movement detectors or surveys. TMERT estimates serve as "virtual" detectors that will provide reliable traffic flow information across an entire network. This wealth of information can be fused, managed, and manipulated to provide a comprehensive picture of how the network is performing.

This linear estimation technology comes from the field of Operational Research, where it was invented to optimize the costs of distributing water and electricity. High-speed network flow algorithms estimate the "state" of our power and water distribution systems in real time from a minimal set of measurements.

TMERT was originally developed with support from the UK Government, California PATH, and the University of Utah. ITS-IDEA funded this comprehensive evaluation of the effectiveness of TMERT and the quality of its estimates. With the benefit of a rigorously developed theoretical network, the model has now been tested with over 7,000 simulations. This was done to better understand the relationship between actual detector deployment and the quality of the estimates.

Most methods of traffic flow estimation rely on some notion of flow distribution, usually associated with the familiar Origin and Destination Matrix. These are appropriate for the wider view and will provide information on trends but make certain behavioral assumptions. TMERT simply serves to "fit" unknown flows into a network constrained by a partial set of detected data. This State Estimation technique allows network-wide evaluation rather than focusing on individual intersections. The network oriented, non-behavioral characteristics of TMERT provide multiple application possibilities including on-line functions, such as turning movement estimates and support of adaptive control traffic signal systems, and a range of off-line functions from updating fixed time signal plans to planning level land use impact estimates.

TMERT will be most immediately useful in supporting adaptive control signal systems. The benefits of adaptive control are well documented, however these systems tend to require saturation detector coverage and the cost of this has limited their use. TMERT can provide the flow estimates needed for adaptive control with a minimal requirement for new detector installations, which should facilitate widespread implementation of these systems.

Project Results

The model's performance as a function of detector coverage is represented by a natural log curve with diminishing return as coverage increases (figure 1). The study shows that threshold detector coverage of 30% provides high-integrity estimates (75 to 90 percentile R^2). Coverage in excess of 30% brings diminishing returns. These results are illustrated in figure 1.

Network congestion influence on model performance is substantial under low detection levels but as detector coverage increases, the influence of congestion is reduced.

A detector location algorithm allows each link in a network to be ranked by its desirability as a detector location. This enables the user to identify where to locate new permanent detectors to maximize TMERT effectiveness.

The TMERT model has been applied to a range of networks including radial and sector types with successful results on all. The 7,000 plus simulations of this project represent the most rigorous evaluation to date providing increasing validation for the TMERT model.

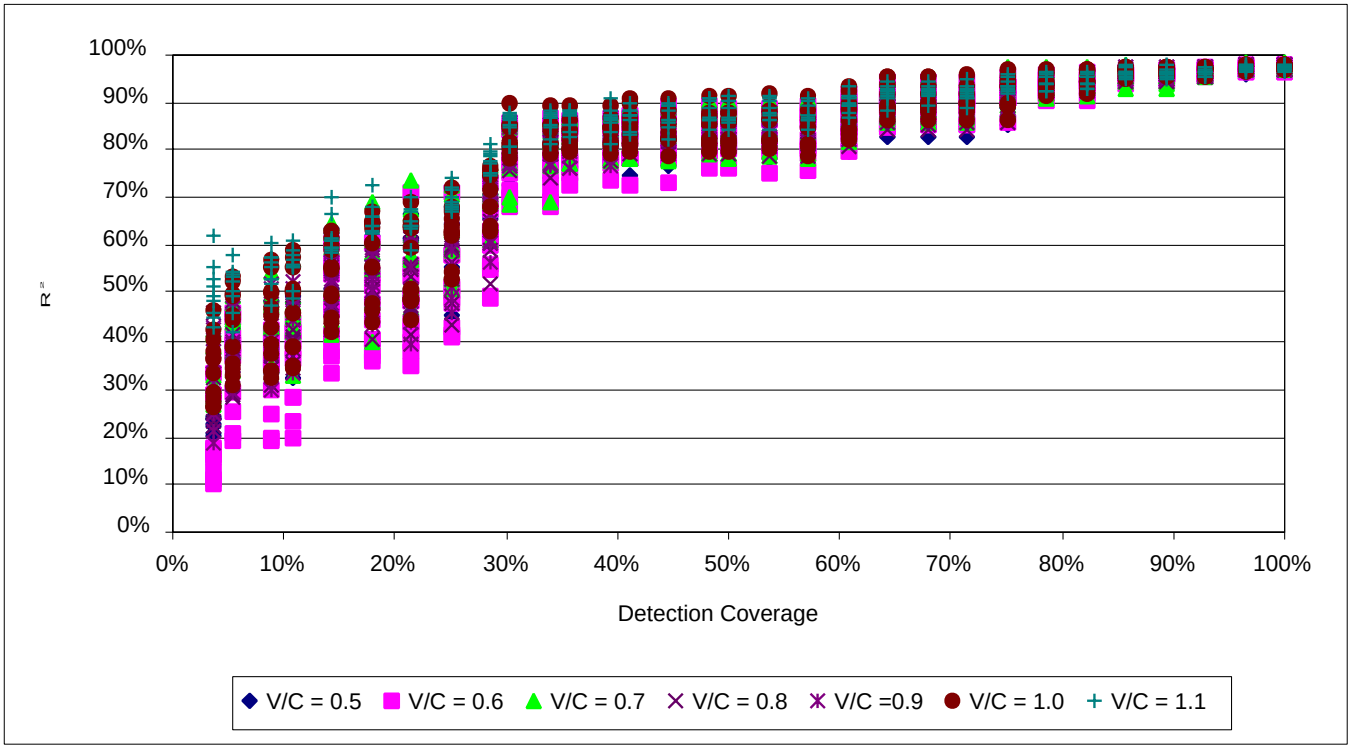


Figure 1

Effect of detector coverage and congestion (as Volume/Capacity) on quality of estimated flows (as R^2)

ITS-56:
Snow and Ice Removal Monitoring and Management System (SIRMMS)

Principal Investigator: Eric Anderson (eganders@erim-int.com 734-994-1200 x2973)
ERIM International, Ann Arbor, MI

Other Participants: NCHRP-IDEA, Wayne County Michigan, AVL Information Systems, Environmental Systems Research Institute, Ameritech, and the University of Michigan

Started: 5/97, Completion: 2/99, Final Report: 4/99

$352,218 total cost with an IDEA contribution of $120,006

Concept and Product

Wayne County Michigan's snow and ice control costs average more than $6 million per year to cover the Detroit Metropolitan area. Removal of snow and ice on county roads is done by some 160 snowplow trucks that are each given one of 130 routes and are then unsupervised for the duration of the time they are working. It is very difficult for a dispatching supervisor to have a clear idea how the road clearing operation is progressing, since every storm presents different conditions. If the dispatcher had a clear picture of what routes had been completed, a more intelligent coordination of the trucks could be done.

In an attempt to address this need ERIM International (EI) worked with Wayne County to develop a computerized winter maintenance program that was funded by ITS- and NCHRP-IDEA programs. A public/private partnership was set up to run the program. EI provided the program management and client software, AVL Information Systems provided the automatic vehicle location (AVL) equipment, Environmental Systems Research Institute (ESRI) provided the geographic information system (GIS) software, Ameritech provided the cellular digital packet data (CDPD) communications from the terminal to the trucks, and the University of Michigan provided routing algorithms. In addition, Basic Technologies provided interface electronics and support to connect to their automated salt spreader system and Navigation Technologies provided the Wayne County electronic road map (Figure 1).

The concept was to install AVL systems in trucks from one Wayne County district, provide them with intelligent routing software, and determine what increase in efficiency would be obtained when a dispatcher could determine what portion of a district's roads were plowed and salted by looking at a color-coded CRT map display showing vehicle location and route status. In-vehicle electronics collected information about snowplow blade position, amount of salt being dispersed, GPS vehicle position, etc., and transmitted the information via CDPD cellular communications to the dispatch center.

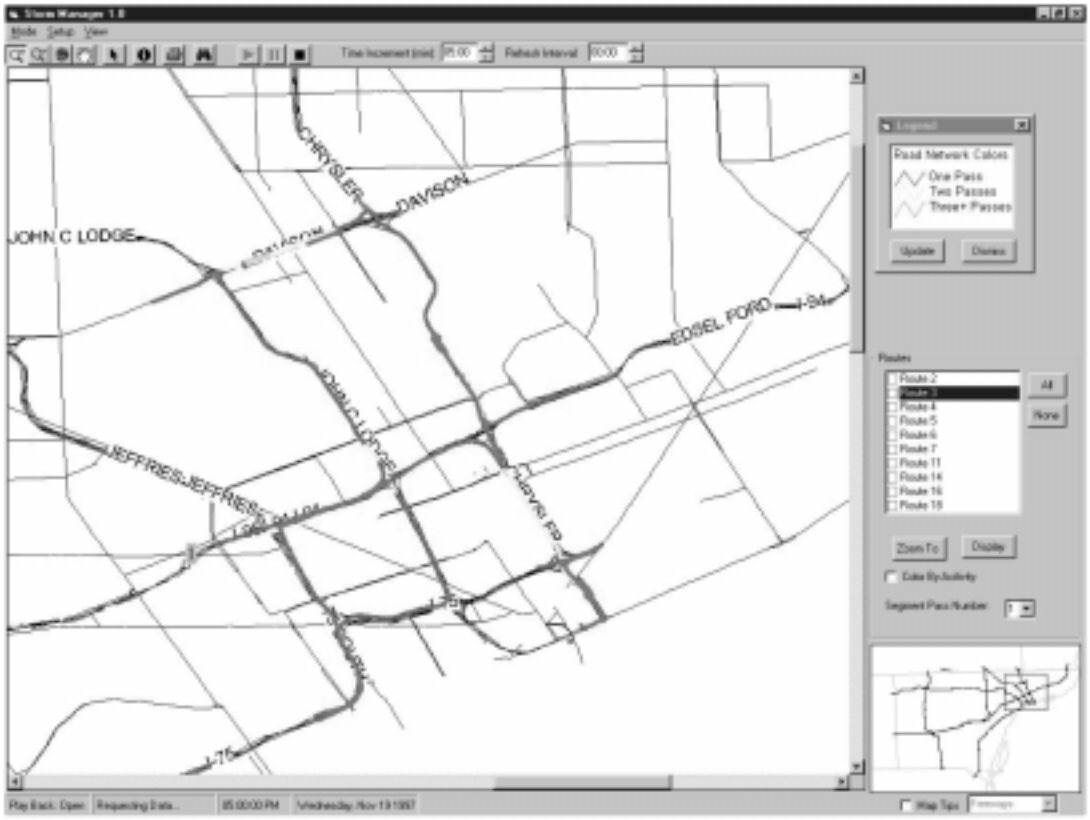


Figure 1

Dispatcher's route status display

Project Results

In general dispatchers responded favorably to the system and the project spawned enthusiasm for the new Southeastern Michigan Snow and Ice Management (SEMSIM) program. SEMSIM is a cooperative effort among Oakland, Macomb, and Wayne counties. Using AVL, it will allow one county to help another by sending salt, plows, and workers across county lines.

This study found that standard main interstate routes do not see a great improvement using the route-optimization program. The U of M's final static routing algorithm produced only a 3-4% reduction in deadhead miles on Wayne County's freeway routes. More improvement is expected on non-freeway primary roads. The operational aspects of this problem turned out to be more complicated than expected. Possibly "dynamic" routing might be able to improve dispatching efficiency more, by generating vehicle routes based on the current location and status of maintenance vehicles and routes. The University of Michigan is now working on this.

ITS-57: Differential Braking for Limited-Authority Lateral Maneuvering

Principal Investigators: Charles MacAdam and

Robert Ervin

Both from the University of Michigan Transportation Research Institute

Started: 9/97, Completed: 9/98, Final Report: 10/98

$149,218 total cost with an IDEA contribution of $83,200

Concept and Product

The project developed a driver–assist technology for reducing unintended roadway departure events by equipping vehicles with supplementary sensing and control functionality. Since single-vehicle roadway departure accidents account for approximately 25% of highway accidents, and 33% of highway fatalities in the United States, even modest reductions can result in significant savings in lives and associated injury costs.

