

California ATMS Testbed
PHASE III: Operational Research Implementation
Final Report

Volume 1
Executive Summary

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ORGANIZATION OF THE EXECUTIVE SUMMARY

This report summarizes research and development that has been conducted to position the Testbed to support prototype deployment and evaluation of Advanced Transportation Management Systems (ATMS) products and services. The various elements contained in the report generally involve both research and development; funding for the research aspects reported herein was provided by the Caltrans Division of Research and Innovation (DRI) under the Partners for Advanced Transit & Highways (PATH) research program with Testbed support funding for those aspects of the research that involve development and management of the ATMS Testbed infrastructure in support of the Department's research agenda. This joint effort targeted research activities that, with Testbed support, might lead to candidate products for deployment. In that sense, the research funded under this agreement has been in support of the Advanced Transportation Management and Information System (ATMIS) research program of DRI, PATH, California Center for Innovative Transportation (CCIT), and other such organizations.

The work accomplished under this agreement is divided among three basic categories:

1. Testbed Resources/Technical Assistance/ Management
2. Testbed Deployment
3. Testbed Research and Development

They are summarized in the following sections; the Testbed Research and Development Activities are discussed in detail in the Final Technical Report Volume II, which includes a set of accompanying Testbed Technical Reports.

PART 1

TESTBED RESOURCES/MANAGEMENT/ TECHNICAL ASSISTANCE

Testbed Infrastructure and Data Streams

The ATMS Testbed Program was initiated in early 1991 to provide an instrumented, multi-jurisdictional, multi-agency transportation operations environment linked to university laboratories for real-world development, testing and evaluation of near-term technologies and applications, and to serve as an ongoing testing ground for California and national Intelligent Transportation Systems (ITS) efforts. Located in Orange County, California, and under the direction of the University of California, Irvine (UCI) Institute of Transportation Studies, the Testbed is intended to:

- accelerate deployment through advanced technology research;
- demonstrate the readiness of advanced systems;
- implement and evaluate operations of an integrated multi-jurisdictional, multi-agency transportation operations system.

The Testbed is based on real-time, computer-assisted traffic management and communication. The transportation operations system that forms the backbone of the Testbed is structured to provide intelligent computer-assisted decision support to traffic management personnel by integrating network-wide traffic information (both surface street and freeway) in a real-time environment. The Testbed currently either has, or is developing, direct links to three traffic operations centers (TMC), Caltrans District 12 TMC, City of Anaheim TMC, and City of Irvine Transportation Research and Analysis Center that provide real-time data links from area freeways and major arterials directly to dedicated Testbed research laboratories located at UCI.

The broad mission of the Testbed Program is to work toward overcoming institutional, technical and philosophical barriers to introducing innovative technologies into the management of complex transportation systems. Working together with CCIT, California PATH and the Testbed Partners, the Testbed Research Implementation and Prototype Development Program is designed to establish an intermediary link between basic research in ATMS/ATIS technologies and their full deployment.

The Testbed covers the entire freeway system in Orange County and two contiguous sub-areas comprising an arterial system that includes most of the major decision points for freeway travelers in the region. The City of Anaheim sub-area encompasses the City's major special event traffic generators and is centered about two of its designated "smart streets," Harbor Boulevard and Katella Avenue. This sub-area is ideal for network-wide applications of advanced technologies in traffic management. The City of Irvine sub-area provides freeway access to many business and office complexes on both sides of the 1-5 freeway and is ideal for corridor-level integration of real-time communication and control in traffic management.

A comprehensive testing and evaluation system has been established to support activities in the Testbed. The system has been developed to interface with existing traffic surveillance and control components and provide a common integrated real-time traffic database for ATMS research conducted within the Testbed. The system design is built upon a wide-area communications network backbone linking the Cities of Anaheim and Irvine Transportation Management Centers (TMCs) to the California Department of Transportation's District 12 TMC and with the ATMS Research Laboratories at the UCI Institute of Transportation Studies. The communications network is configured to permit easy future expansion to accommodate appropriate private/public sector research implementation projects that may be conducted within the Testbed.

The Testbed has the following main components:

1. Testbed Labs
2. Data Streams
 - a. Historical
 - b. Real-time
3. Surveillance
 - a. Freeway
 - b. Arterial
4. Wireless Data Capabilities and Real-time Vehicle Tracking
5. Travel Behavior Monitoring
6. Microscopic Simulation
7. Mobile Surveillance
8. Mobile Transportation Management Capability
9. Testbed Resource Web Access

The Testbed laboratories form a computerized research environment connected to the real world transportation system. The laboratories are a testing ground for the development of particular ATMIS *modules* and of integrated ATMIS *applications*. The goal is for the Testbed laboratories to have a complete simulation of the transportation systems that are part of the Testbed. The Paramics (parallel micorsimulation) traffic model is the core simulation for the Testbed laboratories. It can simulate all of the existing and currently envisioned traffic measurement and control devices associated with ATMS.

The Testbed Real-time Integrated Control and Evaluation Prototype System (TRICEPS) was developed as an implementation platform to provide plug and play capabilities for the testing and evaluation of a range of ATMIS modules. TRICEPS permits modules to be configured for various ATMIS applications and run in simulated, real-time, and integrated modes. Any particular ATMIS application thus can be implemented by being connected to both simulated and real-world transportation systems so that overall effectiveness can be first assessed in the laboratory and then evaluated in the field.

Access to Testbed research, testing and evaluation resources is provided via an integrated website. The web page features a real-time graphical user interface whereby researchers and Caltrans staff can download information (both historical and real-time) from Testbed data collection services (e.g., real-time freeway and arterial loop data and signal status, probe vehicle information, video surveillance, detector testbed data, etc.), as well as coded networks, various API's and other software tools developed under the Testbed using a browser for query. The web page is available on the Testbed network as well as via the Caltrans Wide Area Network.

Technical Assistance to Caltrans, CCIT, and Partners

The purpose of this element is twofold: 1) to provide a continuing capability for Caltrans to analyze and measure the expected net benefits of ATMS projects proposed by Caltrans, typically by applying a microscopic simulation approach to evaluation of traffic improvement projects, and 2) to provide technical assistance to Caltrans, CCIT, and Testbed Partners in their use of Testbed resources.

Work conducted under this element focused on providing an "on demand" environment for Caltrans' strategic planning exercises involving both ATMIS as well as capital improvement projects, using the analysis capabilities of Paramics, the physical testbed and the rest of the Testbed Workbench applications.

In addition, human resource capability was maintained to service “on demand” requests for such analyses and evaluations.

The UCI Testbed Team provided assistance in four broad categories:

1. On-Call Direct Support of Paramics
2. Technical Guidance on Micorsimulation
3. Micorsimulation Research-related Support
4. Technical Support of Use of Testbed Resources

The UCI Testbed team provided technical support for Application Program Interface (API) developed by Testbed personnel on an on-call basis. Due to PARAMICS new builds and updated versions, the released APIs needed occasional maintenance to ensure full PARAMICS compatibility.

As different scenarios that could not be handled by current API versions were identified by Caltrans, an assessment was made by the project team to define necessary API modifications and these enhancements then programmed. For any modified or new APIs developed as part of this task, both source code and technical documentation were provided to Caltrans.

Microscopic simulation models have the capability to evaluate transportation facility plans and design alternatives as well as traffic operation strategies. However, lack of appropriate guidance and/or direction may lead to inappropriate use of and inaccurate results from these models. It is anticipated that, as Caltrans' districts use micorsimulation models with increasing frequency, a standardized guidance and evaluation process would facilitate model application and analysis, as well as the comparative interpretation of model results. The UCI Testbed team provided Caltrans with guidance and evaluation for simulation studies relative to traffic modeling and micorsimulation.

Upon request, the UCI Testbed team evaluated Caltrans on-going simulation studies, and provided input to guidelines for application of micorsimulation models. It is anticipated that experience gained with the current micorsimulation applications in California will contribute significantly to the development of guidelines.

As expected, there is increasing demand to utilize Testbed resources in support of deployments within the Testbed. The Testbed team maintained a capability to technically support such deployments.

ATMS Testbed Laboratory Development and Maintenance

The UCI Institute of Transportation Studies is responsible for the overall development and management of the ATMS Testbed Laboratories. Acting on behalf of the Caltrans Division of Research and Innovation, it continued to:

- develop necessary software enhancements to bring prototype Testbed model simulation systems to full operational capability.
- develop protocols for “plug and play” operation.
- develop API’s for research and prototype deployments conducted within the Testbed.
- develop and coordinate an equipment and software upgrade and replacement program to keep Testbed capabilities within current industry standards.

- incorporate and integrate appropriate simulation/modeling advancements emanating from associated Caltrans research programs and other national/international efforts within the Testbed modeling environment.
- maintain and manage the Testbed Communications Network, including security provisions.

Testbed Management

The UCI Institute of Transportation Studies is responsible for the overall management of Testbed operations. Acting on behalf of the Caltrans Division of Research and Innovation, it continued to:

- develop and maintain the Testbed facilities in a manner that facilitates the overall goals of Caltrans DRI, CCIT, and the Testbed Program.
- establish and coordinate the activities of the various management committees charged with overseeing Testbed operations.
- act as liaison between CCIT, PATH researchers, private and public sector users and the Testbed operating agencies that comprise the Testbed partnership.
- identify and coordinate enhancements to the Testbed that serve its basic functions.
- coordinate and assist in the procurement of hardware/software necessary for the conduct of deployments within the Testbed.
- develop and execute a strategic plan for realizing the maximum potential from Testbed activities.
- represent the interests of the Testbed at national and international forums.
- manage the Testbed Communications network.
- supervise and coordinate the activities of Testbed researchers assigned to the Testbed Program.
- act as Caltrans agent in all such other Testbed activities not specifically delegated.

PART 2

TESTBED DEPLOYMENTS

Traffic Detector and Surveillance Sub-Testbed (TDS²)

Summary

- What is it?
 - A real-world laboratory for the development and evaluation of emerging traffic detection technologies relative to: appropriateness for ITS operations and performance measurement, data quality and consistency, ease of use, ease of installation, and overall cost.
- What does it consist of?
 - The latest-generation IST detector cards installed along both the freeway mainline as well as on the associated on- and off-ramps; these installations provide data for signature analysis associated with the Caltrans REID vehicle reidentification development.
- How has it been used?
 - This facility has already proved extremely useful in the testing and evaluation of overhead-mounted detectors (laser), side-mounted detectors (OMRON Vision Sensor Detector, Wavetronics and RTMS radar sensor detector, Pan-Tilt-Zoom Webcam, Spread Spectrum Radio), and in-pavement detectors (enhanced double loop, High-resolution Detector Blade).
- How can it be used?
 - Test and evaluate new sensors for traffic management; obtain section-related speeds; vehicle classification; estimate O-D patterns

Description

To fully exploit the benefits of the new generation of Intelligent Transportation Systems now under development, including applications for homeland security, more accurate and appropriate real-time traffic data need to be collected from the urban highway transportation network and communicated to traffic management centers, traffic operations personnel, travelers, and other agencies.

To assist in identifying and evaluating detector technologies for ITS deployment, the Testbed initiated development and construction of a Traffic Detector and Surveillance Sub-Testbed (TDS²) within the Testbed. The overall purpose of the Traffic Detector/Surveillance Sub-Testbed is to provide a real-world laboratory for the development and evaluation of emerging traffic detection technologies relative to: appropriateness for ITS operations and performance measurement, data quality and consistency, ease of use, ease of installation, and overall cost.

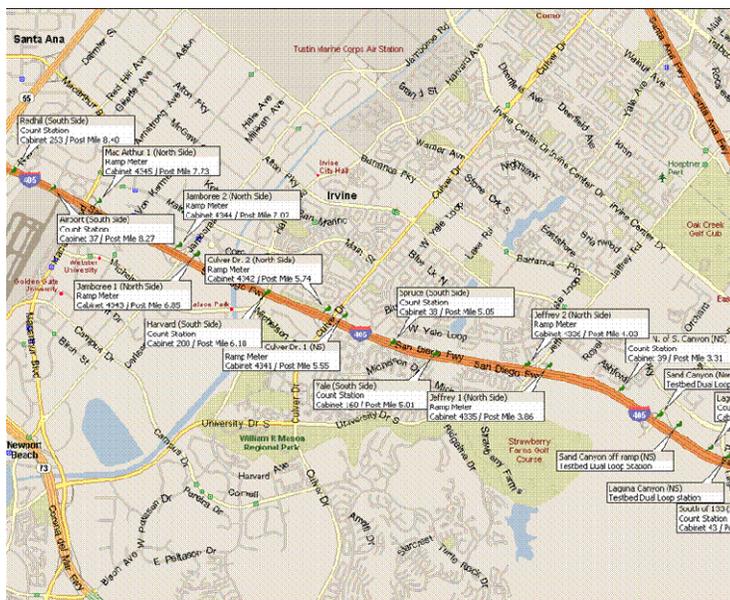
The first phase of the development of TDS² focused on the installation of “ground truth” sensing equipment and attendant communications infrastructure at two contiguous sites along the I-405 freeway within the Testbed —at I-405 and Laguna Canyon Road, and at I-405 and Sand Canyon Avenue. At these sites,



Ground Truth Camera Installation

“ground truth” video cameras were installed over each lane of traffic, connected to a bank of VCRs and to an automated video image capture and re-identification system. Data from these systems are transferred to the UCI Testbed Laboratories via a combination of wireless technology (SSR) and fiber optic (F/O) cable. This facility has already proved extremely useful in the testing and evaluation of overhead-mounted detectors (laser), side-mounted detectors (OMRON Vision Sensor Detector, Wavetronics and RTMS radar sensor detector, Pan-Tilt-Zoom Webcam, Spread Spectrum Radio), and in-pavement detectors (enhanced double loop, High-resolution Detector Blade).

Work under this component continued the development of a real-world corridor-level testbed facility that would permit field testing and evaluation of advanced traffic sensor, detection and surveillance technologies to enhance the ability of Caltrans to deploy such technologies as well as advanced systems for improved traffic management and control of California's freeways and signalized arterials. Specifically, 18 detector cards were purchased to populate the TDS² cabinets. IST Inc., a Testbed private sector partner, developed and implemented web-based software to collect, store and make available the traffic data collected on NB Rte. 405 to researchers over the internet (a mysql database server was created to collect all incoming vehicle event records). A total of 120 additional signature cards were secured for the 18 new sites along NB Rte. 405 from the El Toro Y to Jamboree. IST also provided enhancements to the GUI web interface.

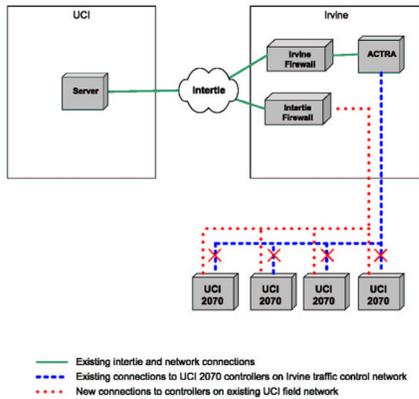


Freeway IST Detector Installation

In its current configuration, TDS² comprises a fully instrumented facility for the testing and evaluation of advanced detectors—one that has been utilized extensively (with considerable success) by Caltrans staff to evaluate several alternative detection technologies. With the completion of the current phase of construction, an 8 km corridor comprising both a freeway (I-405 NB) and adjacent arterial (Alton Parkway, both directions, including 18 intersections) has been fully instrumented to provide real-time data streams detailing traffic movement through the corridor; in addition to providing raw loop data for all detectors on all approaches, the arterial subsystem is instrumented to furnish real-time status information of the signal displays at each of 18 intersections. The freeway

locations have the latest-generation IST detector cards installed along both the freeway mainline as well as on the associated on- and off-ramps; these installations provide data for signature analysis associated with the Caltrans REID vehicle reidentification development. For the arterial sites, 2070 controllers and associated detection software (ACTRA) have been deployed at the 18 intersections and are planned to be outfitted with IST detector cards and blade sensors. Software elements of the project included modification and enhancement of existing field to central server communications and real-time data base and web-site access, deployment and evaluation of advanced vehicle reidentification methods for anonymous real-time tracking of individual vehicles, real-time travel time and performance measurement, real-time management and control, and potentially homeland security applications.

times a second and set the state of the hardware outputs to whatever the traffic program in the 2070 wants them to be. The field I/O module reads the state of the hardware inputs ten times a second and reports these back to the main 2070 CPU over a synchronous serial link. None of the inputs or outputs has meaning to the 2070 hardware, only to a traffic program running in the 2070.



The IAS replaces the SE-PAC traffic software with a program (not a traffic control program) that simply looks at the serial data stream coming back from the 2070-8 NEMA base every tenth of a second, picks out the input status bits (either on or off) and reports these back to a host program via a UDP packet. This approach is very elegant because the host can see the state of all of the inputs into the 2070-8 NEMA base for every 10th second of time. The host may then archive or process the data as desired. The software supports the following:

Communications Architecture

- Allow communications via Ethernet using the UDP protocol on port 20000.
- Allow the user to remotely query the date and time of the unit.
- Allow the user to remotely set the date and time of the unit
- Allow the user to specify a rate at which the state of the filtered input bits on the - 8 NEMA base are transmitted to the user.
- Periodically send the user the state of the filtered input bits on the -8 NEMA base at the specified rate.

V2SAT Detector Verification and Database System

Summary

- What is it?
 - A video image processing system that detects and classifies passing vehicles.
- What does it consist of?
 - 14 video detection cameras above the same number of traffic lanes, attached to the bridge railing with unique mounting brackets, together with specialized software employing fuzzy inference methods.
- How has it been used?
 - Provided ground truthing of vehicle reidentification research based on IST magnetic induction signature analysis.
- How can it be used?
 - Enhanced surveillance system that provides accurate speed estimation, vehicle classification, and O-D information

Description

This project involved the design and deployment of specialized equipment and technical services to support the testing of various types of traffic detectors in the Caltrans Irvine Detector Testbed. The primary hardware/software deliverable was the V2SAT (Video Vehicle Signature Analysis and Tracking) system, a distributed video data acquisition system configured to serve as a ground-truth system for the Testbed. The V2SAT system includes vehicle re-identification capabilities for tracking of vehicles among the three primary test sites located on the NB Route 405 freeway at Laguna Canyon overcrossing, Sand Canyon overcrossing, and Sand Canyon off ramp. In addition, we were responsible for the design and installation of all video cameras and video-related components, the performance of most of the field tests, and the design, operation and maintenance of the central Testbed server which functions as the central repository for all detection test data and verification images. Hardware/software deliverables included:



V2SAT Camera Installation

- 14 V2SAT site detection computers installed at three field locations
- One central server located at UCI/ITS
- Software for video detector ground-truth verification, verification and archiving on central server, and vehicle reidentification
- Deployment of 14 video detection cameras above the same number of traffic lanes, attached to the bridge railing with unique mounting brackets
- Equipment for precise time-synchronization of video-tape records acquired at all sites
- 3kW UPS at all field sites

- System Operators Manual and Technical Supplement



V2SAT Images

The V2SAT computer vision systems acquire an image of every vehicle passing below each down-looking video camera. These images and the related detection data are maintained in a distributed database accessible from the central server located at ITS. During daylight hours, reliability of detection has been found to be over 99%, with fewer than 0.2% false detections. Most errors are due to ambiguous lane positions of vehicles during lane changes or merging.

Detector data verification and reduction is done on the server, which receives data from all field units and can be remotely accessed by authorized UCI and Caltrans personnel, as well as vendors participating in studies.

In addition, the vehicle re-identification feature of the system matches vehicles detected at the Laguna Canyon Site with vehicles detected at the Sand Canyon Site. The computer vision systems analyze acquired video images and generate relatively small numeric vectors, which characterize each vehicle. Vectors acquired at each site are transferred over the Testbed wireless network to the V2SAT server located at UCI/ITS. This function does not work at night since it requires ambient illumination.

Vectors are compared using fuzzy inference methods, to match vehicles, which were detected at both sites, and reject vehicles detected at only one site. Computer verification tools such as the one shown at the right are provided to confirm the accuracy of the reidentification, while also providing a means for monitoring and cataloging all traffic during test periods at all Testbed locations. Vehicle images shown in the user interface screenshot can be set to update in near real-time, or may be selected from archives of previously acquired data.



V2SAT Server

Testbed ATMS Training and Development System

Summary

- What is it?
 - A high-end simulator for use in Caltrans operator training efforts as well as in the development of a true testing environment for ATMS upgrades and enhancements within an environment with the full functionality of a Caltrans TMC.
- What does it consist of?
 - An ITS Test Center and TMC Simulator that provides connectivity to the Testbed's real-time data streams (field and simulated). Provides both "live" and "virtual" connections to Caltrans field traffic control systems including vehicle detector stations, dynamic message signs, and camera stations. An adjoining "classroom" has data and video input/output capability to ATMS Simulator software (ATMSSIM). The classroom has capacity for fifteen Caltrans trainees.
- How has it been used?
 - Provides Caltrans TMC operator training.
- How can it be used?
 - Test and evaluate upgrades/enhancements to TMC operations in a secure environment that exactly duplicates actual TMC software systems and data feeds.

Description

The Testbed ATMS Training and Development System brings operational capability to the TMC Simulation Laboratory, providing networking that links the simulator to the Testbed Laboratories. This provides a foundation for the evolution of an ATMS development environment that can be used to support isolated, independent testing and evaluating of ATMS products prior to their deployment in a district operating environment, as well as to provide operator training using the latest version of the ATMS software in a simulated environment.

The system features a stable network in support of the ITS Test Center and TMC Simulator that provides connectivity to the Testbed's real-time data streams (field and simulated). The network has been designed to isolate network traffic depending on the nature of services needed or open communication among different subnets. A simulation environment is in place that features:

1. a "live" connection to Caltrans field traffic control systems including vehicle detector stations, dynamic message signs, and camera stations;
2. a "virtual" (through simulation) connection to Caltrans field traffic control systems including vehicle detector stations, dynamic message signs, and camera stations;
3. an ATMSV2 Graphical User Interface (GUI) with geographic map depicting freeways and field element icons for displaying traffic status by levels of speeds, volumes, or occupancies at vehicle detector stations, and simulated status for dynamic message signs, and camera stations;
4. Connection of ATMSV2 software to Paramics for simulation of real-time operation.