This IDEA project designed a braking system that can support active ITS vehicle control systems aimed at preventing unintended road departure events. The basic concept is described in Figure 1, in which a vehicle's departure from the roadway is interrupted and the vehicle is re-directed, through intelligently applied differential (left- and right-side) braking, back onto the roadway or shoulder area. That is, the vehicle is steered left or right by means of braking forces appropriately applied to either side of the vehicle by a control algorithm.

It should be emphasized that the proposed differential braking system is easily over-ridden by driver steering activity. Consequently, drivers who are only temporarily distracted, and become quickly re-engaged in the driving process during a roadway departure scenario, can easily recover full control of the vehicle through steering action alone, irrespective of whether or not the differential braking system is active at the same time.

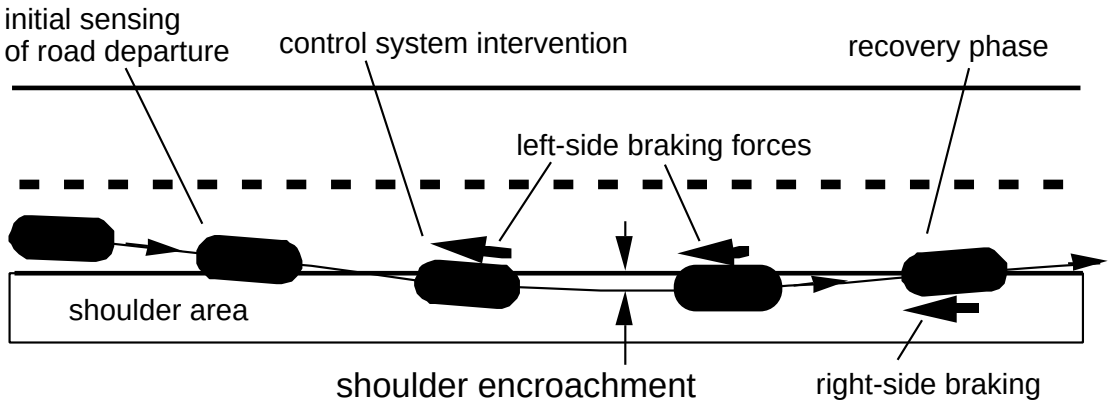


Figure 1

Depiction of a differential braking control intervention during a roadway departure event

Work under this project has concentrated on development of the control algorithm aspects within such a system using computer simulation to demonstrate the effectiveness of the concept under different operating conditions (speeds and surface friction). Initial vehicle track tests supported the analysis by providing measurements of how a representative vehicle responds to differential braking at various speeds and application pressures.

An open-loop braking system was installed in a test vehicle in order to characterize the resulting vehicle dynamics during single-wheel braking applications. Test track experiments were conducted to evaluate vehicle responses from single-wheel braking at left and right wheel locations.

A control algorithm was then developed and evaluated with the use of a computer tool that simulated the differential braking system. The overall goal was to sense an impending roadway departure event (through a forward-looking camera or equivalent sensor system), warn the drivers and ultimately intervene with the differential braking system if the driver does not respond.

An expert panel consisting of representatives from Ford Motor Co. (industry and vehicle dynamics perspective), the NHTSA (safety and ITS systems), ERIM International (sensor expertise), and UMTRI Human Factors Division (driver behavior) acted as technical advisors to the project.

Project Results

Both Ford Motor Co. and the U.S. Army Tank-Automotive Command have provided previous support and are interested in further developing the basic technology. Other parties such as FHWA, NHTSA, state transportation departments, automotive manufacturers, and various automotive parts suppliers would also likely have increased interest as the potential product becomes more mature and proven in use.

ITS-60:
Visibility Monitoring System For Dust Storms

Principal Investigator: Terry Wilson (terry_wilson@sensor-tech.com 480-483-1997)
Sensor Technologies & Systems, Inc., Scottsdale, AZ

Started: 4/97, Completion: 11/99

$88,206 total cost with an IDEA contribution of $75,000

Concept and Product

Advanced warning of potential dust storm conditions and immediate warning of actual dust storms along critical transportation routes can save lives and reduce personal injuries and property damage due to vehicle collisions. These advanced warnings should be made available to drivers, ITS traffic management centers, and emergency response agencies as an alert to a developing roadway hazard. This project is developing an optical sensor to detect visibility impairment of the kind caused by dust storms. Other atmospheric sensors can be integrated with the visibility sensor to provide data on wind speed, wind direction, temperature, and humidity, so that pre-dust storm conditions can be determined and appropriate cautions issued.

The dust sensor is based on applying low cost, near-infrared laser sensing and range finding technology in a unique way to sample large volumes of atmosphere. The sensor works by line-of-sight alignment of the emitter/detector to the reflector 1 km away (Figure 1). The obscurant, dust in this case, changes the signal monitored by the detector. This change in signal is used to indicate a reduced visibility condition. By strategically positioning the sensors in areas where dust has been a problem, it is hoped that multi-car pile-ups can be avoided. The installation sites can be semi-permanent or mobile for more short-term problems.

The near-infrared laser was chosen for its sensitivity to the size of particles expected in a dust storm. The emitter and detector are co-located to simplify the system design. A reflector placed 1 km from the emitter/detector provides adequate return signal over the desired range. A breadboard system has been built and successfully laboratory tested.

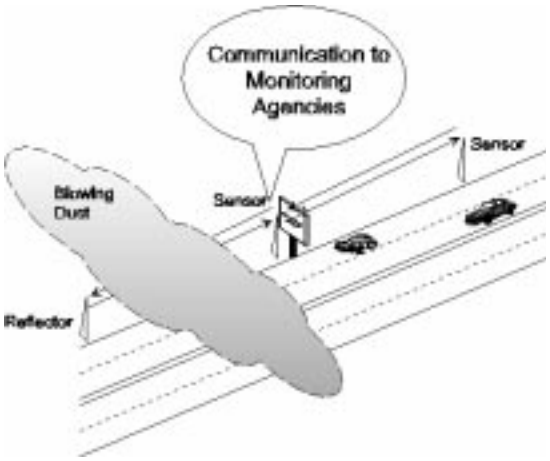


Figure 1

System concept

Project Results

Field tests were conducted on an unpaved road, with dust generated by driving a vehicle on the road. Dust clouds from 0 to 1 km away were detected in every instance. By moving the reflector in range, the range scale factor was determined to be 0.282 electrical degrees/meter. The expected value is 0.273 degrees/meter. This equates to only about a 3% error, which is mainly attributed to the measuring accuracy of locations where the data were recorded.

Attempting to apply the range factor to the dust cloud data with the reflector at 1 km is difficult due to the stronger signal return from the reflector than the churning dust cloud. However, at this time, the analysis is still in progress. It is not known if the range of the dust cloud can be pinpointed.

There is another very important aspect to consider. The size of dust storms is typically very large (Figure 2), covering from $^{1}/_{2}$ mile to several miles. Smaller dust storms (dust devils) don't have nearly the hazardous conditions of these larger storms. Therefore, the range resolution of less than 1 km may not be required.

Items for consideration in the next step to provide a complete turn-key system include: 1) develop the prototype system suitable for manufacturing, 2) integrate the standard ITS interfacing for warning systems, and communication to the monitoring station, 3) integrate auxiliary sensors, 4) develop a microprocessor control system, and 5) deploy a prototype system in the field for an extended monitoring period.

Figure 2

Typical dust storm

ITS-61 & 81: Infrared Ranging via Image Subtraction (IRIS)

Principal Investigators: Ioannis Kanellakopoulos (ioannis@ee.ucla.eduand, 310-206-5278)

and Oscar Stafsudd (stafsudd@ee.ucla.edu)
both at the University of California, Los Angeles

ITS-61 Started: 7/97, Completion: 10/98, Final Report: 10/98

$352,218 total cost with an IDEA contribution of $120,006

ITS-81 Started: 6/99

$219,541 total cost with an IDEA contribution of $199,541

Concept and Product

The objective of the concept development project ITS-61 and the continuation project ITS-81 is the development of a new technology for ranging sensors called IRIS. This technology has the potential to produce a new generation of sensors with significantly lower cost and better accuracy and reliability than any of the technologies available today. This technology should have a significant impact on the deployment of near-term ITS applications such as collision warning and adaptive cruise control. Commercial vehicle operations will also benefit from medium-term ITS applications such as the electronic towbar and automated freight transport.

In its most advanced version, the IRIS sensor hardware includes two infrared illuminators (LEDs or low-power lasers) two CCD receiver cameras and a microprocessor that processes image data from the cameras to produce the range estimates.

The operating principle of the IRIS sensor is based on image subtraction, and stereoscopic vision: each sensor records two images of the scene ahead in rapid succession: one with the illuminator off, and another with the illuminator on. The first image is then subtracted from the second; this eliminates irrelevant background information and leaves only the reflections from the taillights and license plates of vehicles ahead. Using the known fixed distance between the two receiver cameras as a baseline, range, azimuth, and yaw information is computed for each vehicle using triangulation. The primary innovation is the method of recording two images in a very short time interval. This results in a highly accurate and reliable sensor with significantly lower production cost than any of the competing technologies.

Project Results

Project ITS-61 developed a first prototype of the sensor that used only one camera with a complex masking scheme and only one laser illuminator. This assumed that the distance between the taillights of the preceding vehicle was known and could be used as the baseline for triangulation. The hardware was either purchased or built at UCLA, and the software for the prototype was developed entirely by the research team. This prototype was used to conduct static laboratory experiments as well as dynamic experiments with two vehicles in motion. These experiments resulted in measurements with 99% accuracy for distances of 2-20m at an update rate of 2Hz. In project ITS-81, the prototype has been improved by replacing the masking scheme with a much simpler one and the laser illuminator with an array of power LEDs. This new arrangement extends the range of the prototype to 250m (approx. 800ft) with 90% accuracy and improves the accuracy at close distances to 99.5%. In the remainder of the project,

the investigators plan to replace the current laptop computer that performs the data acquisition and processing with a dedicated microprocessor, and to upgrade the software to add more functionality to the prototype.

To ensure the commercial implementation of the IRIS technology, the investigators are focusing on the development of a fully functional prototype. This prototype will be mounted on an experimental electric vehicle and will be used to conduct vehicle following experiments. The IRIS team is in close contact with several potential industrial partners (DaimlerChrysler, Ford, Siemens, TRW, and Visteon), who have declared an interest in the technology. Potential partners that want to pursue the commercialization of this technology will be able to borrow a prototype so that they can install it on one of their own vehicles and evaluate its capabilities.

Figure 1

One of a stereo pair of IRIS sensors

ITS-62: Wavelet-Based Image Compression System for ITS

Principal Investigator: C. H. Chen (cchen@umassd.edu, 508-999-8475)
University of Massachusetts, Dartmouth

Started: 12/97, Completion: 12/98, Final Report: 3/99

$66,200 total cost with an IDEA contribution of $54,700

Concept and Product

This IDEA project developed a completely software-based PC system for video compression using wavelet transform techniques for ITS. At an average compression ratio of 25, the wavelet-based system can send compressed traffic surveillance video at 2 frames per second using a standard phone line connection and an inexpensive 56K modem. The reconstructed video compares well with the original. This demonstrates an inexpensive solution to accessing remote traffic surveillance locations.

Conventional discrete cosine transform (DCT) based video compression has been widely used in industry as the JPEG and MPEG2 standards. This technique requires that the image be divided into blocks of suitable sizes before compression, which results in undesirable image-degrading blocking artifacts. Wavelet-based compression does not require blocking and so has the advantage of eliminating this source of degradation. In this project a new wavelet compression procedure using a "lifting" scheme and 3-D subband coding was developed. The procedure runs on a standard personal computer (PC) and does not require any special hardware. It can achieve the large compression ratios needed to transmit video over standard telephone lines. Using this system compressed video can be transmitted through a 56K bits/sec. modem at 2 frames per second while achieving high quality reconstruction at a signal-to-noise ratio of 25 or above. This is fast enough to provide essential surveillance information for normal vehicle speeds.

Project Results

Surveillance video is captured by a video camera and sent to a PC equipped with a frame grabber and a 56Kbps modem. The frame grabber will sample and digitize the video. The wavelet software will compress the digital video in real-time and send it by modem through local telephone networks. A PC at a traffic management center receives and decompresses the data into video signals. The cost is low and installation is easy.

Table 1 shows statistics for some typical one-minute traffic video segments (frame size is 240x320 pixels). Figure 1 shows a frame from file 22 before compression. Figure 2 shows the same frame after compression and reconstruction. Project results, as demonstrated at the Boston Traffic Management Center, showed that wavelet-based compression can provide both large compression ratios and good reconstructed image quality. Wavelet algorithms for eliminating fog due to dirty camera lenses and for background elimination were also demonstrated. The investigator is looking for partners interested in participating in commercialization of this IDEA product.

Table 1 Statistics of sample one-minute traffic videos

File #	Frames / sec.	Compression ratio	PSNR (dB)	RMSE
21	2	50.5	22.3	19.6
22	2	56.5	21.7	20.9
41	4	48.8	23.0	18.0
42	4	54.6	22.3	19.6
81	8	64.7	23.3	17.4
82	8	56.3	22.8	18.6

Figure 1

Original video frame from file 22

Figure 2

Reconstructed video frame from file 22

ITS-63: Auto Radio Override Alert System For Emergency Vehicles and Trains

Principal Investigator: Douglas Maxwell (dmax1415@aol.com 612-926-8652)
Midland Associates, Inc., Minneapolis, MN

Started: 2/98, Completion scheduled: 4/00

$251,566 total cost with an IDEA contribution of $81,566

Concept and Product

This electronic safety system permits an emergency vehicle or train to override active radios in all passenger cars in the immediate area to warn the drivers of the approach of the emergency vehicle or train. No modification to the passenger car is needed and only minimum interference occurs with traffic on parallel streets.

A transceiver and antenna located on the emergency vehicle or train will transmit an emergency message sequentially at various frequencies over the AM and FM bands at the proper power level to reach all vehicles traveling in the vicinity and path of the emergency vehicle or train. Drivers listening to the radio will hear an emergency message repeated every 4 seconds. It is transmitted only over a narrow arc along the path of travel of the emergency vehicle. For railway applications, the message is transmitted to the right and to the left of the path of travel of the train to warn motorists that a train is approaching a grade crossing.

The Auto Radio Override Alert System overcomes the inability of the motorist to hear the siren or other warning device of the emergency vehicle or train due to the fact that he/she is riding in a well-insulated vehicle with the windows closed and the air conditioner running and the radio playing at high volume. The system permits intelligent communications from emergency vehicles or trains to the driving public.

Project Results

Experimental low-power broadcast transmitters were constructed for the AM and FM broadcast bands. These transmitters were tested with three experimental antennas for the AM band and one for the FM band. The AM transmitter used a Hewlett Packard signal generator as a modulated source to drive a low-power linear amplifier rated at 20 watts continuous output. The programming message was recorded onto an audiocassette tape and a portable cassette player was used to modulate the signal generator.

The first AM antenna tested was a pXm (“p” cross “m”), the second was a simple loop antenna, and the third antenna tested was a helically loaded vertical antenna. This third antenna proved most useful for this purpose; in a lab environment, it was possible to obtain a good impedance match to the antenna, but in the field this was not possible for any combination.

The FM antenna tested was a modified Yagi-Uda array consisting of a three-element array of quarter-wave elements. This antenna was well matched from below the FM broadcast band (below 88.5 MHz) up to about 98 MHz. A sufficiently wide (20 MHz) bandwidth can be achieved by trimming and moving the three elements.

Figure 1 shows the area of coverage resulting from a one-watt and a 10-watt transmitter. The illustration shows achievable results for a typical snow plow installation or a railway crossing installation where the message would be broadcast at right angles to the path of the train.

Hardware and software are being developed to enable the emergency message to be transmitted to active radios in all passenger cars in the immediate area. FCC approval is needed to transmit this message across the AM and FM bands. Further research for a more efficient tunable AM antenna and a sophisticated antenna-matching network is required to track the transmitter as it rapidly hops from channel to channel. Preliminary contacts with corporations currently selling communications equipment to municipal and business radio buyers have resulted in potential follow-on interest once the IDEA contract has been completed.

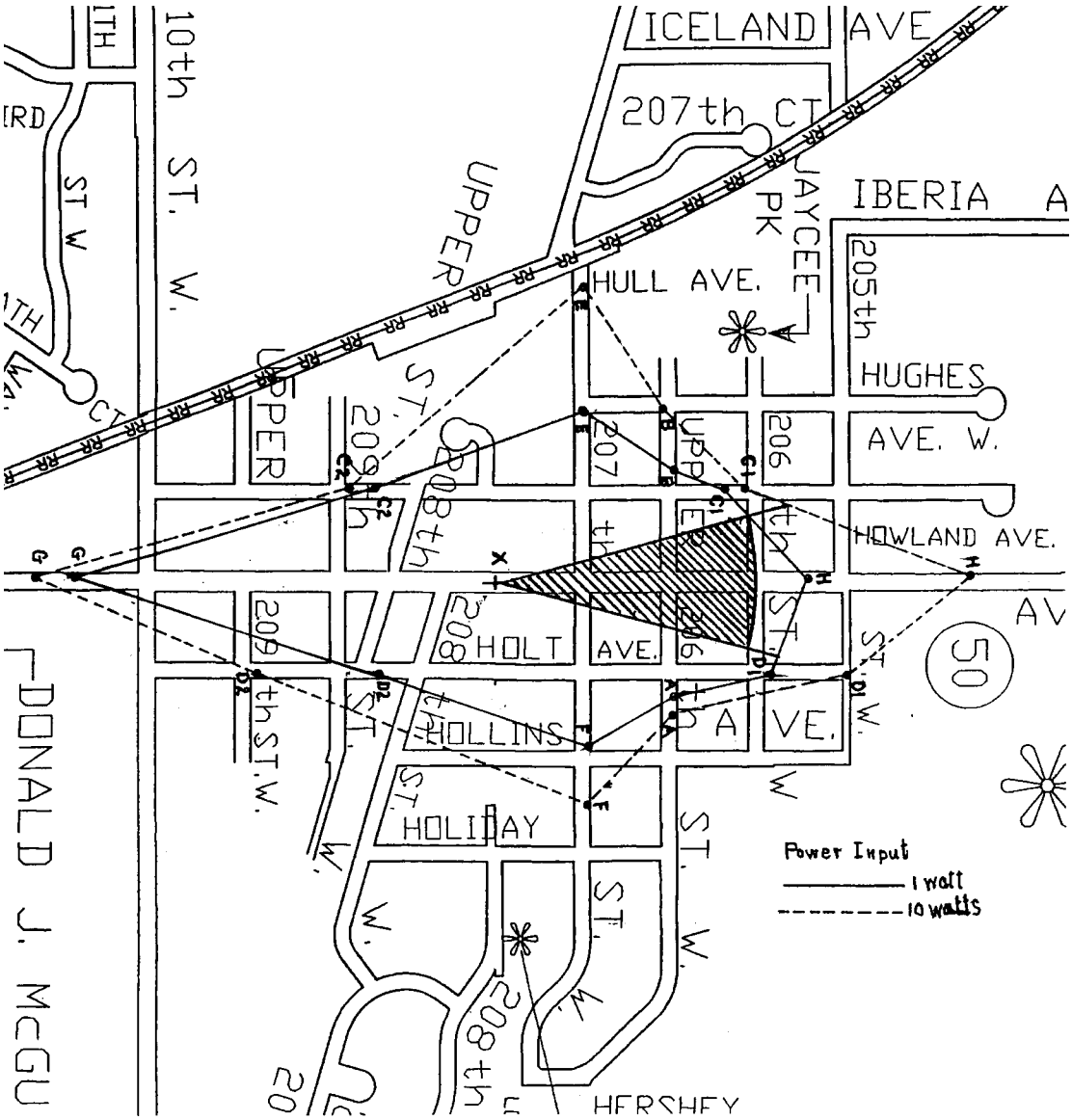


Figure 1

Override area with Modified Yagi-Uda Antenna

ITS-65:
Overhead Optical Sensor for Vehicle Classification and Axle Counting

Principal Investigator: Robert Gustavson (robert@seo.com 407-298-1802)
Schwartz Electro Optics, Inc., Orlando, FL

Started: 4/98, Completion scheduled: 7/99

$63,027 total cost with an IDEA contribution of $52,127

Concept and Product

The *Autosense II* (ASII) vehicle detection and classification sensor, developed under IDEA project ITS-6, has been proven to be very successful using rule-based algorithms to do shape-based vehicle classification. It achieved 96.5% classification accuracy on a 50,000-vehicle database including a range of weather conditions and traffic conditions. However, most tolling applications in the U.S. still require vehicle classifications based on the number of axles a vehicle has as opposed to shape-based classification. Thus toll collection applications in the U.S. must include an axle counter, usually a treadle installed in the pavement. Transportation professionals at all levels have expressed interest in an overhead sensor that will count axles and perform tasks that the axle counter cannot do, such as vehicle separation. As a result of this project a new overhead optical sensor, the *ASII-A* has been developed to fill this need.

Project Results

This project began with collection of a side-view laser range-image data to determine the optimum sensor location. Three different mountings were tested at a site on S.R. 441 in Orlando. Data collected from each position was analyzed to determine the best mounting location for counting axles. A 45-degree mounting angle was found to be the best and a database of 2,000 vehicle range images was collected from that mounting configuration. Axle counts and FHWA Scheme 'F' vehicle class for each sample were verified from video images as shown in Figure 1. Table 1 shows the counts and percentages of the different categories in the database. A rule-based axle counting algorithm was developed and tested using the database. Axle detection accuracy for the algorithm was calculated at 99.5% with a false alarm rate of 0.97%. The laser scanner used was an unmodified Schwartz *ASII* unit.

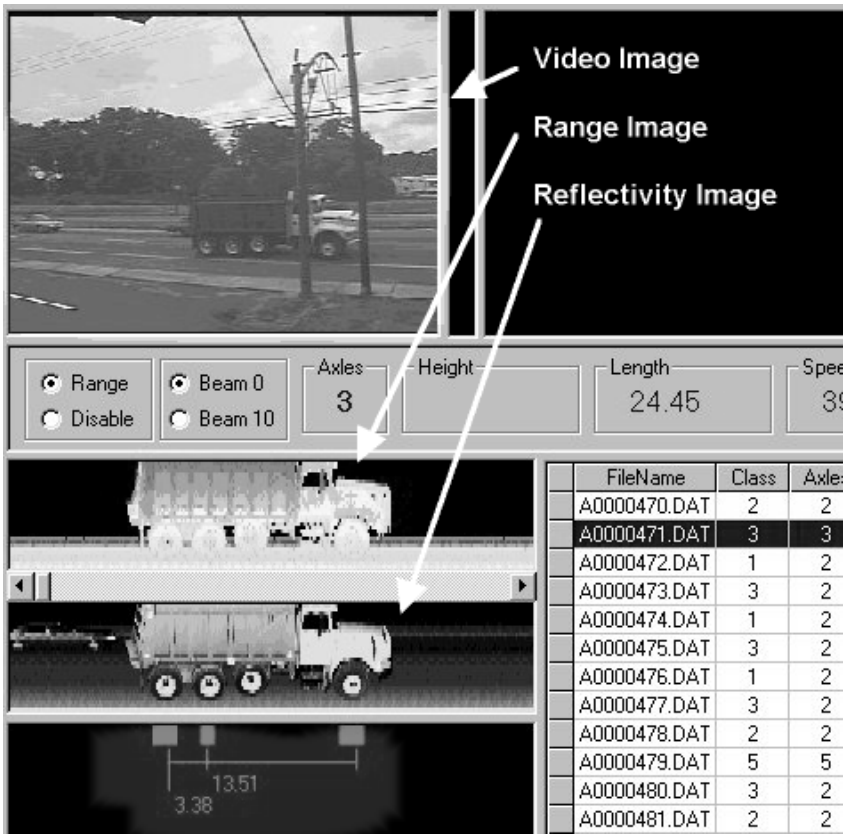


Figure 1

Range & Intensity data from 45-degree mounting configuration

Table 1 Vehicle Database Distribution by FHWA Classes

Class	Description	Count	Percent
1	Motorcycles	2	0.1%
2	Cars	812	40.5%
3	Pickups & Vans	895	44.7%
4	Buses	14	0.7%
5	2-Axle, Single Unit	120	6.0%
6	3-Axle, Single Unit	43	2.2%
7	4-Axle Single Unit	1	0.1%
8	2-Axle Tractor, 1 or 2-Axle Trailer		
	3-Axle Tractor, 1-Axle Trailer	28	1.4%
9	3-Axle Tractor, 2-Axle Trailer	76	3.8%
10	6-Axle Tractor Trailer	6	0.3%
11	5-Axle Multi-Trailer	0	0.0%
12	6-Axle Multi-Trailer	0	0.0%
13	7 or more Axles	0	0.0%
14	Unknown	7	0.3%