In a joint effort among the Testbed, Cal Poly, and Caltrans Division of Traffic Operations, a realistic training environment has been provided for Caltrans TMC operators based on a simulation version of ATMSV2 that has been developed by NET specifically for use by the Testbed in support of Caltrans'

TMC operator training program. The ATMSV2 Simulation (ATMSSIM) is based on the port of District 7's ATMSV2 with 7.2 functionality to District 11 using upgraded COTS software.

With this system, the Caltrans TMC Operator Training is being conducted in the Testbed facility at UCI. The Testbed ATMS Training and Development System both supports Caltrans' operator training efforts as well as establishes a true testing environment for ATMS upgrades and enhancements.

Training operations are supported by a freestanding, custom designed, Display Wall System. The Display Wall System includes (5) Christie Digital XGA DLP projectors. The system features a Christie Digital FRC 5100 Display Wall Processor, designed for 24/7 operation as an integral part of the video wall, capable of driving ultra high resolution tiled wall displays of virtually unlimited local or network-based software applications, real-time video inputs and multiple RGB Inputs. The processor can be controlled through a touch panel, RS-232 and IP with software on local workstations.



TMC Display Wall

The processor hardware is configured to accept (20) video feeds and (4) RGB sources. A VGA and a Composite video feed are routed to adjacent rooms for viewing. A Crestron TPS-5000 connected via Ethernet to the Caltrans Pro2, switches the camera inputs at the matrix switcher. A Crestron Pro2 CPU provides control of local TMC equipment.



TMC Operator Training Classroom

Operator training itself is carried out in an adjoining "classroom," that has data and video input/output capability to ATMSSIM. The classroom has capacity for fifteen Caltrans trainees. Video and audio surveillance of the trainees is provided to the instructors in the control room. Using this facility, TMC operator personnel will be able to interact both with actual, real-time or "playback" field data as well as with specific operational scenarios developed from loop-simulated data generated by the Paramics real-time microscopic traffic model.

Caltrans District 12 Real-time Data Intertie

Summary

- What is it?
 - A real-time data retrieval subsystem that interfaces directly with the Caltrans District 12 Front End Processor (FEP), providing loop detector data from all loop stations and real-time video from any two CCTV stations, in a dedicated, independent environment that is functionally isolated from the Caltrans District 12 operating system.
- What does it consist of?
 - A real-time data feed of 30-second “poll-data” from all of Caltrans District 12’s SATMS 170 controllers via a secure network connection between D12 FEP and the UCI Testbed private network, restricted by the D12 firewall to permit transmission only from the D12 FEP to the UCI Testbed Labs; transmissions to the D12 FEP from the UCI Testbed Labs are strictly prohibited. The real-time data is received by a dedicated server at the UCI Testbed Labs; the data is then stored in a database and made available for distribution to various real-time research and development activities.
- How has it been used?
 - Has provided data for numerous PATH and other Caltrans research projects, as well as been the foundation for TMC Operator Training.
- How can it be used?
 - Test and evaluate upgrades/enhancements to TMC operations, including adaptive control, in a secure environment that exactly duplicates actual field conditions and data feeds.

Description

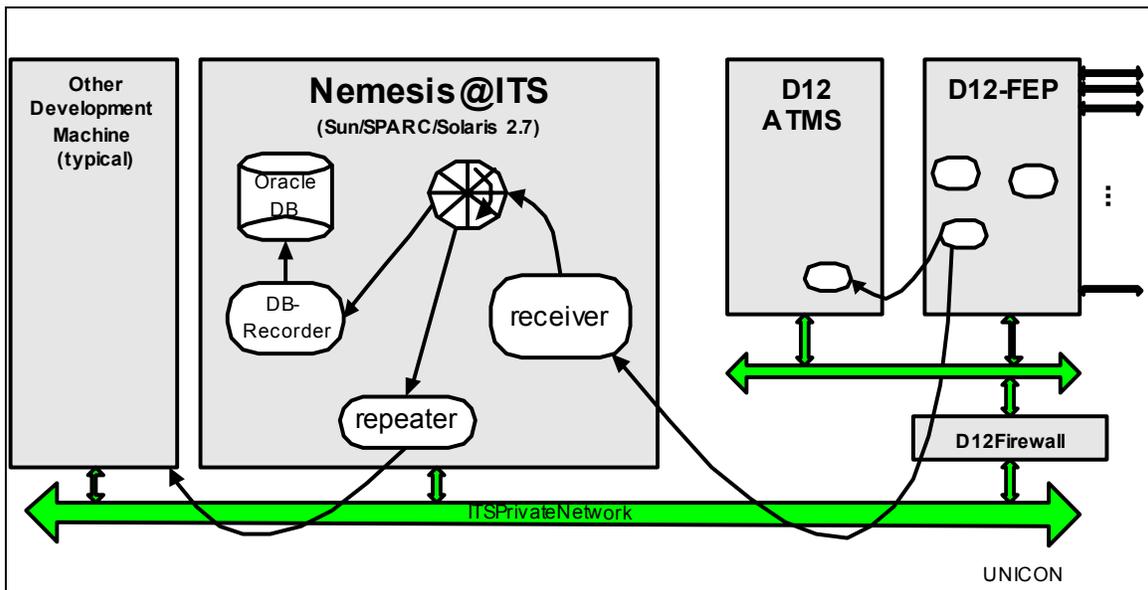
The data intertie with Caltrans District 12 has been configured based on a system architecture that, to the extent possible, renders the UCI ATMS Testbed Intertie to function in a dedicated, independent environment that is functionally isolated from the Caltrans District 12 operating system. Specific care has been given to adopting a design that will ensure that the Testbed Intertie remains operational, with minimal revision, as the Caltrans District 12 ATMS is upgraded or is otherwise changed.

The real-time data retrieval subsystem has been designed to interface directly with the Caltrans District 12 FEP system that includes a dedicated computer that collects data from traffic controllers via modems and interfaces with the outside world via TCP/IP network connection. It acts as a small central repository for the data collected from all of the traffic controllers that are connected to it. As it has limited memory it cannot hold large quantities of data, but does have the ability to respond to requests from a remote computer that wants to receive a copy of the traffic controller data that it collects. During normal operation the FEP continuously polls the traffic controllers and stores the returned data internally, together with diagnostic information regarding the communication link, timestamps, etc. This information is held in a small internal buffer and the oldest data is overwritten by the newest as the data arrives.

In the Testbed laboratories, a RECEIVER program that runs on a separate workstation under the Solaris 7 operating system (a version of UNIX) retrieves this internally stored data over a standard TCP/IP network. This program instructs the FEP to send whatever traffic controller data that it has stored in RAM, together with diagnostic information, back to the RECEIVER program. The RECEIVER program then formats this information in a human readable way and outputs it to a stream (e.g., console or disk file).

Under the current Testbed integration with D12’s ATMS and SATMS-170 controllers, the Testbed Labs at UCI receives the same type of data feed from the D12 FEP that the D12 ATMS receives. This data stream is a real-time data feed of 30-second “poll-data” from all of D12’s SATMS 170 controllers. The network connection between D12 FEP and the Testbed private network is restricted by the D12 firewall to permit transmission only *from* the D12 FEP *to* the Testbed Labs; transmissions *to* the D12 FEP *from* the Testbed Labs are strictly prohibited.

The real-time data feed from the D12 FEP is received by machine *Nemesis* at the Testbed Labs; the data is then stored in a database and made available for distribution to various real-time research and development activities. The diagram below outlines the current configuration.



Schematic of Caltrans District 12 Real-time Data Intertie

High-speed switching and firewall equipment provides a secure gigabit Ethernet data link between the two sites. Data from the D12 FEP is sent from the TMC to the Testbed Labs over a fiber link. Two simultaneous video feeds from the Caltrans D12 TMC cameras across the fiber link to the Testbed Labs are available to visually verify traffic conditions. A touch screen panel is used as the physical interface for the Testbed Labs to select the traffic feeds from the Caltrans D12 TMC.

Mobile TMC/Mobile Surveillance Units

Summary

- What is it?
 - A mobile laboratory equipped with full functionality of a Caltrans TMC.
- What does it consist of?
 - The Mobile TMC and the Mobile Ramp Metering and Surveillance units are capable of operating in conjunction with the Caltrans District 12 TMC or independent of it. These two systems provide on-site traffic data collection, video surveillance, and management functions to support Caltrans TMC operations.
- How has it been used?
 - Provides on-site traffic data collection, video surveillance, and management functions to support Caltrans TMC operations
- How can it be used?
 - Provide surveillance in construction zones; provide surveillance and ramp metering functions for event and major incident management.

Description

The Mobile TMC and its integration with mobile ramp-metering and surveillance trailers that were developed under previous Testbed contracts are designed to improve incident/disaster response and managing special events traffic situations through the use of mobile transportation management systems and field elements. The Mobile TMC supports TMC operations by performing the following functions:

1. Assist in incident management and highway system recovery
2. Act as a relay station for mobile surveillance trailers
3. Assist in interagency field coordination on the scene of major events or incidents
4. Provide a temporary facility in the event a TMC becomes disabled due to a catastrophic event.

The Mobile TMC was developed and has been maintained for Caltrans Division of Research and Innovation (DRI) between 1999 and 2004 as part of the ATMS Testbed. The Mobile Ramp Metering (MRM) system, developed previously, has been modified and integrated to operate in the field with the Mobile TMC. The Mobile TMC and the MRM are capable of operating in conjunction with the Caltrans District 12 TMC or independent of it. These two systems provide on-site traffic data collection, video surveillance, and management functions to support Caltrans TMC operations. Performance specifications for both the Mobile TMC and the Mobile Ramp Meter have been developed, allowing procurement of additional units to support Caltrans traffic operations (see Volume II, TTR3-23).

Baxall codecs allow relay of video from the Mobile TMC to the District 12 TMC over the Mobile TMC's satellite communications link. A 5.5kw Onan generator powers all AC electrical equipment on board the Mobile TMC, including on board computers and satellite communications system.



Mobile TMC

Anaheim Network Testbed

Summary

- What is it?
 - A system of 2070 controllers running the SCOOT adaptive control system in the convention/Disneyland area of the City of Anaheim (COA).
- What does it consist of?
 - Implementation of an interface for remote control access of the COA's SCOOT system field elements, providing the capability for closed-loop control, based on industry-standard communication technologies.
- How has it been used?
 - Test and evaluation of implementation of SCOOT adaptive control system using California-standard loop detector placement
- How can it be used?
 - Test and evaluate adaptive signal control algorithms; test and evaluate event management approaches

Description

A key operational element of the Testbed is the TMC located in the City of Anaheim (COA) and used to manage the flow of traffic in the Anaheim portion of the Testbed. The City SCOOT system is an enhanced deployment that enables ATC Model 2070 controllers to be integrated into SCOOT with a more robust protocol to accommodate real-time traffic information exchange to the TMC. A real-time data intertie between the Anaheim TMC and the Testbed Laboratories allows exchange of data from this system with other Testbed partners, enabling research into network-level control and traveler information systems, utilizing real-time traffic information for input into the various models and algorithms, and also providing closed-loop control capability of the field devices for validation of the technologies under development.