ITS-66: Use of Ultra Wideband Technology for Designated Short-Range Communications for Highway and High-Speed Rail

Principal Investigator: Robert Fontana (rfontana@multispectral.com 301-590-3978)
Multispectral Solutions, Inc., Gaithersburg, MD

Started: 1/98, Completion scheduled: 11/99

$131,287 total cost with an IDEA contribution of $81,287

Concept and Product

Multispectral Solutions, Inc., (MSSI) has directed its efforts, under the IDEA project, toward the development of an ultra wideband (UWB) electronic license plate (ELP). The ELP will be capable of transmitting both driver and vehicular information to law enforcement personnel and will be capable of detecting the vehicle's proximity to other vehicles, objects, or obstructions. Both the tagging function and the collision avoidance function have a wide range of applications throughout the intelligent transportation and law enforcement communities.

The innovative use of UWB technology in the ELP allows it to overcome interference. The short duty cycle of signal transmissions from the ELP makes it possible for many ELPs to be deployed in the same area, on the same frequency, without interference. Received signals are often attenuated when simultaneous reception of reflections of the same signal off the ground and other objects interferes with the main signal that has traveled a direct path. The very short (nanosecond) UWB pulses eliminate this source of interference since multi-path signals will arrive after the main signal.

Project Results

The primary requirements of the ELP are to transmit driver/vehicle information to a roadside reader and to determine the presence of, and distance to, other vehicles and objects. The IDEA ELP uses a radar-based solution to meet the latter requirement since this approach offers lower implementation cost and does not require hardware on other vehicles. A communications-based system was considered but this would be more complicated and targets not equipped with sympathetic hardware could not be detected. The system has the following general specifications:

Collision Avoidance Radar

Frequency of Operation	5.4-5.9 GHz (C-Band)
Pulse Repetition Rate	10 KHz
Vehicle Detection Range	100 feet
Range Resolution	1 foot
Primary Power	12 Volt DC

Electronic License Data Communications

Frequency of Operation	1.3-1.7 GHz (L-Band)
Pulse Repetition Frequency	400 kb/s UWB Burst
Communications Range	1000 feet
Communications Data	Text and Image
Primary Power	12 Volt DC

Final field tests will be conducted to determine the range, accuracy, and detection pattern against various objects of interest including pedestrians, automobiles, bicycles, and telephone poles. For these tests, the ELP will be mounted on the front bumper of a vehicle in an open parking lot. Tests will be made against both stationary and moving targets of interest. Particular attention will be focused on nuisance alarms experienced during testing. Field tests of the data communications link will be conducted to establish the reliability of the ELP link. Testing will be done in both open and congested roadway environments. The maximum reliable operational range of the link will be determined under varying conditions.

ELP technology should have wide transferability to a number of transportation applications. MSSI has applied UWB technology in the design of a C-Band radar backup sensor for heavy equipment in the industrial/mining environment where it is used to detect obstructions in the rear quadrant at ranges of 1-60 feet. This could be applied to commercial vehicles, automobiles, and to pedestrian detection. The tagging application could be employed for automated tolling, facility access, and freight management systems. Application of UWB technology for this purpose would greatly expedite the location, identification, and billing of vehicles and cargo.

Figure 1

Electronic License Plate (ELP)

ITS-70:
Real-Time Traffic Control of Oversaturated Conditions

Principal Investigator: Elena Prassas (eprassas@poly.edu 718-260-3550)
Polytechnic University, Brooklyn, NY

Other participants: Edward Lieberman,
KLD Associates, Huntington Station, NY (kldhunt@aol.com)

Started: 10/98, Completion scheduled: 10/99

$159,002 total cost with an IDEA contribution of $79,747

Concept and Product

The goal of this IDEA project is to develop a real-time adaptive traffic control system designed expressly for congested networks and to test the developed algorithm in simulation and in the real world. The control principles, which include internal metering, queue control, intersection spillback avoidance, control of platoon dispersion, and maximizing productivity (throughput) differ markedly from existing treatments. Congestion is a growing problem along major corridors in the United States, increasing travel times, wasting fuel, generating pollutants, and harming economic activity. An effective control policy for congestion relief in oversaturated corridors can have significant advantages in each of these areas.

The concept is simple, but elusive. When traffic demand routinely exceeds the capacity of intersections, existing signal control policies (even queue sensitive ones) fail to adequately control the resulting unstable growth of queues over successive signal cycles. These growing queues lead to intersection spillback, intersection blockage, and the consequent spread of congestion. A better approach is a control policy that "switches objectives" when oversaturation is detected to enforce the explicit conditions that intersections should not be blocked by queue growth, or "starved" for vehicles to process. These new control objectives are: (1) control queue formation to prevent (or minimize the frequency and extent of) spillback into intersections; (2) fully utilize all available green time at the highest service rate to maximize productivity; (3) effectively utilize existing roadway storage capacity; (4) provide equitable service to competing traffic streams; (5) minimize delay along the undersaturated elements. Note that "minimizing delay" only applies to the undersaturated elements of the arterial; the first four objectives for oversaturated elements differ intrinsically from most existing RT-TRACS objectives.

The policy first developed assumed a steady-state traffic environment that could exhibit under-saturated flow conditions on some links of an arterial network and oversaturated conditions on other links. The resulting model, named IMPOST (Internal Metering Policy to Optimize Signal Timing) took the form of a Mixed-Integer Linear Program (MILP) that could serve as an off-line tool to provide signal cycle length, phase timing, and offsets, to satisfy an objective function based on queue lengths. This objective function, in combination with the constraint equations, satisfies the five objectives enumerated above. The MILP was then expanded to include left-turn phasing and extended the concepts into the real-time domain.

This extension takes the following form of cycle-by-cycle adjustments of signal phase duration to ensure that recurring queue formations on oversaturated links are stable over time and that their lengths are controlled to lie within computed (min,max) bounds. The system must continually test for a change in state from under- to over-saturation (and vice-versa) on every link in the system. A change in state prompts the policy to recompute optimal signal offsets and phasing, and queue lengths, using the MILP formulation with updated coefficients, and to modify the cycle-by-cycle adjustments of signal phase duration.

This paradigm rests on the observation that the offsets calculated with the MILP formulation remain optimal if phase duration changes, provided the actual queue lengths do not depart too far from the optimal (computed) queue length. Consequently, the MILP calculations (which are very fast) need be executed relatively infrequently. The result is an efficient, variable-cycle, variable-timing control policy that promotes queue stability and satisfies the five policy objectives.

Project Results

To date on this project, the RT/IMPOST formulation has been reviewed and refined, and the necessary real-time implementation algorithms have been developed and tested. The software for the real time/IMPOST has been developed and put into the WATSim model for extensive testing in a simulated real-time environment.

The final stage of this IDEA project will be a deployment of RT/IMPOST in the City of White Plains, New York; the field demonstration will happen in the autumn of 1999 and will provide a comparison of traffic operations with their existing Generation 1.5 control policy. Recently Polytechnic and KLD were awarded a contract by NYSERDA (New York State Energy Research and Development Authority) to extend RT/IMPOST from an arterial control policy to a grid network control policy.

ITS-71:
Real-Time Signal Control Using Queue Length Information Deployed at an Intersection

Principal Investigator: Bob Larson (bob.larson@ssc.de.ittind.com 719-599-1594)
ITT Industries, Systems Division, Colorado Springs, CO

Started: 9/98, Completion scheduled: 7/99

$138,931 total cost with an IDEA contribution of $77,808

Concept and Product

This project is developing a video camera-based technique for determining vehicle queue lengths at signaled street intersections. This technology will ultimately provide input to adaptive algorithms for traffic signal control where signal timing depends on accurate queue length information. Traffic congestion worsens at urban intersections when turn lanes overflow. Usually, traffic backs up into adjacent lanes. By recognizing queue lengths and adjusting signal control strategies in real time, a video camera-based queue length detection system could help optimize vehicle throughput.

ITT Industries has developed a video camera-based system capable of determining vehicle queue lengths within the camera's field of view. Existing technologies to estimate queues use loop sensors that are embedded at fixed intervals under the road surface at intersections and in on-ramp roadbeds. These sensors are vulnerable to damage and wear. Because of their location they are difficult to maintain, requiring lane closures for repairs and servicing. In contrast, video-based sensors are non-intrusive and can be serviced from a bucket truck. They can also serve as video traffic monitors of the scene if the video images can be transmitted back to a Traffic Operations Center. During this project, a web-based streaming video capability was developed as a part of the system, permitting a greater video update rate for traffic surveillance. A web page allows users access to the streaming video from the Pan/Tilt camera connected to the system.

Figure 1

Live images and queue length data

Project Results

Figure 1 shows the system master control software displaying images and showing the queue length calculation. The window on the left shows a map of the location of the camera site in Colorado Springs. In the second window there are two regions of interest for which queue lengths are being calculated. Lane one is the right-hand lane; lane two is the left-hand lane. The vehicle count from the queue length algorithm is zero in lane one and three in lane two, as shown. The third window in the lower right-hand corner of the figure is the streaming video from the sensor viewed using Microsoft NetMeeting software.

Implementing this approach would involve making the algorithm more robust to changing environmental conditions. Determining an appropriate threshold for filtering noise in the image proved to be problematic during the project. As a result, algorithm performance was somewhat dependent on changing lighting conditions during the day. An adaptive approach that senses changes in image contrast and changes the threshold value is a significant next step. Reliable tracking was sometimes hard to achieve in the field. Better performance was obtained in the lab under controlled conditions. Part of this was due to the threshold problem, part due to difficulties in proper calibration, and part was due to the effects of the environment on the camera. Ongoing improvements in these areas will make the algorithm more robust to real world implementation.

ITS-72:
Demand Responsive Service for Standard Ground and Intermodal Freight Movements

Principal Investigator: Amelia Regan (aregan@uci.edu 714-824-1746)
University of California, Irvine

Started: 8/98, Completion scheduled: 10/99

$70,687 total cost with an IDEA contribution of $54,985

Concept and Product

This project (subtitled *Implementable Dynamic Dispatching Algorithms for Carrier Fleet Operations*) develops and tests algorithms tailored to dynamic freight and fleet management associated with local truckload trucking operations such as those supporting rail or maritime intermodal environments. These problems require solution methods that work quickly, allowing dispatchers time to examine solutions, and in some cases to make changes and re-solve. In addition, assignments must be updated many times during the course of a day as new demands become known and traffic, transfer center, or customer location delays force the reassignment of loads from one driver to another.

The operations of both exclusively ground-based transportation service providers and carriers specializing in service to intermodal operations have changed dramatically as a result of numerous factors, including a precipitous increase in the demand for service to time-sensitive customers; the continuing growth in just-in-time manufacturing, service and retail operations; and, global logistics operations and technologies capable of providing continuous updates on the status of freight movements. In addition, growth in intermodal transportation has created a need for efficient local ground operations to support these services. The efficiency of the ground portion of intermodal freight transportation is a key factor in its overall competitiveness–competitiveness that will lead to the more efficient use of our nation's infrastructure and to improvements in air quality and safety.

While software that partially automates the routing and scheduling process for long-haul trucking operations has achieved a reasonable degree of acceptance in the industry, similar packages for local operations and those intended explicitly for real-time operations are lacking. The ability of carriers to operate effectively hinges, in part, on the development of tools that will enable them to take full advantage of real-time information. Such information includes regular status and location updates for both drivers and service requests, as well as associated time-windows for pick-ups, deliveries, and intermodal transfers.

In local truckload and less-than-truckload operations, carriers typically know only a portion of loads that must be moved more than a few hours before the moves take place. In addition, the high degree of randomness associated with time spent at intermodal facilities and at customer sites makes it difficult for dispatchers to develop reliable schedules for even the known loads at the start of the day. Therefore, the assignment of available drivers to loads takes place in real-time, shortly before the load must be moved. Carriers providing service to intermodal operations must be prepared to deal with the complexity of meeting schedules imposed by the interfacing modes in addition to uncertainty with respect to the number and timing of requests for service.

Project Results

Several assignment methods that mix global and local optimization techniques and require varying degrees of real-time information updates have been developed and tested. A GIS-based simulation environment has been developed specially for this purpose. The simulation environment mimics the local operations of the largest rail-ground intermodal service provider in the United States and can easily be modified to represent any intermodal operations. The simulation environment is a tool for analyzing the efficiency of operational practices. Company demand data have been used to develop and test the assignment techniques under a wide range of scenarios with respect to the variability of times spent at customer docks, network travel times, and the fraction of loads known at the start of the day. In addition, a system for generating representative dynamic problems flexible enough to be applied to a wide range of operations has been developed and will be made available to other researchers via a web site describing this research.

Performance of the most promising assignment methods will be tested against dispatcher generated assignments during the fall of 1999. JB Hunt Transportation will be supporting the research both by providing a grant and also by providing access to data, engineering managers, and dispatchers during this time. If the tests are successful, plans will be made to implement the assignment system in live operations within a year and to move from lab quality to field quality software.

Figure 1

Data from the Los Angeles Intermodal freight transfer facility was used in this study.

ITS-73:
Animated LED 'Eyes' Traffic Signals

Principal Investigator: Ron Van Houten (Rvhcerstss@aol.com 902-434-6274)
Center for Education and Research in Safety, Gulfport, FL

Other participants: Relume Corporation, Troy, MI

Started: 7/98, Completion scheduled: 9/99

$182,748 total cost with an IDEA contribution of $79,500

Concept and Product

This project developed and tested a signal technology used to prompt pedestrians and drivers to look for potential conflicts. The innovation is that it displays a pair of eyes with eyeballs that scan back and forth. Tests have demonstrated that adding the animated eyes display to the pedestrian signal significantly reduces motor vehicle-pedestrian/conflicts at signalized intersections (Figure 1). Another application of the animated eyes display is to actively prompt drivers when a potential threat is present. Microwave sensors are used to detect pedestrians at unsignalized crosswalks or at parking garage exits and activate an LED sign that consists of two pedestrian symbols with animated eyes between them. When a pedestrian is detected approaching from the driver's right, the pedestrian symbol facing the intersection on the right side is illuminated along with the animated eyes. When the pedestrian is approaching from the driver's left, the pedestrian symbol facing the intersection on the left side is illuminated with the animated eyes. The animated eyes sign used at garage exits (Figure 2) produced a large increase in drivers yielding to pedestrians and a reduction in motor vehicle/pedestrian conflicts. As part of this project the animated eyes are also being evaluated at mid block crosswalks and at railroad grade crossings.

The animated eyes are populated with blue or white LEDs driven at a 10 percent duty cycle and a P.R.F. of 20 khz. When pedestrian symbols were used to signal drivers they were populated with yellow LEDs. The eyes scan back and forth at a rate of 1 cycle per second. The size of the eyes is scaled to meet the needs of the particular application.

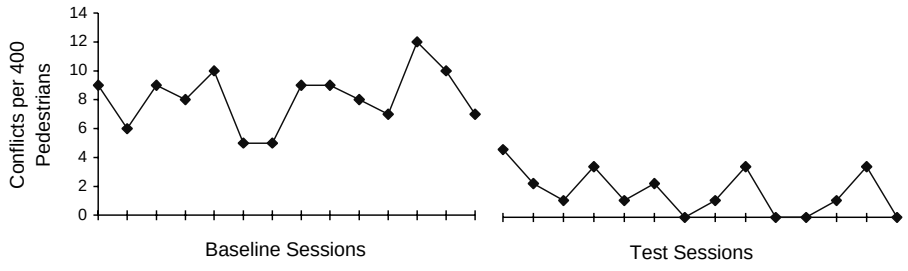


Figure 1

Test results for pedestrian "shifting eyes" signal head

Figure 2

Garage exit application

Project Results

Figure 1 shows the total number of motor vehicle/pedestrian conflicts per 400 pedestrians for 14 days prior to and 14 days following the implementation of the scanning eyes display at eight signalized intersections. When the animated eyes were added to the pedestrian signal at each intersection, the number of conflicts was markedly reduced. These results were obtained regardless of whether the crosswalk traversed two-way or one-way streets. The results of more extensive data collection at some of these sites showed that reductions in conflicts at these sites were associated with increased pedestrian observing behavior and that the effects persisted for at least a year.

Human factors research has demonstrated that pedestrians with low vision (legally blind with some vision) could identify the WALK indication 50% further away when the animated eyes display was present. This advantage for low vision pedestrians along with advantages conferred to persons with no vision by the Messaging feature present in all Relume pedestrian signals, offers a major advantage to all members of the visually impaired community.

Tests have shown a marked reduction in the percentage of motorists who did not look in the direction of approaching pedestrians at an indoor parking garage exit following the introduction of the intelligent animated eyes sign. Conflict reductions were also associated with the introduction of the sign.

The use of animated eyes to prompt pedestrians to look for turning vehicles at signalized intersections, and to prompt drivers to look for pedestrians has been developed and field tested in a variety of field conditions in three cities. In response to data from these studies that show significant reductions in motor vehicle/pedestrian conflicts, the Signals Technical Committee of the National Committee on Uniform Traffic Control Devices approved wording to be sent to AASHTO sponsors at the June 1999 meeting. Relume Corporation is preparing to market these devices for crosswalks and garage exits once they are included in the Manual for Uniform Traffic Control Devices.

ITS-74:
Data Communication with Remote Sensors Using REFLEX Narrowband PCS Technology

Principal Investigator: Sudhir Murthy (sudhir.murthy@cwix.com 781-863-0813)
Lexington Consulting Company, Lexington, MA

Started: 12/98, Completion scheduled: 9/99

$33,990 total cost with an IDEA contribution of $29,290

Concept and Product

This IDEA project integrates an off-the-shelf two-way pager system with traffic sensing devices to allow traffic operations center (TOC) personnel to conveniently access traffic sensors at remote sites. It provides a reliable, cost-effective, method of communicating with various types of remote traffic monitoring devices. Data from a device can be accessed by a TOC workstation using the newly released Motorola CreataLink2 pager modem. This is the same technology commonly used to send and receive two-way alpha-numeric pages and is available in almost any urbanized area.

The system can best be described in terms of data flow. A micro-controller ((C), connected to a traffic monitoring device, periodically requests a download of the collected data under software control. Once the (C obtains this data it uploads it into the pager modem's memory. The (C then waits until the next time period to request the next data sample from the traffic monitoring device.

The pager modem packages the data from the (C using the ReFLEX protocol and transmits it into the paging network. The transmission is received by a local base station and moved through land-based or satellite communication links to the pager service provider's Network Operations Center (NOC), where it is stored on a server in a pre-assigned "mailbox." The mailbox can be accessed from the TOC using a standard personal computer workstation equipped with the right software and a dial-up modem. Data is retained in the mailbox for a set length of time before being deleted or replaced.

There are several major advantages to this system:

- Typical ITS traffic measurements, such as volume, occupancy, and speed involve only a small number of bytes of data. The paging-based communication system is best suited for transmission of small quantities of data.

- The connection to the remote traffic sensor is wireless. Consequently it is considerably cheaper to install than a wired telephone line.

- Since the system is wireless it can easily be moved to another location. This could be useful in the temporary traffic management installations used for construction projects and event management.

- There is no need for a TOC workstation to constantly poll the various field devices.
- The proposed system is intrinsically conducive for data-sharing among various agencies since the mailbox is accessible to several users.

Project Results

The project is still in its testing phase. The proposed communication method will be tested at three locations, as shown in Table 1 below.

The project is being conducted in close coordination with the Massachusetts Highway Department. As shown in Table 1, two of the three locations chosen for testing are owned by Mass Highway. They have expressed interest in this project, as it will provide them with an alternative cost-effective communication method.

Table 1 Traffic Monitoring Device Locations for Testing

Location (Type of Facility)	Type of Monitoring Device and Coverage
I-93/Route 3 northbound Junction, Braintree - (4-lane one-way suburban freeway)	170E Controller with Overhead Radar covering two lanes on I-93 NB and two lanes on Route 3 NB.
Route 2, Concord – (4-lane two-way suburban highway)	TrafiCOMP III Model 241 with Loop Detectors on all four lanes in both directions.
Route 2 southbound, Arlington – (3-lane one-way urban expressway)	Remote Traffic Monitoring System (RTMS) mounted on a sign bridge to cover the three Route 2 SB lanes.

ITS-75: Application of a Heavy Vehicle Brake Condition Monitoring System

Principal Investigators: Per Reinhall and Robert Scheibe (scheibe@u.washington.edu 425-556-5555)
University of Washington, Seattle

Other participants: GT Engineering, Redmond, WA

Started: 5/99, Completion scheduled: 5/01

$28,5543 total cost with an IDEA contribution of $122,684

Concept and Product

This project is a continuation of work that was started under IDEA project ITS-13, which developed an on-board, brake condition monitoring system (BCMS) for air-brake-equipped commercial vehicles. The BCMS is an inexpensive electronic module that mounts in the cab or tractor of a truck or bus and constantly monitors a small number of parameters related to vehicle braking performance. It provides real-time information about brake condition to drivers, maintenance personnel, and authorities without the necessity for wheel-to-wheel inspections. Because it tracks trends in actual braking performance, it permits the prediction of potential brake malfunction well in advance of any threat to safety. The BCMS, in its simplest form, requires the addition of only a few inexpensive sensors that are not already carried on modern vehicles. It is well suited to complementing other on-board safety systems and diagnostics, including anti-lock brake systems (ABS) and electronic braking systems (EBS). In addition to the safety benefits, the BCMS will enhance commercial vehicle productivity by reducing unnecessary delays at inspection points.

Recent statistics show that a disturbing proportion of commercial vehicles are operating with brakes that are out of adjustment or otherwise improperly maintained. Air brake systems on multi-axle vehicles are particularly sensitive to brake adjustment and provide poor feedback of deteriorating performance to drivers. Currently, the only active warning is for low air pressure; drivers receive no information about the effectiveness of the total system.

The BCMS concept (Figure 1) considers the vehicle as a system (rather than considering wheel-to-wheel measurements), and tracks trends in braking performance rather than attempting to judge performance at a single point in time. It compares actual vehicle deceleration with deceleration that would be expected for that vehicle under ideal conditions. It also considers the effect of brake pressure response time (particularly release decay time, which is independent of vehicle deceleration and weight) to enhance diagnostic capability.

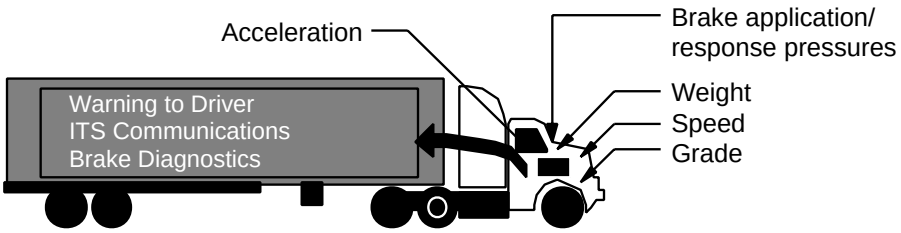


Figure 1

Brake condition monitoring system concept

Project Results

During the earlier IDEA work, two full-scale vehicle test programs were performed on a typical five-axle tractor-trailer. The first session established basic relationships between brake application pressure, brake adjustment, deceleration, vehicle speed, brake temperature, vehicle weight, and pushrod force. The second session provided confirmation of algorithmic formulation and testing of the BCMS under actual operating conditions. Comparisons of actual and modeled (ideal) deceleration from this testing clearly show degradation in brake effectiveness when adjustment is at or beyond the limit when brakes are hot (Figure 2).