With this system, the City's traffic control system disseminates real-time traffic signal controller information to the Testbed labs. This provides a framework for establishing SCOOT real-time control capabilities from the Testbed Laboratories, and can be used in the development and implementation of an interface for remote control access of the COAs SCOOT system field elements, providing the capability for closed-loop control, based on industry-standard communication technologies.

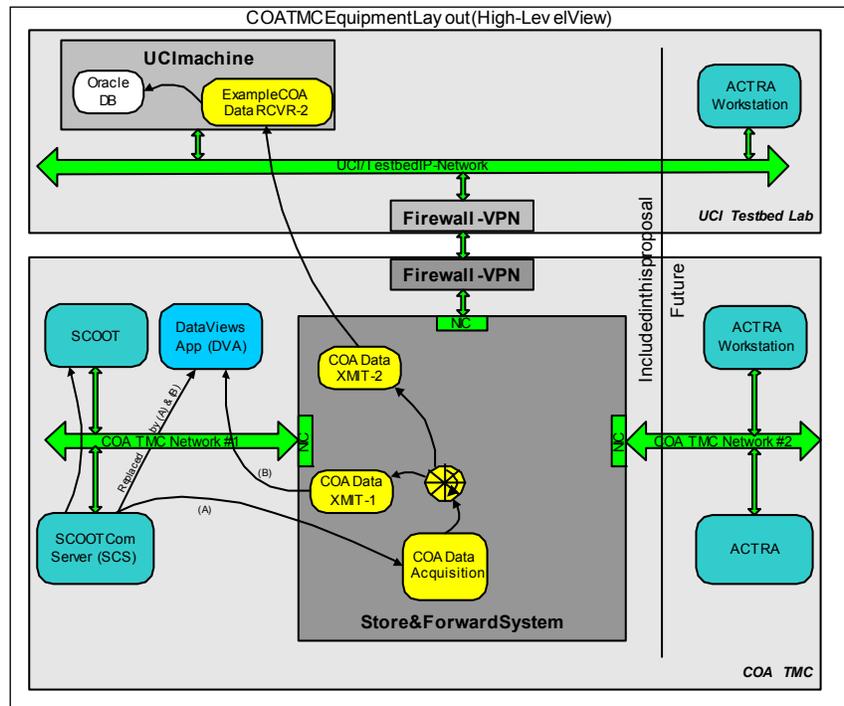
The diagram outlines the City of Anaheim TMC system configuration. Arrows in the diagram reflect data flows related to Testbed data acquisition. The SCS (SCOOT COM. Server) is currently capable of delivering data to two network nodes. Node-1 is the SCOOT system and node-2 is the COA Data Views Application (DVA) system. The approach taken was to redirect SCS node-2 to the Testbed SAF (Store & Forward) system. SAF system software is then responsible for storing the data locally and forwarding the SCS data back to the COA DVA system (via XMIT-1) and also forwarding the SCS data to machine 'Nemesis' at UCI (via XMIT-2). The diagram also shows the various components and the normal operational data flow. The Testbed hardware is installed at the COA TMC and consists of the following components:

- The *Store-and-Forward* (SAF) system is a rack-mounted mini-server that is configured with two network adapters. This system runs the *Store-and-Forward* (SAF) application components.

- The **Firewall-VPN box** provides network security for the SAF system and indirectly for the COA TMC.
- DSL supports the Testbed access to the SAF system within the COA TMC.

As the COA TMC real-time traffic data is acquired by the SAF system, it is stored locally in a circular buffer located in a shared memory data structure (SMDS). Once the data are stored in the SMDS they are then retransmitted to the COA DVA machine as well as to a machine at UCI. The local buffering on the SAF system allows the data acquisition process to proceed without concern for the speed of outgoing transmission processes. It also allows multiple transmitting agents to operate completely independently and without side effects. The design allows for the continuous recording of data locally and the reliable forwarding of data to the COA DVA system even if the network link to UCI should go offline. The storage requirement on the SAF system is minimally only a few seconds. This minimal interval provides sufficient storage to prevent a loss of data during typical momentary networking delays; however, this buffer area has been sized to accommodate several days of COA TMC data. In this way an extended network downtime can be tolerated without an actual loss of data—data would just continue to be stored locally until the network link is restored (up to the limit of the buffer used).

This allows Testbed management a reasonable amount of time to notice a networking problem and arrange for link repair prior to a loss of data. Once the link is restored, the SAF system software would simply forward the data stored locally over to system Nemesis at UCI as fast as the network link will allow.



COA Testbed Network Configuration

On the UCI side of the connection, a COA TMC data reception application RCVR-2 has been developed to accept the COA TMC real-time data stream as it arrives from the SAF system. This application stores the data in the existing Testbed Oracle database for distribution on the Testbed website.

Orange County Micro-sim Data Library

Summary

- What is it?
 - A series of coded Paramics networks, and associated data.
- What does it consist of?
 - Coded freeway and arterial networks within Caltrans District 12, including: API plugins developed by the Testbed researchers; network geometry data; OCTAM planning model; Caltrans Tachrun data; traffic counts from cities of Irvine and Anaheim.
- How has it been used?
 - Used in a variety of micorsimulation studies
- How can it be used?
 - Test and evaluate traffic management strategies

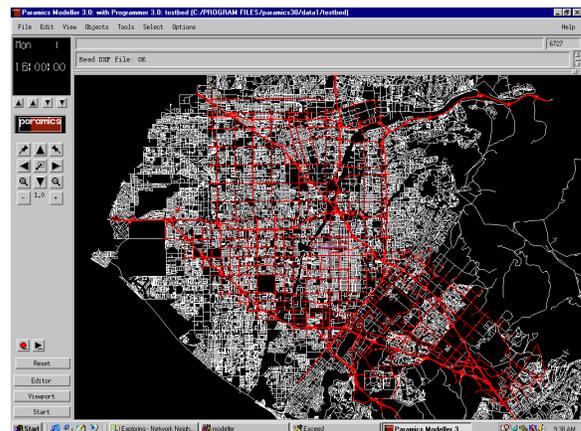
Description

Microscopic simulation studies need various data as inputs. Data used for network coding includes background images, network data, traffic control data, traffic detector data, traffic zones and demand tables, and vehicle data. Data used for model calibration include traffic counts and travel time along freeways and arterials. Due to the requirement of large amount of data for microscopic simulation studies, researchers may take a long time to collect data. The Orange County Micro-sim Data Library establishes a secure web site that allows traffic agencies, such as Caltrans and OCTA, and universities to share all available data securely.

The secure website was implemented using Apache, PHP, and MySQL. Briefly, the web service is designed to run on a Windows machine, using the Apache web server, together with PHP (a scripting language for writing web-based applications) and MySQL (the database that the PHP application uses). The application itself is a PHP application built from the ground up, making use of standard HTML Forms as the basis for the interface. Necessary security technologies (SSL) were setup and integrated into the PHP application.

The secure website provides functions for system administrators to manage the website and its data. The registered users can upload or download data. Currently, the site has about 1GB data from Caltrans District 12, City of Irvine, Orange County Transportation Authority (OCTA), including (1) API plugins developed by the Testbed researchers; (2) Network geometry data; (3) Previously coded Paramics networks; (4) OCTAM planning model; (5) Caltrans Tachrun data; (6) Traffic counts from cities of Irvine and Anaheim.

The secure website provides an efficient mechanism to share data between different traffic agencies and universities; its continued usefulness will depend on the involved traffic agencies making a practice of uploading any new data to the secure website.



Sample Paramics Network

Tracer

Summary

- What is it?
 - A GPS-based travel data collection and analysis system.
- What does it consist of?
 - Software and hardware designed to collect and store GPS data for later retrieval and analysis. These devices consist of a Garmin GPS antenna (either a Garmin 16 or Garmin 35), and a small embedded computer running Linux, which enables data collection, communication, and so on. The data are stored locally on a CompactFlash card, and can also be transmitted wirelessly via CDPD modem, via WiFi wireless network connections, or via a traditional wired ethernet connection.
- How has it been used?
 - Used to generate travel diary information, travel speeds and route choice.
- How can it be used?
 - Generate vehicle trajectory information. Can use this geographic data fusion to enable Caltrans staff to identify loop detectors that need recalibration in order to accurately report traffic characteristics.

Description

At its core, the fundamental task of the Tracer system is to collect and store GPS data for later retrieval and analysis. From this simple core, however, has grown a large, complex system. The Tracer database, as produced by this project, has been designed to manage this complex, evolving system.

The device that performs this data collection is the Extensible Data Collection Unit, or EDCU. Owing to its flexibility and extensibility, there are multiple configurations of the EDCU that can be used at any given time. All of the device attachments and optional configurations are included in the database schema.

Any qualified Testbed researcher can request one or more EDCUs. The EDCUs might be used by the researcher directly in a mapping study or a traffic speed survey, and so on. Alternately, the researcher might be conducting a travel behavior study, and therefore will need to subsequently distribute those EDCUs to any number of survey participants, if necessary. The Tracer database is able to track who is using the EDCU, and who has rights to view which GPS records.

A GPS point is based on well-defined latitude and longitude coordinates. Specifically, the GPS antennas used by the EDCUs record their data in what is known as the WGS-84 datum. Therefore, in order to be compared with data from another datum (such as TIGER/Line files) or using another projection, one must be able to convert the GPS data correctly. The Tracer database handles this by leveraging the open source Post- GIS database library, built on top of the PostgreSQL database. In addition, TIGER/Line files from the US Census have been downloaded for Los Angeles and Orange Counties, and included in the database as well. Thus using only the data available in the Tracer database, one can generate a map of the local area and plot recorded GPS points on it. The Tracer website uses a large Java library to access and manipulate the data.

The primary elements of the Tracer database and website has been up and running for approximately one year. Additional data visualization interfaces are being developed as needed and as time permits. Taking a broad view of the system, there are two aspects to the Tracer system: inventory control, and GPS data

management. Both of these are transferable to other projects. First, the inventory control aspect of Tracer could be used to manage any circulating Testbed resource. The database schema, described in detail in the project final report (Report TTR3-08), links Testbed researchers with Tracer devices through intermediate join tables. This approach can be used with any other resource, while preserving the core database and Java code that manages user log in, device use, and so on. While the details of managing the highly configurable EDCUs cannot be directly transferred to another device, the approach can serve as a model, which may simplify implementation.

Second, the GPS data management aspect of Tracer is directly transferable to any other geocoded data resource. The Tracer system has to cope with moving devices, and track data across time, space, and across different devices for different users. Other geocoded resources, such as the data feeds from embedded loop detectors, can be managed using a subset of the EDCU Java code and database tables since there would be no need to track the device itself beyond its initial placement.

As was stated above, data visualization enhancements to the website are being added as time permits and research needs dictate. One recent enhancement has been to leverage the public API of Google Maps to display the collected GPS data. The figure shows a recent screen-shot, with the GPS data being plotted on top of USGS aerial orthoimagery. In addition, the core Java code and geographic tables are being used to track data from inductance loop detectors throughout Orange County. Since the locations of loop detectors and the positions of vehicles are being tracked in the same database, when this work is complete it will be easy to compare the two sources of data. One goal is to use this geographic data fusion to enable Caltrans staff to identify loop detectors that need recalibration in order to accurately report traffic characteristics.



ATMS Testbed Resource Website

(www.atmstestbed.net)

Summary

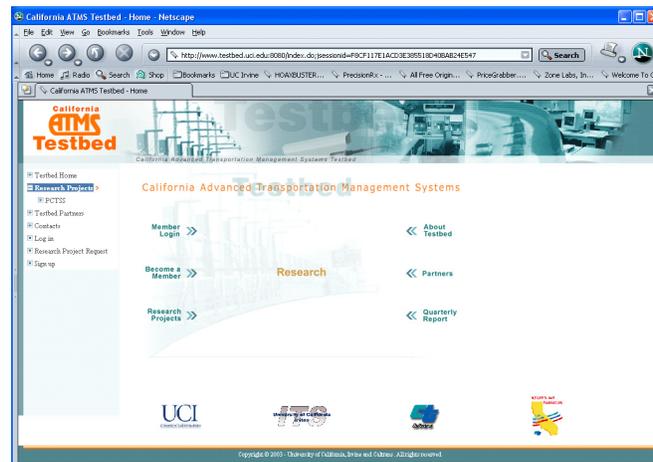
- What is it?
 - An interactive real-time graphical user interface for obtaining traffic information from the Detector Testbed, area freeways and arterial, as well as access to historical databases using a browser for query.
- What does it consist of?
 - A “virtual gateway” both to the traffic data streams (real-time and historical) generated in the Testbed as well as the analysis tools (e.g., Paramics APIs) developed by Testbed researchers.
- How has it been used?
 - Has provided Caltrans and university researchers with virtual access to the full complement of services available through the Testbed.
- How can it be used?
 - Run experiments, retrieve data, test and evaluate ATMS components within the Testbed from virtually any location without requiring physical proximity to the Testbed.

Description

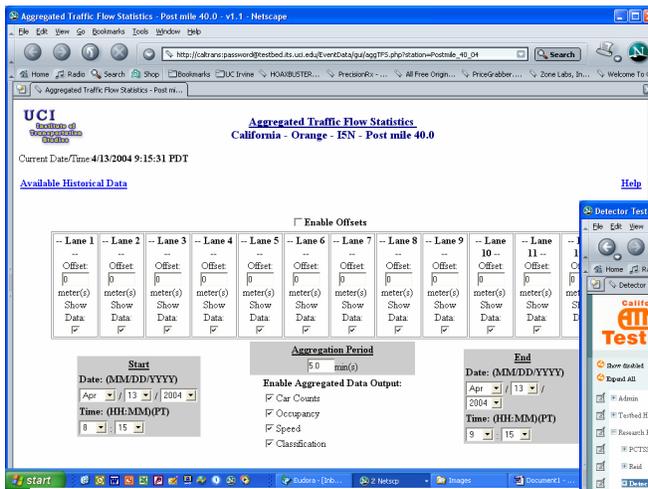
Access to the resources of the Testbed are provided through the ATMS Testbed website. The website has a real-time graphical user interface for obtaining traffic information from the Detector Testbed, area freeways and arterial, as well as access to historical databases using a browser for query. The website was developed and is maintained by the Testbed staff.

The ATMS Testbed website can provide university researchers, Caltrans staff, and public and private sector partners with a “virtual gateway” both to the traffic data streams (real-time and historical) generated in the Testbed as well as the analysis tools (e.g., Paramics APIs) developed by Testbed researchers. Examples of some of the data currently available on the Testbed website are given below.

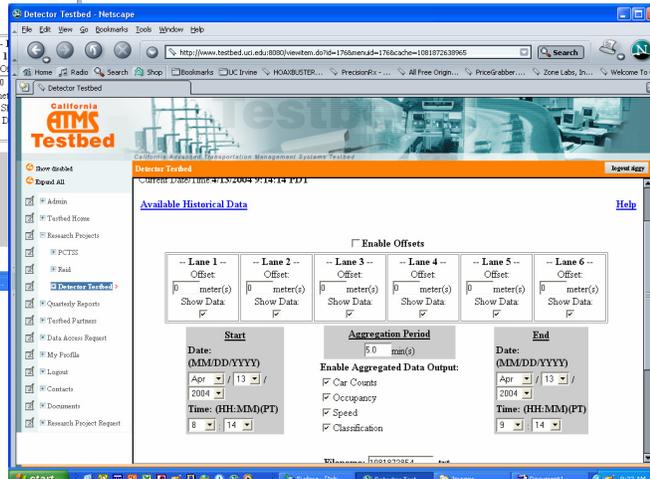
The ATMS Testbed website maintains a rich complement of both real-time and historical data generated within the Testbed that are being made available to researchers.



ATMS Testbed Website Homepage



Through the website, members (researchers, Caltrans, public and private sector partners) can obtain access to the various resources maintained by the Testbed, under varying levels of access privilege. For example, information pertaining to the Traffic

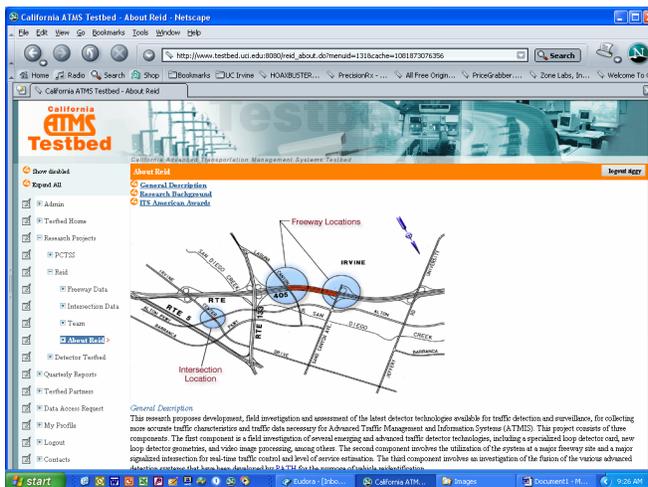


Traffic Detector Sub-Testbed

Detector and Surveillance Sub-Testbed (TDS²) can be accessed through a “pull-down” menu from which either historical data, either raw or statistical can be retrieved.

Utilizing vehicle re-identification systems developed jointly by PATH and the Testbed, real-time section data can be obtained both for arterial and freeway networks within the Testbed.

Historical data



The full complement of resources (e.g., data streams, streaming video, software packages) available at the Testbed are incorporated in the ATMS Testbed web page in a manner that provides “virtual” access to these resources. The web page has a real-time graphical user interface for Orange County freeways and traffic information from the cities of Irvine and Anaheim, access to historical database using a browser for query, and IP streaming video. The web page is available on the Testbed network as well as via the Caltrans Wide Area Network.

Advanced Loop Detector Locations

PART 3

TESTBED RESEARCH AND DEVELOPMENT

Development and Deployment of Corridor Management Prototype

Why was this research undertaken?

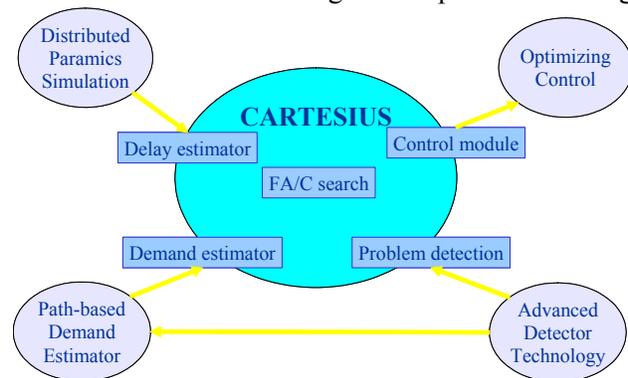
A central Advanced Transportation Management Information System (ATMIS) capability is a timely and efficient response to non-recurring congestion. The complexity of traffic in urban corridors requires substantial interaction between the various agencies that share responsibilities for corridor management. Coordinated response to congestion phenomena between these agencies avoids the implementation of responses that may be conflicting and therefore counter-productive.

The problems of transportation management in urban areas are complicated by jurisdictional as well as operational problems. The spatial and administrative organization of transportation management agencies in metropolitan networks requires a coordinated solution effort that preserves the different levels of authority, guarantees privileged data control, and in general reflects the inherent distribution of the decision-making power. A coordinated response to congestion avoids the implementation of operational solutions that may otherwise conflict, and therefore be counterproductive.

What was done?

The Testbed functionality in this broadly defined ATMIS application is centered on the real-time multi-agent incident management system CARTESIUS (Coordinated Adaptive Real-Time Expert System for Incident management in Urban Systems), deployed within the Testbed Real-time Integrated Control and Evaluation Prototype System (TRICEPS). CARTESIUS approaches this problem by employing advanced cooperation and conflict resolution methodologies for coordinated traffic management operations among multiple agents. This system is at the cutting edge of the application of agent technology to traffic management and has been tested extensively using laboratory simulation with positive outcomes reported across the scenarios evaluated. To date, however, it has not been deployed in the field.

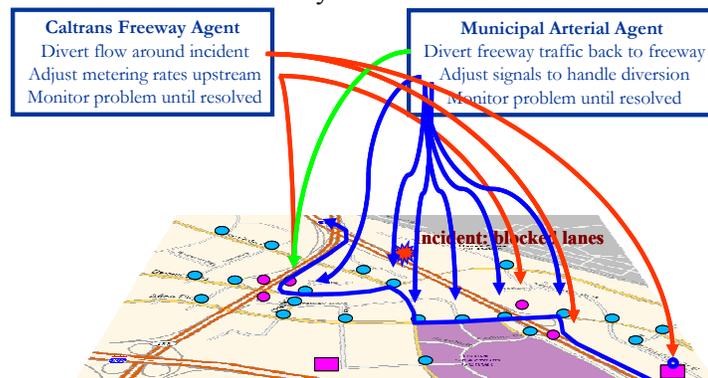
In an ongoing joint Testbed/PATH project, TRICEPS/CARTESIUS is in the process of being field tested in two evaluation modes. In the first mode, the system processes real-time data coming from sensors in the field and provides advisory management strategies and control actions for the consideration of Caltrans District 12 (Caltrans D12) and City of Irvine Traffic Management Center (ITRAC) personnel. The second evaluation mode involves developing CARTESIUS as a client under CTNET, and deploying the system in its real-time, interactive, mode in the TDS² corridor. The deployment will utilize dynamic O-D patterns and travel times derived from the vehicle reidentification research (REID), which is a separate ongoing PATH research effort, to assess alternative routing of vehicles through the corridor. Signal timing recommendations selected with the aid of TRICEPS/CARTESIUS will be implemented via the Cartesius/CTNET system that will be deployed by the Testbed along Alton Parkway; ramp meter settings will also be implemented based on enhancements to the Caltrans D12 Testbed intertie as part of the follow-on Testbed contract.