The evaluation of trends in deceleration performance, in conjunction with brake pressure decay time, provide for reliable, early detection of brake deterioration. A U.S. patent has been granted and commercial partnerships with brake and vehicle manufacturers are being pursued.

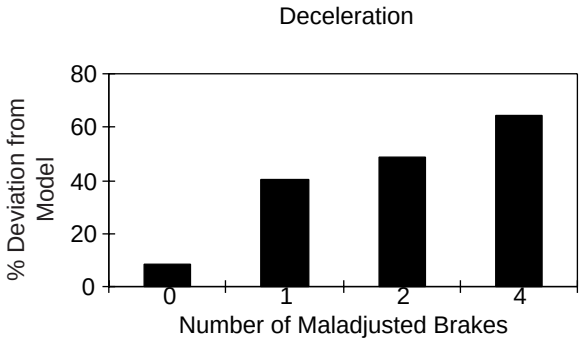


Figure 2

Average deviation from ideal deceleration model for vehicle with hot, maladjusted brakes

ITS-77: Inexpensive Inertial Navigation System (INS) with GPS-Based Attitude Determination

Principal Investigator: Randy Galijan (galijan@sri.com 650-859-3217)
SRI International, Menlo Park, CA:

Other participants: University of California at Berkeley (ITS-78)

Started: 7/99, Completion scheduled: 1/00

$75,000 total cost with an IDEA contribution of $45,000

Concept and Product

The intended product of this project is an accurate and inexpensive sensor suite capable of providing three-dimensional location, velocity, and attitude data for vehicle safety, control, and comfort applications. It consists of a three-antenna GPS system, which in addition to centimeter-level location can also measure both translation and rotation, and an array of accelerometers, which is used to sense both translation and rotation. The sensor suite does not use gyroscopes because accurate gyroscopes are expensive, and their costs have decreased only slightly over the last few decades. This is a joint project in cooperation with California PATH/UC Berkeley, who will be doing most of the accelerometer work. SRI will be responsible for the GPS attitude measurement system.

The traditional approach to designing integrated navigation systems is based on the combination of (1) determining absolute navigation parameters (coordinates and velocity), which are obtained from the GPS, and (2) determining relative navigation parameters (relative changes in coordinates and velocity), which are obtained from the accelerometer array. Our INS approach provides the required update rate of the navigation parameters between the GPS fixes and also during loss of a GPS signal. However, the INS errors in determination of linear and angular parameters of motion grow with time. GPS data is used to correct these errors. Traditionally, for precise determination of angular parameters, accurate (and expensive) gyroscopes are used. It is more economical to replace gyroscopes with an array of relatively inexpensive semiconductor accelerometers. In this approach, determination of the linear and angular parameters of motion is based on the weighted averaging of data from the accelerometers. However, substituting data from an array of (cheap) accelerometers in place of (expensive) gyroscopes leads to an increase in attitude errors. This, in turn, causes a rapid increase in errors of linear parameters of motion (coordinates and velocity) between GPS fixes. Therefore, in a gyro-free system, abrupt degradation of navigation system accuracy can be observed.

Our use of GPS attitude determination, via multiple GPS antennas, and an array of accelerometers, will allow accurate determination of vehicle location and three-dimensional attitude. Although the use of three GPS antennas adds to system cost, GPS receiver prices have been falling rapidly while gyro prices have fallen slowly. Thus, the critical point in designing gyro-free navigation systems is incorporation of an algorithm for the initial attitude determination and the correction of attitude errors on the basis of GPS data. The idea of a “virtual gyro,” consisting of distributed accelerometers combined with a multiple-antenna, GPS-based, attitude-determination system, is an economically attractive solution.

Project Results

This project is in its beginning phases. Output from a number of SRI's earlier experiments on GPS attitude determination have been supplied to UC Berkeley. Our plan is to use a Kalman filter to combine the GPS and the accelerometer array data. Testing will then begin on a rotating platform located with a reasonably good view of the sky.

Radar based adaptive cruise control (ACC) systems are just now being introduced on some luxury cars. These systems have a problem determining which lanes the radar targets are in, especially when the road curves. The sensor system under development during this project will be able to solve this problem by knowing attitude and lane position of the ACC equipped car. The system can also be used for lane departure warning. It should be noted that both of these applications require an accurate database of lane coordinates, a development effort not addressed in this project.

PATH/UCB and SRI are both currently negotiating with a major automaker on development of an advanced driver-assistance system, and other automakers and OEM suppliers have also expressed interest. The results of this project will provide the basis for further development of a product that has the potential to be an integral part of advanced driver-assistance systems. PATH/UCB and SRI will continue development of the resulting product, for both the AVCS research community and the worldwide auto market, and we will make research results available to the AVCS community. This is designed as a six-month project so that we can proceed rapidly with more development and commercialization.

ITS-78:
Simulation Model for Evaluating Traffic Management Strategies on Intermodal Passenger Terminal Access Roadway Systems

Principal Investigator: Prianka Seneviratne (Prianka@cc.usu.edu 435-797-3980)
Utah State University, Logan

Started: 6/99, Completion scheduled: 6/00

$120,230 total cost with an IDEA contribution of $89,996

Concept and Product

The product of this project will be a computerized tool to visually and analytically evaluate the performance characteristics of roadway systems that access intermodal passenger terminals. This will enable the impact of alternative traffic management strategies, such as on-street parking restrictions, roadway capacity changes, and traveler information systems, on traffic delays and emissions to be more accurately evaluated as part of the design process.

Advanced computer graphics and object-oriented programming techniques are being used to model the roadway system and animate vehicular movement (acceleration/deceleration, lane-changing, and parking) under different levels of demand and traffic management strategies. When used together with real time traffic data, the model can be used as a tool for testing alternatives before implementation. Traffic data is being collected at the Salt Lake City Airport for use as traffic flow input to the simulation.

This project requires the investigation of two separate aspects of traffic simulation. One is the understanding and development of vehicle dynamics rules in general and, in particular, vehicle parking dynamics. While several car-following and lane-changing models have been proposed and tested in the past, vehicle parking dynamics, which can accurately describe vehicle movement in pick-up/drop-off areas near terminal areas have not been fully explored. The investigators plan to develop parking dynamics models that can also be adapted to traditional network simulations to represent on-street parking on arterials.

The other aspect of traffic simulation that will be explored is a methodology to rapidly and easily build the access road network (with nodes, processors, and sinks) and represent it graphically, which provides a real-life sense of the physical environment at the site to the user. The network builder, which will allow a user to define characteristics and locations of each node, link, processor, and sink on a CAD or picture background of the site, will be designed in consultation with computer graphics experts at Utah State University. Figure 1 is a screen capture of the current simulator display.

Project Results

Since the project began in June 1999, a complete review of literature on vehicle dynamics and simulation tools has been performed. The review included an investigation of programming languages and graphics environments used to date. It was found that there are no universally accepted vehicle dynamics for lane changing or car following, and parking dynamics are virtually non-existent. Object oriented programming has advanced considerably, and several different programming languages have been employed with varying opinions about their pros and cons. A design document outlining the model features has been prepared based on the above findings.

The model is being developed with continuous input from Leigh Fisher Associates, a leading Airport Consulting firm from San Francisco and the Planning and Operations Division at Salt Lake City International Airport. Both entities have agreed to field test the model.

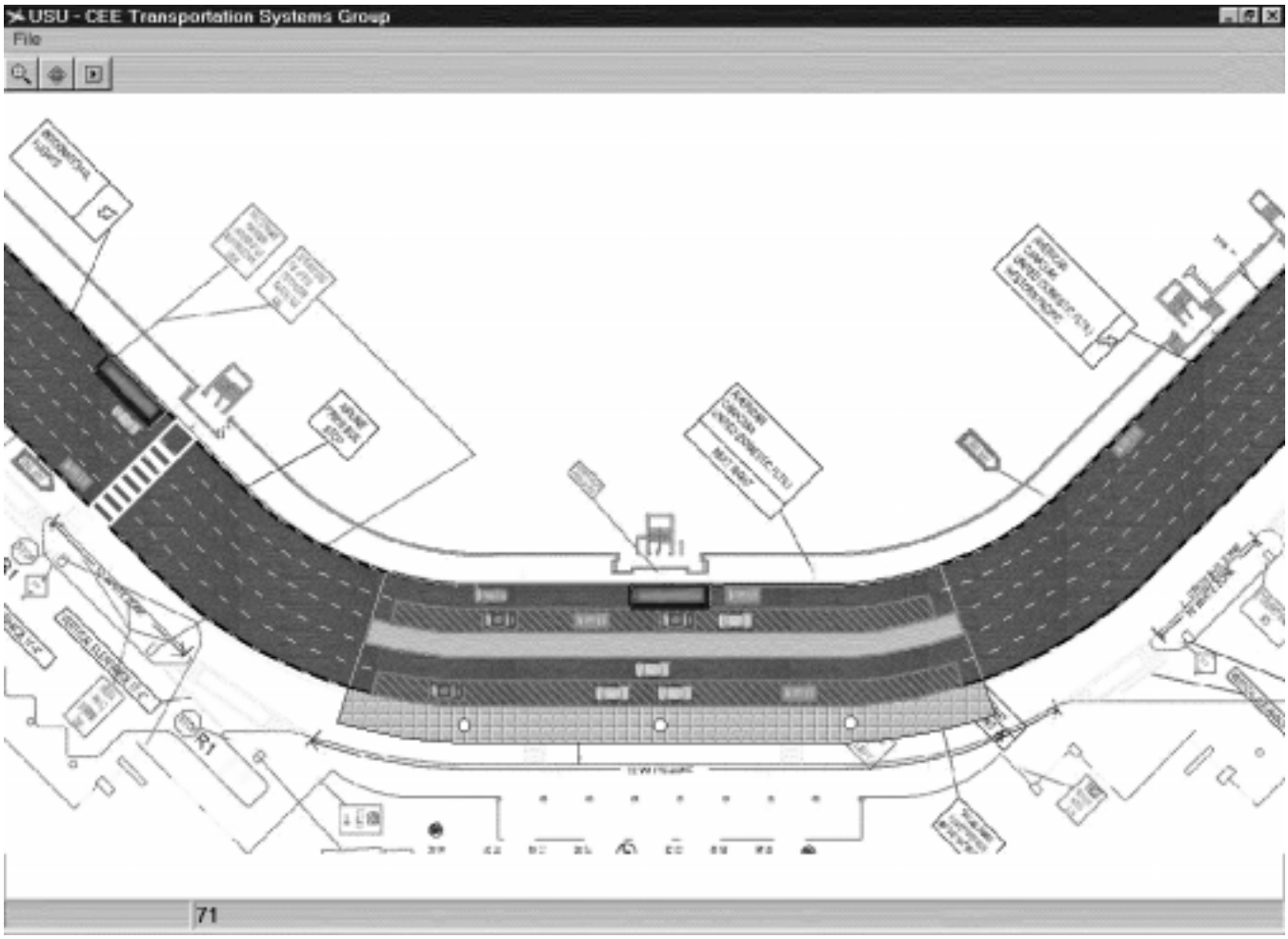


Figure 1

Simulator display of simple passenger loading zone.