CARTESIUS Components

What can be concluded?

The product of this work will be deployment of a multi-jurisdictional, multi-agent traffic management decision support system using an extensible implementation architecture. The deployment will utilize the products of current and prior Testbed research and evaluate their use in practical settings. The field deployment of TRICEPS/CARTESIUS will produce a functional multi-agent, multi-jurisdictional traffic management system for the real-world transportation corridor that is part of the Testbed. This system will coordinate management strategies between Caltrans D12 and the City of Irvine. The TRICEPS/CARTESIUS system is a mature research project utilizing agent technology to implement strategies that “coordinate freeway and arterial operations among multiple agencies.” The work conducted here will produce a pilot deployment of this system in a specific real-world setting. This will permit further evaluation of both the performance of the architecture as well as provide feedback on the practical usability of the system from the operators' perspectives.



CARTESIUS Operational Scenario

What do the Researchers recommend?

Because CARTESIUS will be deployed in the Irvine I-405 transportation corridor, it offers the potential to conduct study in the following important areas:

1. *Assessments of impacts of application of technologies:* The impact of TRICEPS and CARTESIUS on various non-recurrent congestion scenarios in Irvine corridor will be assessed.
2. *Studies of institutional coordination issues:* The efficacy of CARTESIUS mediated inter-jurisdictional coordination of traffic management strategies between the City of Irvine and Caltrans D12 will be evaluated.
3. *Post-deployment evaluations of effectiveness:* While full evaluation of the deployment will likely require longer-term calibration of the system and subsequent monitoring, preliminary evaluations of its performance will be produced and used to feed further fine-tuning of the deployment.

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Distributed Paramics Development

Why was this research undertaken?

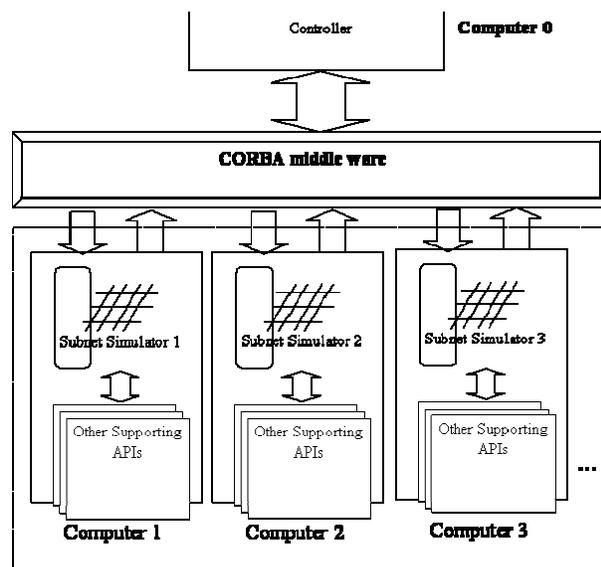
Micro-simulation modeling is an increasingly popular and effective tool for analyzing a wide variety of dynamical problems, which are not amendable to study by other means. As a suite of ITS-capable, user-programmable, high-performance microscopic traffic simulation package, PARAMICS offers very plausible detailed modeling for many components of an ‘ideal’ simulator. It has become a widely used microscopic simulation model in the US (especially in California). However, for it to be incorporated effectively for real-time applications involving California’s urban freeway networks, it needs to have scalability, so that these large networks can be simulated in something close to (or, even exceeding) real time.

What was done?

Research is being conducted under the auspices of both PATH and the Testbed to develop a distributed version of Paramics that will be truly scalable. In this project, we developed a distributed modeling framework for large-scale microscopic traffic simulation and implemented a scheme with global control and independent subnets using the PARAMICS model. Unlike the previous studies using the dedicated high performance machines, our efforts are to utilize the low-cost networked PCs that are commonly available. By using the Application Programming Interface (API) functions supported by off-the-shelf PARAMICS, we are able to simulate the traffic in a large region simultaneously with independent subnets running on separate desktop PCs and vehicle transferring from one subnet to another.

In the distributed simulation environment being developed, the targeted large network is divided into sub-networks, and each sub-network is simulated on a separate desktop PC. The general distributed architecture includes: 1) a “controller” simulator running the "master network," and 2) several sub-network simulators. Although the controller may have various tasks related to coordinating the traffic simulation itself, the essential task from a computational architecture standpoint is the synchronization of the time in each sub-network, either at every simulation time-step or at specified time intervals. To synchronize the simulation time, the controller has the ability to start and stop the sub-network simulation at any time. In addition, such information as boundary zones and their corresponding ownerships are established in the controller computer.

During a simulation run, the controller and simulators communicate over the distributed platform. The sub-network simulators act as slaves to the controller. During a time step of simulation or certain time interval, a simulator executes a non-blocking loop (asynchronous communication) while waiting for a new request from the controller. A request is simply a message associated with a specific task. When the request arrives into a sub-network simulator, it starts with an execution of the corresponding sequential code. When the request task is completed, a notification is sent back to the controller. When all simulators are “checked in”, the simulation master clock advances by



Distributed Paramics Schematic

one step and broadcasts the new times to every simulator in the system. Each simulator then proceeds until it reaches the master clock time. A pictorial description of the scheme used for distributed processing is shown in the figure. The communication between the simulators and controller is through the CORBA distributed platform.

What can be concluded?

Performance testing and analysis of the implemented prototype demonstrate that the proposed framework is very promising. Since synchronous communication is used among simulators and controller, each simulator can only run as fast as the slowest one; proper and balanced decomposition of the network is critical to the overall performance. Because the total computational requirement for a microscopic traffic simulation is dominated by the number of vehicles in the network at any time, the ideal division of network is to create N regions that each has exactly V/N vehicles, where V is total number of vehicles in the simulation and N is the target number of processors. The speed-up performance of the simulation in distributed processing is also dependent on the communication to computation overhead: if there are a large number of communication operations for each computational operation, the overall process will reduce in speed. In order to minimize the communication to computation overhead, distributed simulations require methodological decomposition of the large network to find a subdivision where there are as few boundaries as possible and the computational load is spread evenly across the processors.

In the design, not only does the controller synchronize the time clock of simulators but it also manages the global abstract network, global O-D matrix and global routing table. The benefit from this design is that vehicle's origin-destination and its path are all controlled at the global level, as opposed to the local level. In this aspect, the simulator's design is similar to the simulation over single processors in terms of routing, with the distinction of updating vehicle's location over distributed processors. But the communication load between the controller and simulators is also significantly higher than that of the light controller-heavy simulator, which may slow down the simulation.

The controller has the global abstract network, global O-D matrix and global routing table. Each simulator also has its own local routing table. When a vehicle is generated in the sub-network, if its origin and destination belong to different sub-network, its temporary destination in the originating sub-network will be determined from the global routing table, but its path in the originating sub-network will be determined locally from the local routing table. Instead of routing every individual vehicle at the global level, the design allows a vehicle's route calculated at the local level, and significant communication overhead is reduced.

What do the Researchers recommend?

The platform should be tested and on several large networks. For early testing, it is recommended that the large Orange County Testbed network recently fine-tuned at UCI be used. This network is one of the largest networks coded in Paramics, with as many as 100,000 vehicles being present at any given time.

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Development of the Capability-enhanced PARAMICS Simulation Environment

Why was this research undertaken?

Micro-simulation modeling is an increasingly popular and effective tool for analyzing a wide variety of dynamical problems, which are not amendable to study by other means. As a suite of ITS-capable, user-programmable, high-performance microscopic traffic simulation package, PARAMICS offers very plausible detailed modeling for many components of an 'ideal' simulator. It has become a widely used microscopic simulation model in the US (especially in California). Its typical applications are the evaluation of different traffic control and management strategies. To be qualified as an appropriate simulator for these studies, Paramics should have the capabilities to model the real-world traffic condition and various operational strategies. However, PARAMICS does have some functional deficiencies. For example, Paramics can basically model the fixed-time signal control but not the commonly used actuated signal control. Using the powerful API programming ability of Paramics, this project aimed to complement its functionality in signal control and enhance its capabilities in the modeling of ITS strategies.

What was done?

This project developed a capability-enhanced PARAMICS simulation environment through integrating ten plug-in modules implemented in Paramics API. These ten plug-ins included actuated signal, multiple actuated signal timing plan, actuated signal coordination, detector data aggregator, ramp metering control, on-ramp queue override control, ALINEA ramp metering control, BOTTLENECK ramp metering control, SWARM Ramp metering control, and Freeway MOE (Measure of Effectiveness). They complemented the current Paramics simulation model and enhanced its functionalities.

What can be concluded?

Our tests using the capability-enhanced PARAMICS simulation environment show that the commercial PARAMICS model functionalities can be effectively complemented and enhanced through API programming. The enhanced PARAMICS simulation can better model and evaluate ITS.

Our experiences also show that API can be used to access the core models of a micro-simulator and potentially, researchers can use commercial micro-simulators as a shell for testing their own models and algorithms. Since other commercial micro-simulators, such as VISSIM and AIMSUN 2, also provide users with their own API functions, users can replicate our methods to enhance their capabilities.

What do the Researchers recommend?

These developed plugins need to be continuously maintained because the upgrade to a new version of Paramics may cause them to work abnormally. This is because these plugins were developed based on the core models of Paramics, which may be changed or modified in a new version.

Our current capability enhancements of Paramics only cover some aspects of the microscopic simulator. More efforts are expected in order to make the enhanced PARAMICS better fit to more ITS-related studies.

The ten developed plugins have been released to Caltrans for use. Since the current plugins are developed for the research purposes, extra development for user-friendly graphical interfaces may be needed.

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Real-time Adaptive Systemwide Ramp Metering and Signal Control

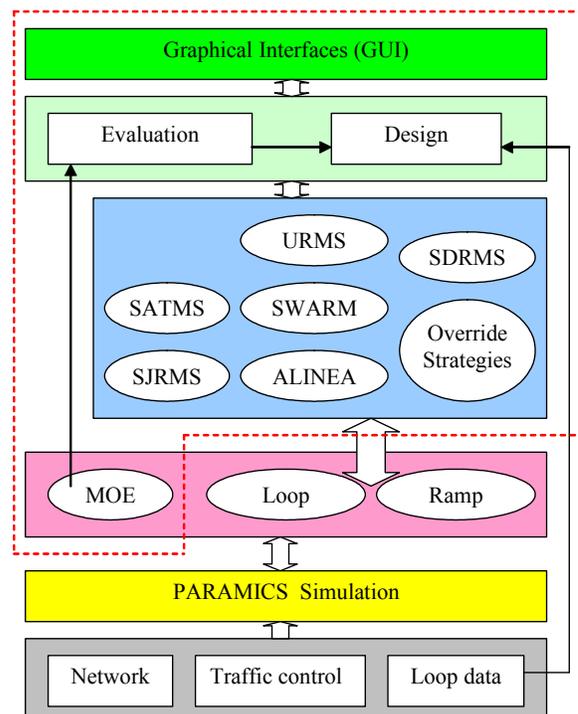
Why was this research undertaken?