ITS-79:
Roadway Flash Flood Warning Devices – Feasibility Study

Principal Investigator: Edward Boselly (boselly@weathersolutions.com 636.230.5672)
Weather Solutions Group, Chesterfield, MO

Started: 4/99, Completion scheduled: 8/99

$30,000 total cost with an IDEA contribution of $30,000

Concept and Product

The anticipated result of this project will be a warning system that detects water over-the-road at significant levels or rates of rise that would cause accidents or deaths due to vehicle intrusion into the flooded area. This will be used to alert emergency management or highway maintenance personnel as well as warn motorists through signage, signalization where possible, and automatic barricading of roads where practical or necessary. The ultimate goal is the reduction in highway deaths due to flash flooding.

One project goal is to develop a low-cost, robust, durable, and reliable sensor that can survive the harsh environment of stream beds when dry or wet, and when being subjected to the rigors of flash flooding and its associated debris. The sensor subsystem will be required to be operational 100% of the time, including over large periods of inactivity and will incorporate redundancy to assure this capability.

Another product of the research will be a web-based monitoring system for use by emergency and highway maintenance managers. These personnel will be alerted via cell phone or pager directly from the site(s) when critical thresholds of water levels or rates of water-level rise are exceeded. The managers can then check the web page to determine from water level sensor output and video from the site (if available) what measures need to be taken. These managers will have the capability to activate signs and automated barricades, determine that they have been deployed, and dispatch emergency crews to attend to the area. The sensor and warning subsystems will have built-in diagnostics to verify proper operation and to warn of malfunctions of components. Key weather information, such as radar data, will be available to managers through the web page.

Project Results

The research team has determined that a new, rugged sensor needs be developed for this application. Special sign development is also anticipated and a design is already underway. Automated highway barricades must be designed to successfully prevent intrusion into a flooded area. Temporary barricades installed by emergency personnel are frequently ignored and therefore ineffective. One possible design is a railroad crossing quad-gate system.

The next stage will be a full-blown demonstration of actual roadside warning, traffic signal preemption, and highway barricading devices. One or more trial sites will be installed with the potential cooperation of the Missouri Department of Transportation, St. Louis (Missouri) County, and the cities of Kansas City and Chesterfield, Missouri.

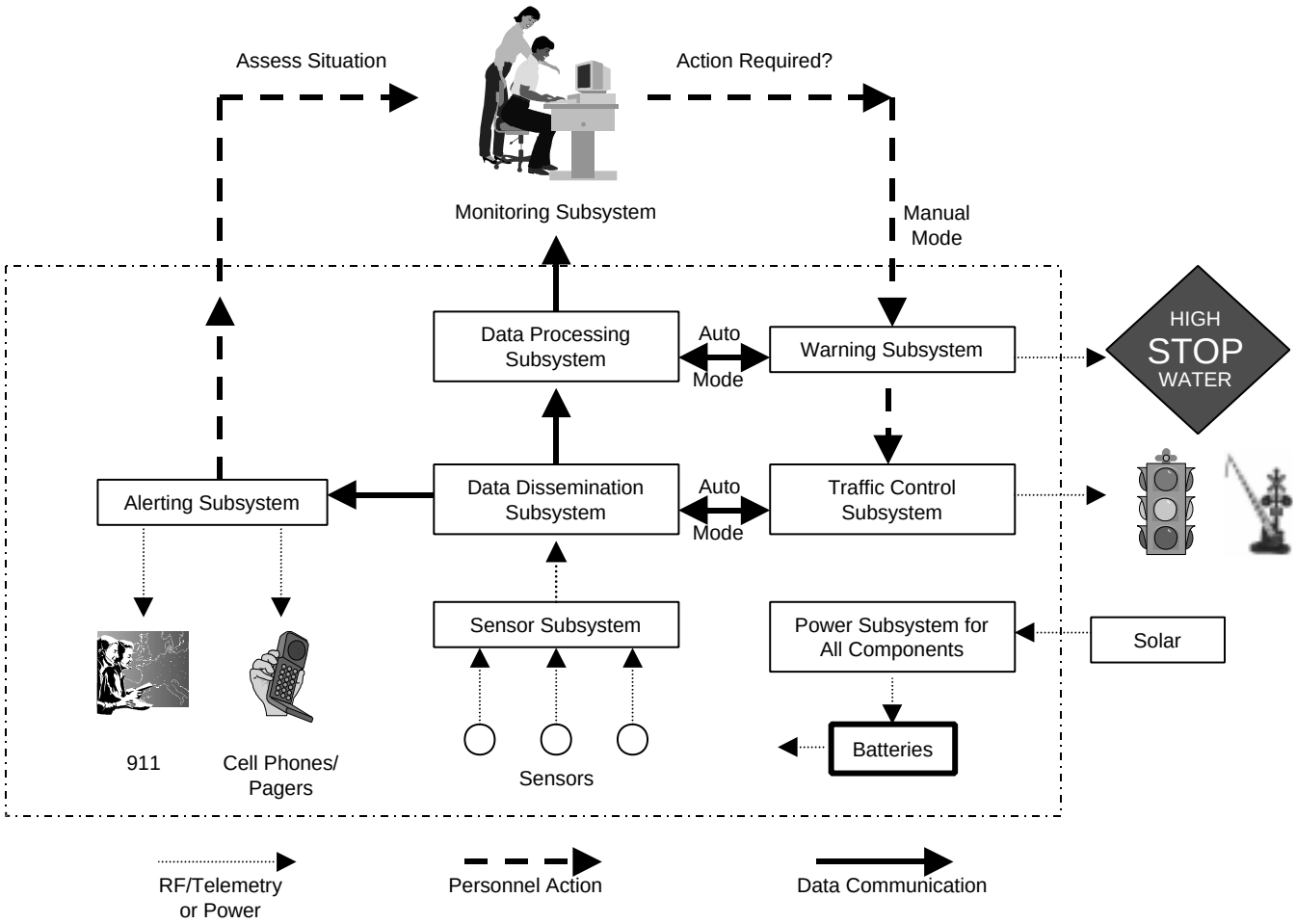


Figure 1

Roadway Flash Flood Warning System Conceptual Design

ITS-80:
Snowplow Operator Assist System

Principal Investigators: Marthand Nookala (marthand.nookala@dot.state.mn.us 651-296-1615) and
Stephen Bahler (steve.bahler@dot.state.mn.us 651-296-0152)
Minnesota Department of Transportation, St. Paul

Other Participants: University of Minnesota, 3M, Altra Technologies, Booz-Allen and Hamilton

Started: 6/99, Completion scheduled: 6/00

$1,400,000 total cost with an IDEA contribution of $149,572

Concept and Product

The Minnesota Department of Transportation (Mn/DOT) and other partners in this project have been researching and testing new technologies that will allow snowplow drivers to operate safely and efficiently in low-visibility conditions. A major barrier to deployment of these technologies after testing is an understanding of the benefits relative to the costs. This ITS-IDEA product will be an evaluation of the utility of these technologies to snowplow drivers, an understanding of the safety ramifications of applying these technologies, and an assessment of their potential to improve the efficiency of snowplow operations.

This project is developing and testing both autonomous and cooperative sensing of lane boundaries. Differential Global Positioning Systems and Magnetic Lateral Warning and Guidance Systems are being used to provide snowplow drivers with information about the position of the truck on the road surface. Mn/DOT is also proceeding with testing of radar based collision warning systems and displays that will optimally provide information from the lateral guidance and obstacle detection systems to the drivers for safe and efficient operation of the snowplow in adverse conditions.

Project Results

Mn/DOT has acquired the services of the consulting firm Booz-Allen and Hamilton to perform a detailed evaluation of snowplow driver response to use of these technologies. Baseline assessments of driving in low-visibility conditions is expected to begin in the fall and winter of 1999-2000 using two operational tests of different assistance technologies.

The first test that will be evaluated is Minnesota Highway 19. This highway is a two-lane rural highway that has been equipped with 17 miles of magnetic tape installed along the centerline of the highway. One snowplow truck has been equipped with a magnetic lateral guidance and warning system that detects the magnetic tape and advises the snowplow driver of the position of the snowplow relative to the tape. The truck is also equipped with an Altra Technologies forward and rear collision warning system (Figure 1) to alert the driver of potential obstacles on the shoulder or in the lane ahead of the plow.

Figure 1:

Rear radar collision warning system including radar detector and high intensity strobe warning lights. The strobe lights are too bright for continuous operation, but when a vehicle is detected approaching the rear of the snowplow at a potentially unsafe closure speed the strobes are automatically activated. Minnesota experiences about one fatal crash per year due to rear end collisions with snowplows in low visibility conditions.

These systems were tested to assure they perform as intended during the winter of 1998-1999. During the winter of 1999-2000, snowplow drivers will be given full access to the output from these systems. A system of cameras, sensors, and time-stamped data bases on the truck will record events that will be used to determine what effect these systems had on driver performance. For example, the lateral guidance system is at the extreme range indicating that the driver is about 3 feet over the centerline. Cameras will determine if this event was deliberate or accidental and what corrective action the driver took.

The second project will involve autonomous lateral guidance and obstacle detection integrated on a heads up display (HUD). This project will be undertaken on 10 miles of Minnesota Highway 101, which is a four-lane divided suburban expressway. The lanes and roadside fixtures have been digitally mapped. This information will be projected on the HUD. When the radar detector identifies an object not mapped, it will be inserted into the HUD as an obstacle warning.

PROJECTS UNDER NEGOTIATION IN JUNE 1999

ITS Type 1: Commercial Vehicle Operations and Fleet Management
IDEA Project 83

ITS Type 2: Intelligent Vehicle Systems
IDEA Projects 76, 84, 85

ITS Type 4: Improved Traffic Management and Analysis
IDEA Projects: 82, 86

ITS Type 7: Advanced Weather Applications
IDEA Project 85

PROJECTS UNDER NEGOTIATION IN JUNE 1999

ITS-76: Inexpensive Inertial Navigation System with GPS-Based Attitude Determination

Principal Investigator: Pravin Varaiya
(Varaiya@eecs.berkeley.edu 510-642-5270)
University of California at Berkeley
$75,000 total cost
with an IDEA contribution of $45,000

Project Description

This project will develop and test an inexpensive GPS/inertial navigation sensor (INS) that can detect the 3-dimensional attitude of a vehicle accurately enough to support advanced vehicle control systems. A distributed semi-conductor accelerometer design for the inertial system will be explored. The inertial position tracking system will be initialized and updated by a multiple-antenna, GPS-based, attitude and position determination system. Development of this "virtual gyro" system for transportation applications is intended to perform in conjunction with SRI International's work on their contract ITS-77. This contract is not, however, contingent upon the SRI contract in any way.

ITS-82: Modeling Bicycles in Traffic for Advanced Traffic Management and Control

Principal Investigator: Sarosh Khan
(skhan@khan.CUDenver.EDU 303-556-5246)
University of Colorado at Denver
$60,000 total cost
with an IDEA contribution of $50,000

Project Description

This project will investigate the feasibility of developing bicycle models for incorporation into microscopic traffic simulation software. These software improvements will allow simulation of bicycles in a general traffic stream to test new concepts in traffic management designed to better accommodate bicycles. Understanding bicyclist behavior and developing appropriate models of it will be the primary goal of this project. Additional tasks will address the feasibility of incorporating these models in the CORSIM family of traffic simulations. The ultimate goal is to facilitate evaluation of ITS technology for improving traffic flow efficiency where bicycles are part of the traffic mix, particularly at signalized intersections.

ITS-83: Deceleration Warning System for Commercial Vehicles

Principal Investigator: Joseph Bango, Jr.
(jbango@connix.com 800-836-1028)
Connecticut Analytical Corporation, Bethany, CT
$89,000 total cost
with an IDEA contribution of $69,500

Project Description

This project will develop and test an auxiliary brake light system that is activated by vehicle deceleration rather than by pressure on the brake pedal. An array of inexpensive accelerometers will be integrated into a reliable deceleration sensor. Sensitivity, dynamic range, and other response characteristics will be determined by the requirements for this application. When significant deceleration is detected, the system will activate a warning light similar to the current brake lights. The location, power source, and configuration of the lights and sensor are to be determined during the investigation. The goal is to produce a prototype for a product that is practical in terms of cost, functionality, and installation.