Ramp metering has been recognized as an effective freeway management strategy to avoid or ameliorate freeway traffic congestion by controlling access to the freeway. However, studies show that significant benefits can be obtained from ramp metering only when implemented correctly and operated effectively. In order to ensure the success of the implementation, it is important to first investigate during a pre-implementation phase questions related to whether or not ramp metering is warranted, which kind of ramp metering algorithm is suitable to the peculiarities of the target network, how to implement a specific metering algorithm, and how to setup the parameters of the algorithm. With the advancement of technology, more complicated metering algorithms, such as System Wide Adaptive Ramp Metering (SWARM), have been (and will be widely) implemented in the real world. These algorithms have more parameters and depend on accurate detector data. Their correct implementation and performance optimization depend on greater expertise from operators and more research on the part of researchers.

What was done?

In support of Caltrans' ramp metering deployment efforts, an evaluation platform based on PARAMICS simulation is being developed jointly by the Testbed and PATH. The ramp metering design tool handles how to implement a metering algorithm within a target freeway corridor. The ramp metering evaluation tool employs the testing and evaluation of a metering algorithm and its design based on performance measures obtained from simulation. A library of metering algorithms either currently or potentially applied in California is included in this platform. These algorithms include District 3, 6, 8, and 11's SDRMS, and District 7 and 12's SATMS, as well as some adaptive metering strategies (e.g., ALINEA, and SWARM) that potentially can be applied. The platform has intuitive graphical interfaces in order to facilitate Caltrans practitioners.

The overall framework of the platform is shown in the figure. The input data of PARAMICS simulation are network geometries, traffic control data, and traffic demand data estimated from real-world loop data. The platform has four main modules, and each module is made up of several components. The components within the red dotted box represent the newly-developed modules. The light green module is the core module, including two functional tools, design and evaluation. The bright green module is the graphical interface module through which users can access these tools. The blue module is metering algorithm module that consists of a library of Caltrans' metering algorithms (implemented as PARAMICS plug-ins). The pink module is the supporting module, which includes several PARAMICS API plug-ins used to support various metering algorithms and measurement data collected from the simulation world.



Evaluation Framework

The latest web-based programming technologies have been used to implement the platform; the web pages containing the GUI have been developed using HTML and JavaScript; the core module of the platform is implemented in Java language, which has strong capabilities of the development of graphical interfaces; XML (eXtensible Markup Language) is used for data exchange between the core module and two PARAMICS plug-ins modules, including metering algorithm module and supporting modules.

A series of performance measures for evaluating various aspects of ramp metering can be extracted, including the following time-dependent measures:

1. Average mainline travel speed / travel time and its standard deviation
2. Total delay at an on-ramp
3. On-ramp queue length
4. Time percentage of queue spillback to the local streets at an on-ramp
5. Travel time from an on-ramp to downstream end of freeway and its standard deviation

The evaluation tool of the ramp-metering platform employs the evaluation of the metering design of a metering algorithm, and various traffic operational aspects of the ramp metering control. It links a specific ramp metering study, such as a study of freeway mainline efficiency, with required performance measures. Examples of these ramp-metering studies include freeway mainline efficiency, on-ramp delay, and equity analysis of a metered freeway corridor. As a result, the applications of the evaluation tool are:

1. Investigate whether metering has been operated correctly and efficiently
2. Analyze, evaluate and improve the current metering operations
3. Test new algorithm and fine-tune parameters

These studies can be done based on trial-and-error method and selected performance measures. Through the GUI, users can dynamically observe the performances of various aspects of metering control.

What can be concluded?

Compared to field tests, the platform should provide a quick and cost-effective way to conduct ramp-metering studies in the microscopic simulation environment. The platform can be used to analyze and improve current metering operations, to test a new algorithm, to fine-tune parameters of an algorithm, to evaluate various aspects of performance of a metering strategy, and to conduct a series of deeper level analysis of the performance of the algorithm.

What do the researchers recommend?

The platform can serve as a training environment for Caltrans personnel to gain experience with various metering algorithms, especially those coordinated metering algorithms that are characterized by many parameters and complicated control logic. This platform should be used to guide Caltrans personnel on how to successfully manipulate the various aspects of the ramp-metering systems, including initializing parameters, fine tuning of parameters, performance analyses, and hypothetical "what if" simulated testing.

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Performance Evaluation of Adaptive Ramp Metering Algorithms

Why was this research undertaken?

Adaptive ramp metering has undergone significant theoretical developments in recent years. However, the applicability and potential effectiveness of such algorithms depend on a number of complex factors that are best investigated during a planning phase prior to any decision on its implementation. A field operational test is one way to evaluate metering operation. The method can provide the ultimate fair evaluation of the actual performance of a ramp metering system as applied in the real world, but they are usually very expensive and time-consuming to conduct. Moreover, without prior testing, such tests have the potential to adversely impact traffic conditions, and such uncontrollable factors as incidents or variations of demand patterns often make it difficult to fairly compare algorithms or even before-after results. As an alternative, this project studied a microscopic simulation based evaluation method.

What was done?

Three well-known adaptive ramp-metering algorithms, ALINEA, BOTTLENECK and ZONE were selected for evaluation. ALINEA is a local feedback control algorithm and the other two are area-wide coordinated algorithms. Paramics was adopted as the simulation platform for further evaluation of these metering algorithms. Several Paramics plugin modules, including loop detector data aggregation (used for on-line data collection), ramp metering control (used to mimic ramp signal operations), and ramp metering algorithms (metering logic implementations of ALINEA, BOTTLENECK and ZONE), were developed to build a simulation based ramp metering evaluation framework. The evaluation was then conducted over a stretch of the I-405 freeway in California. The performances of these metering algorithms were compared with respect to different demand patterns under both recurrent congestion and incident scenarios.

As an alternative to the difficult task of fine-tuning them in real-world testing, a hybrid Genetic Algorithms (GA) simulation method was developed to optimize four operational parameters of a particularly effective algorithm, ALINEA, including the update cycle of the metering rate, a constant regulator, the location and the desired occupancy of the downstream detector station. In the hybrid method, GA-simulation was used for parameter optimization, and micro-simulation (i.e. Paramics) was used for performance evaluation. The objective of the study was to achieve system optimum for all metering freeways and ramps. Simulation results showed that the genetic algorithm was able to find a set of parameter values that can optimize the performance of the ALINEA algorithm for the whole controlled system.

What can be concluded?

Simulation results showed that adaptive ramp-metering algorithms can reduce freeway congestion effectively compared to the fixed-time control. ALINEA shows good performance under both recurrent and non-recurrent congestion scenarios. BOTTLENECK and ZONE can be improved by replacing their native local occupancy control algorithms with ALINEA. Compared to ALINEA, the revised BOTTLENECK and ZONE algorithms using ALINEA as the local control algorithm are found to be more efficient in reducing traffic congestion than ALINEA alone. The revised BOTTLENECK algorithm performs robustly under all scenarios. The results also indicated that ramp metering becomes less effective when traffic experiences severe congestion under incident scenarios.

Since our simulation network does not contain arterial routes, traffic diversion to alternative routes is not considered and thus the performance improvement through ramp metering control is not fully revealed. Ideally, one should consider a corridor network and integrate a variety of control measures, including ramp metering, traffic diversion, and signal timing, to combat traffic congestion. We should also note that

all of the algorithms evaluated in this study are reactive, rather than proactive, control strategies. Algorithms with state estimation and/or OD prediction capabilities are desirable. The development and evaluation of these integrated control strategies will be left to future studies.

Because of the good performance and easy implementation of ALINEA metering algorithm, ALINEA was identified as a good algorithm that can be potentially implemented in the field. The ALINEA algorithm was implemented together with a typical queue override strategy in Paramics as a plugin. The queue override strategy was used to avoid vehicles to spillback to arterials during ALINEA operation with low metering rate.

It was found that the system performance is not sensitive to the variation of the constant regulator under ALINEA control. When the updated cycle ranges between 30 to 60 seconds, mainline detector is placed between 120~140 meters downstream of the on-ramp nose, and the desired occupancy is set to 19% to 21%, the ALINEA control produces the best system performance with most stability in our testing network.

The desired occupancy is the most sensitive parameter among all four selected operational parameters in our study. Choosing a suitable value for the desired occupancy was essential to optimize the performance of ALINEA control. Simulation results show that the occupancy at capacity at the mainline downstream detector station is the best value to be selected. If less on-ramp delay is expected from metering control, a higher desired occupancy (around 30%) could be used.

What do the researchers recommend?

This study showed that micro-simulation with genetic algorithm can be used to calibrate and optimize the operational parameters of ramp metering control algorithms, as a necessary part of successful implementation. Potentially, micro-simulation and genetic algorithm may also be used to fine-tune various other ITS strategies.

The study provides a parameter setting guideline for the ALINEA ramp metering control. Practitioners can use the recommended parameter values as a basic operational reference when they setup ALINEA control in the field.

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Peer-to-Peer (P2P) Traffic Information Propagation

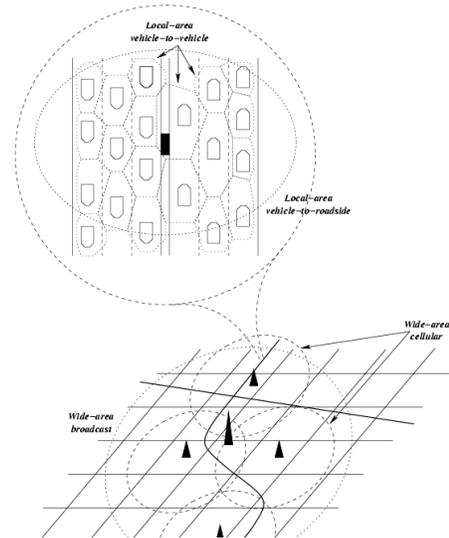
Why was this research undertaken?

Since the introduction of intelligent transportation systems (ITS) in the early 1990s, there has been growing interest in potential applications of the use of wireless communication between vehicles, usually referred to as inter-vehicle communication (IVC). In IVC-based system, vehicles are envisioned to exchange precise position information from satellite navigation data (GPS) via IVC at low cost to optimize traffic flows and provide valuable, real-time traffic information to the drivers. Our focus is on the potential for the concept of IVC-based systems to serve aspects of transportation systems management. We attempt to give answers to two questions: (1) What IVC equipment penetration rate is needed for information propagation to extend to a substantial part of the whole network under various traffic conditions?, and (2) What IVC system requirement is needed to disseminate incident information faster than the attendant traffic/vehicle wave propagates through the network?

What was done?

This project investigated the feasibility of a distributed traffic information system based on IVC technology, focusing on such systems arising principally from the transportation application. Specifically, via simulation modeling techniques, we determined the thresholds for some of the parameters necessary to support the systematic collection and provision of useful and in time (real-time or close to real-time) traffic information in a self-organized, distributed traffic information system, dubbed Autonet, that is based upon the peer-to-peer information exchange among vehicles.

Potential applications of this Autonet concept for traffic management and traveler information are intrinsically based on achieving information propagation throughout the traffic network; however, because penetration of the necessary technology to the fleet of vehicles can be expected to be gradual, a "mixed" network of IVC-capable vehicles and non-IVC capable vehicles will exist for some period of time. In our research, we attempt to give answers to two questions: (1) What IVC equipment penetration rate is needed for information propagation to extend to a substantial part of the whole network under various traffic conditions, and (2) What IVC system requirement is needed to disseminate incident information faster than the attendant traffic/vehicle wave propagates through the network?