ITS-84: I-Witness Black Box Recorder

Principal Investigators: Gary Rayner and Sophia Rayner
(srayner@drivecam.com 619-282-8777)
I-Witness Inc., San Diego, CA
$186,226 total cost
with an IDEA contribution of $100,000

Project Description

This project will develop and test a manufacturing prototype of a "black box" recorder for consumer use in highway vehicles. The proposed product will enable drivers to record the circumstances of traffic incidents and use the data to determine what caused the accident. The small device will mount inconspicuously on the inside of a vehicle windshield and will continuously record the last 20 seconds of specific data on vehicle operation. Recording continues until it is interrupted by either a manual cue or an accident event, at which point it will continue recording for 10 seconds and save all data. The recorded data will then be easily recovered from the device, using available interface equipment, for use in investigation of the recorded incident. The minimum specific data to be recorded are (1) video image of the scene in front of the vehicle, (2) audio inside the vehicle, (3) acceleration along three perpendicular axes measured in the device. Resolution, sampling rates, frame rates, dynamic range, and other parameters of the recorded information are to be optimized during the investigation.

ITS-85: A Mobile Road Condition Sensor as Winter Maintenance Aid

Principal Investigator: Prakash Joshi
(joshi@psicorp.com 978-689-0003)
Physical Sciences Inc., Andover, MA
$296,201 total cost
with an IDEA contribution of $123,500

Project Description

This project will develop, field test, and transition to a commercial product, a sensor system for use on winter road maintenance vehicles. This system will detect and monitor thin films of ice, snow, water, and ice-water mixture on road surfaces and provide real-time road condition information to the vehicle operator and road maintenance systems. The concept exploits the unique near-infrared absorption characteristics of ice, water, and other substances to discriminate among different surface films. The sensor will measure light reflected from pavement in wavelength bands selected to maximize sensitivity for water and ice. The design will incorporate state-of-the-art, low-cost, electro-optical hardware, to result in a relatively compact, energy-efficient, and affordable sensor. Sensor data will be analyzed in real-time by fast discrimination algorithms running on a standard microprocessor. Compatibility with ITS communications protocols will be maintained. Extensive laboratory testing at Physical Sciences, and field testing by Surface Systems, Mass. Highway, and the Colorado DOT will be undertaken to ensure product functionality and reliability.

ITS-86: A 220-MHz Modem for ITS: The Final Step to Deployment

Principal Investigators: Bjorn Bjerede
(bjerede@welkinsystems.com 858-622-0185)
Welkin Systems Incorporated, San Diego, CA
and Michael Fitz
(fitz@ee.eng.ohio-state.edu 614-292-8039)
Ohio State University, Columbus
$194,573 total cost
with an IDEA contribution of $123,965

Project Description

This project will develop and test a 220-MHz wireless modem for use in traffic monitoring and control applications. The goal is to produce a prototype for a product that is practical in terms of cost, functionality, and installation. The resulting units will be based on theory, algorithms, and designs explored during ITS-IDEA contracts ITS-15 and ITS-47. Project focus will be on developing an architecture that has cost-effective performance characteristics, is compatible with traffic control devices, is friendly to use, and has realistic antenna and power requirements. Prototype implementations of the resulting wireless system design will be evaluated and tested in both laboratory and field environments.

ITS-IDEA projects by general ITS interest area

Project Number	Project Title	Page No.	Commercial Vehicles	Intelligent Vehicles	Rural Applications	Traffic Management	Traveler Information	Transit	Weather Applications
	Number of Projects		6	28	9	28	5	5	9
	Percentages		(9%)	(40%)	(13%)	(40%)	(7%)	(7%)	(13%)
Completed Projects									
ITS-1	Vehicle-to-Vehicle Communication for Collision Avoidance and Improved Traffic Flow	4		X					
ITS-2	Models for Real-Time Incident Prediction	4				X			
ITS-3	Computerized Dispatching of Car Pooling Vehicles as Part of an Improved Metropolitan Area Transportation System	5					X	X	
ITS-4	A Distributed Input/Output Subsystem for Traffic Signal Control	5				X			
ITS-5	Feasibility Study of IVHS Drifting Out of Lane Alert System	6		X					
ITS-6	Design of a Sensor to Detect and Classify Highway Vehicles Using Laser Imaging Techniques	6				X			
ITS-7	Driver-Adaptive Warning System	7		X					
ITS-8	Laser Optics Open-air Communication System	7					X		
ITS-9	Decision Theoretic Reasoning for Traffic Monitoring and Vehicle Control	8		X		X			
ITS-11	Scale-Model AHS Research Facility (SMARF)	8		X					
ITS-12	Vehicle Lane Control System	9		X					
ITS-13	Development of an Intelligent Air Brake Warning System for Commercial Vehicles	9	X						
ITS-14	Adaptive Filtering for IVHS and Advanced Vehicle Control	10		X					
ITS-15	Efficient Use of Narrowband Radio Channels for Mobile Digital Communications	10				X			

continued

ITS-IDEA projects by general ITS interest area—continued

Project Number	Project Title	Page No.	Commercial Vehicles	Intelligent Vehicles	Rural Applications	Traffic Management	Traveler Information	Transit	Weather Applications
ITS-16	Engineered Visibility Warning Signals: Tests of Time to React, Detectability, Identifiability and Salience	11		X					
ITS-17	A Sequential Hypothesis Testing-Based Decision-Making System for Freeway Incident Response	11				X			
ITS-18	Three-in-One Vehicle Operator Sensor	12		X					
ITS-19	AutoAlert:Automated Acoustic Detection of Incidents	12				X			
ITS-20	Real Time, Computer-Matched Ridesharing Using Personal Communications Services (PCS)	13					X	X	
ITS-21	Interference Resistant Signals for Collision Avoidance Radar	13		X					
ITS-23	GPS DRAIN: Demonstration of Precise Navigation for Vehicle Collision Avoidance	14		X					
ITS-24	Passive Optical Lane Position Monitor	14		X					
ITS-25	Automated Roadside Brake Inspection Concept Evaluation	15	X						
ITS-26	Fuzzy Inference Based Driver Decision Process and Traffic Flow Simulation	15				X			
ITS-27	Application of Neural Networks to Data Fusion: A Feasibility Study	16				X			
ITS-28	Development and Evaluation of Communication Requirements for Low-Cost, Network-Based Driving Simulators for IVHS Safety Research	16		X					
ITS-32	National Coverage for Emergency Mayday Systems	17			X				
ITS-34	Remote Passive Road Ice Sensor System (RPRISS)	18			X	X			X
ITS-35	Expert System-Based Diagnostic Instrument for Maintenance of ITS Traffic Sensors and Detector Systems	18				X			

ITS-IDEA projects by general ITS interest area—continued

Project Number	Project Title	Page No.	Commercial Vehicles	Intelligent Vehicles	Rural Applications	Traffic Management	Traveler Information	Transit	Weather Applications
ITS-36	Development and Application of Decision Analysis Methodology for ITS Implementation	19						X	
ITS-38	Fiber Optic Visibility Sensor System	19			X				X
ITS-40	Application of Ergonomic Guidelines on Emerging ITS Technologies for Application to APTS Practice	20						X	
ITS-41	Development and On-Road Testing of Prototype Resonant Loop Lane Control System	20		X					
ITS-42	Anti-Glare Device Using Photochromic Focal Plane	21		X					
ITS-48	Instant Rent-A-Car Technology Applied to Transit Station Car Practice	21		X				X	
ITS-49	Travel Time Prediction in Intelligent Transportation Systems	22				X	X		
ITS-52	An Advanced Diagnostic Instrument for Inductive Loop System Maintenance	22				X			
Active Projects									
ITS-33	Radar Based Convoying Using a Frequency Selective Surface Patch for Trucks, Railroads, and AHS	24	X	X					
ITS-43	Feasibility Study for a Regional Traffic Surveillance Concept	26				X			
ITS-44	ITS Integration of Real-Time Emissions Data & Traffic Management Systems	28				X			
ITS-45	Development and Trial Deployment of an ITS Avalanche Hazard Management System	30			X				X
ITS-47	Development and Testing of a Field Deployable Wireless Modem for Spectrally Efficient ITS Digital Communication	32				X			

continued

ITS-IDEA projects by general ITS interest area—continued

Project Number	Project Title	Page No.	Commercial Vehicles	Intelligent Vehicles	Rural Applications	Traffic Management	Traveler Information	Transit	Weather Applications
ITS-50	Road Surface Condition Detection and Monitoring Technology for a Vehicle-Mounted Hazard Warning System	34		X					X
ITS-51	Mitigating Litigation Barriers for Deployment of AHS and ETTM Innovations	36		X		X			
ITS-53	A Real-Time Flow Estimation Model for Advanced Urban Traffic Control	38				X			
ITS-56	Snow and Ice Removal Monitoring and Management System	40			X				X
ITS-57	Differential Braking for Limited-Authority Lateral Maneuvering to Support Active Safety Systems	42		X					
ITS-60	Visibility Monitoring System	44			X				X
ITS-61	IRIS: Intelligent Ranging with Infrared Sensors	46		X					
ITS-62	Wavelet-Based Image Compression Analysis	48				X			
ITS-63	Auto Radio Override Alert System for Emergency Vehicles	50		X		X			
ITS-65	Improved Vehicle Classification Using an Overhead Imaging Lidar System with Axle Counting Capability	52				X			
ITS-66	Use of Ultra Wideband (UWB) Technology for Designated Short Range Communications (DSRC) for Highway and High-Speed Rail	54		X					
ITS-70	Real-Time Traffic Control of Over-Saturated Conditions	56				X			
ITS-71	Real-Time Signal Control Using Queue Length Information Deployed at an Intersection	58				X			
ITS-72	Demand Responsive Service for Intermodal Freight Movement	60	X						
ITS-73	Animated LED “Eyes” Traffic Signals	62				X			

ITS-IDEA projects by general ITS interest area—continued

Project Number	Project Title	Page No.	Commercial Vehicles	Intelligent Vehicles	Rural Applications	Traffic Management	Traveler Information	Transit	Weather Applications
ITS-74	Data Communication for Remote Sensors Using ReFlex Narrowband PCS Technology	64			X	X			
ITS-75	Application of a Heavy Vehicle Brake Condition Monitoring System	66	X						
ITS-77	Inexpensive Inertial Navigation System with GPS-Based Attitude Correction	68		X					
ITS-78	Simulation Model for Evaluating Airport Curbside Traffic Management Strategies	70				X	X		
ITS-79	Roadway Flash Flood Warning Devices - Fesibility Study	72			X				X
ITS-80	Snowplow Operator Assist System	74			X				X
ITS-81	Advanced Prototype Development for the IRIS Ranging System	46		X					
New Projects									
ITS-76	Inexpensive Inertial Navigation System with GPS-Based Attitude Correction	77		X					
ITS-82	Modeling Bicycles in Traffic for Advanced Traffic Management and Control	77				X			
ITS-83	Vehicle Deceleration Warning System for Commercial Vehicles and Automobiles	77	X						
ITS-84	I-Witness Black Box Recorder	78		X					
ITS-85	A Mobile Road Condition Sensor as Winter Maintenance Aid (7169-140)	78		X					X
ITS-86	A 220mhz Modem for ITS: The Final Step to Deployment	78				X			

PROPOSAL REVIEWERS

ITS-IDEA maintains a pool of volunteers who are called upon to review proposals and recommend the most promising to the ITS-IDEA Program Committee which makes the final award determinations. Different reviewers are used for each proposal review cycle so that any inadvertent bias is not persistent. We believe this system provides fair consideration to all proposals. We do not claim that it always picks the best ones (this is a highly subjective determination). The identity of the volunteers who review any given proposal is kept confidential. We greatly appreciate the efforts of our reviewers.

Mr. Thomas Adler
Resource Systems Group, Inc.

Dr. Steve Albert
Montana State University

Dr. Selwyn Berg
Consultant

Dr. Harvey Bordett
Kaman Aerospace

Dr. Michael Bronzini
Oak Ridge National Lab

Dr. Everett Carter
University of Maryland

Ms. Dottie Drinkwater
Consultant

Dr. Azim Eskandarian
FHWA/NHTSA National Crash Analysis Center

Mr. George Frangos
Howard County Government

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