Peer-to-Peer Schematic

We analyzed the two issues mentioned above for various possible IVC technologies and for different roadway network formats and different road traffic conditions. In addressing these open questions that may be barriers for implementation of self-organizing, IVC-based traffic information systems, our focus is on the potential for the concept of IVC-based systems to serve aspects of transportation systems management; the traffic-oriented abstraction evaluation framework is developed without detailed electronic engineering and computer science modeling. Nonetheless, the results serve to identify, at least roughly, the system implementation requirements for both software and hardware sides as well.

We used PARAMICS (PARAllel MICROscopic Simulator) to build our simulation modeling framework. Three IVC scenarios were investigated in the research: uni-directional and bi-directional information

propagation in one-dimensional highway network, and information propagation in two-dimensional arterial streets networks.

There are three major outputs from the simulation that were used in our analysis: 1) IVC success probability, representing the average chance that an individual IVC-equipped vehicle can find other IVC vehicles in the communication radius range and communicate successfully in the traffic network at any particular time; 2) communication bandwidth, indicating the average maximum amount of data that needs to be transmitted by each IVC vehicle in the traffic network, defining the basic requirement for the software and hardware implementation in the proposed system; 3) maximum information propagation distance, at any time an indicator of how fast the information flow is traveling in the traffic network, a key factor in determining whether or not this information flow may potentially benefit the traffic system.

What can be concluded?

Our results indicate that it may be extremely difficult to evolve the proposed self-organizing vehicle-to-vehicle based system to support information propagation for location sensitive, real-time traffic information in freeway networks in which communication is only among vehicles moving in the same direction, especially if the IVC equipment market penetration rate is low and communication radius range is short – two conditions that are likely to characterize the proposed system in its start-up period. Under incident conditions, for such market conditions and available IVC technologies, the incident information wave generally travels slower than does the traffic shock wave due to the incident.

Compared to information propagation employing information exchange only among vehicles in the same stream of traffic, efficiencies and effectiveness of bi-directional propagation systems built upon inter-vehicle communication technology are significantly easier to achieve because mechanisms for information propagation in this case not only include “hopping” along vehicles moving in the same direction of flow as well as “cross transference” of information to vehicles moving in the opposite direction. For market conditions and available IVC technologies that are likely to prevail during the system’s start-up period, the incident information wave generally travels faster than the traffic shock wave due to the incident freeway networks in which vehicles that are moving in opposite directions in close proximity to each other can exchange information.

Traffic information dissemination in two-dimensional urban arterial networks via information exchange among IVC-equipped vehicles is also easier to achieve than in one-direction freeway network cases; however, propagation speed is generally slower than in two-direction freeway network cases. Bandwidth/data rate requirements for IVC in urban arterial streets are relatively high because of the representation of the complex network configurations and high density of vehicles in the traffic network due to the distribution of vehicles in two-dimensional space.

What do the researchers recommend?

This study showed that a traffic information/management system based on P2P communication is feasible. Significant additional study should be undertaken to identify traffic management efficacy, limitations and hardware requirements.

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Dynamic Vehicle Navigation in a Peer-to-Peer (P2P) System

Why was this research undertaken?

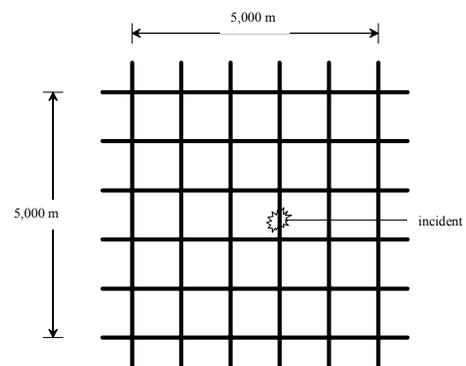
Although inter-vehicle communication and information dissemination in traffic networks have been modeled both from various academic perspectives (transportation engineering, electronic engineering and computer science) and at different levels (highly abstract, software protocols and hardware products), no efforts have been found that systematically model and test such a distributed traffic information system based upon peer-to-peer information exchange relative to drivers' dynamic on-line routing behaviors within it. This work focuses on detailed modeling of a self-organizing, distributed traffic information system built upon vehicle-to-vehicle information exchange, with case testing of the pre-trip route-choice and in-trip re-route behaviors of drivers with access to traffic information from the proposed information system.

What was done?

This project focused on detailed modeling of a self-organizing, distributed traffic information system built upon vehicle-to-vehicle information exchange, with case testing of the pre-trip route-choice and in-trip re-route behaviors of drivers with access to traffic information from the proposed information system. Two different large-scale traffic networks, one comprising grid arterial streets and the other a freeway corridor, are tested with respect to different assumptions regarding drivers' route choice behavior including both pre-trip route choice and in-trip re-route behaviors, and different levels of knowledge of daily recurrent traffic patterns. Potential benefits arising from this proposed information system both for travelers with IVC and for the whole traffic systems, including all travelers with and without equipment, are demonstrated based on simulation study results.

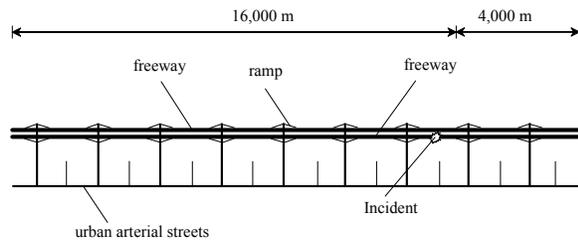
We used the PARAMICS simulation software to build our simulation modeling framework. Within the micro-simulation modeling framework, some vehicles in the traffic network, equipped with IVC systems, geographic information systems (GIS), global positioning systems (GPS), on-board navigation systems, and in-vehicle computing processors, are assumed to generate floating car data information based on their own experiences, exchange traffic information through peer-to-peer communications, and process incoming traffic information in real-time using their on-board processors. In addition, each vehicle within this distributed traffic information system is assumed to optimize its personal route based on its estimation of current traffic conditions obtained from real-time traffic information propagated in the information network and its understanding of recurrent traffic pattern from its historical traffic information database; based on the assumption that each driver is a rational entity, re-routing decisions are examined. Path-based vehicle navigation is implemented for each driver, in which IVC vehicles follow changeable paths; no-IVC vehicles follow no-changeable paths.

The first test case concerned non-recurrent congestion scenarios in a grid network. The 5,000m x 5,000m network evaluated consists of equally spaced two-lane local street roadways with speed limit of 45 mph; the distance between any two neighboring signalized intersections is 1 km. An incident is assumed to have occurred on a link close to the center of the study grid network. This incident is assumed to cause passing vehicles to reduce speed to 5 mph in the direction of the roadway in which the incident occurs and to 10 mph in the opposite direction of the roadway (due to speculator slowing). Three levels of O/D demand were used in



Network Schematic

our simulation studies to generate light, moderate and heavy traffic flow conditions in the network.



Freeway Schematic

The second test case considered non-recurrent congestion scenarios along a freeway corridor with a neighboring alternative arterial street. The freeway and parallel arterial street are connected by other arterial streets running perpendicular to the freeway and freeway on/off ramps spaced at 2000-meter intervals. In the simulation, an incident 4000 meters from the far end of the network occurs 30 minutes into the simulation and lasts for 30 minutes; owing to the blockage caused by the incident, vehicle speed in that direction is reduced to 5 mph near incident location. Three levels of O/D demand are used to

generate light, moderate and heavy traffic flow conditions, both for the freeway and the arterials.

What can be concluded?

Several interesting results are obtained from our simulation studies under non-recurrent congestion scenarios in the grid arterial streets network. First, only when IVC market penetration rate is higher than some threshold values, can IVC-capable vehicles make sufficiently accurate estimations of real-time traffic conditions to take re-routing actions. This threshold value is relatively high compared to freeway networks due to the dimensional characteristics of grid arterial networks compared to freeways. Although the relative travel time saving benefits for IVC-capable vehicles from re-routing decrease after reaching maximum values, IVC-capable vehicles always maintain an advantage compared to their counterparts and total system performance improves by their re-routing.

For most cases in the freeway corridor network, as increasing numbers of drivers have accessibility to real-time traffic information from inter-vehicle information exchange, the redistribution of IVC-capable vehicles enables the system to move toward user equilibrium. The characteristics of this freeway corridor network are such that a traveler has significantly fewer choices than in the grid arterial streets. Under normal traffic conditions the freeway system typically has much more capacity and a better level of service than its surface street alternative, leading to many more vehicles choosing to use the freeway system under these conditions; thus, even a relatively small amount of IVC-capable vehicles’ re-routing from the freeway to arterial streets may dramatically worsen the traffic conditions on the arterial streets, resulting in a general worsening of system performance under heavy demand.

What do the researchers recommend?

This study showed that significant travel time savings may be possible under a traffic information/management system based on P2P communication. Significant additional study should be undertaken to identify traffic management efficacy, limitations and hardware requirements.

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Analytical Studies of Peer-to-Peer (P2P) Information Propagation

Why was this research undertaken?

The rapid advance in available information technology, especially, the development of wireless communication technologies, now makes feasible the exploration of traffic information systems that decentralize the tasks of collecting and disseminating traffic information. Compared to centralized ATIS systems, a decentralized system based on Inter-Vehicle Communication (IVC) offers some significant advantages: (1) the IVC components of the system require no capital investment on the part of the transportation agencies, and can evolve to a full system gradually, once a threshold market penetration is achieved; (2) both the monetary and labor costs to build and operate the system are directly distributed to the users of the system; (3) the system is much more resilient to disruption, particularly in the event of disasters, when communications, management, and control are most important; (4) the system can be anchored to the Internet as a platform for additional applications.

What was done?

In this project, we developed a novel analysis framework for the performance of inter-vehicle communication in a traffic stream. With the assumption that information propagation is instantaneous compared to vehicle movements, we consider the probability of success for information to propagate beyond a location. Most-forward-within-range communication chains and transmission cells were defined, measurement probabilities were modeled regressively, and examples were studied for different traffic scenarios, transmission ranges, and market penetration rates. This mathematical model was found to be consistent with simulation-based studies.

In an effort to understand the structure of the complicated P2P system, we first make an assumption that information propagation through IVC is instantaneous. This simplification is based on the observation that vehicles' movements are inconsequential during the short transmission time of a message (in the order of one-tenth second). Therefore, the effect of traffic dynamics is omitted, reasonably, but the distribution pattern of vehicles caused by road geometry and car-following rules are included.

We start by defining "most forwarded within range" communication chains and splitting a traffic stream into a number of cells based on the transmission range of wireless units. Then by considering the relationship between communication chains and transmission cells, we obtain two basic components for constructing an arbitrary communication chain. With the understanding of the structure of information propagation, we are able to derive a regressive model for computing the success rate for information to travel beyond a certain point.

What can be concluded?

With this model, the user can evaluate the performance of certain wireless communication units for different market penetration rates and traffic patterns.

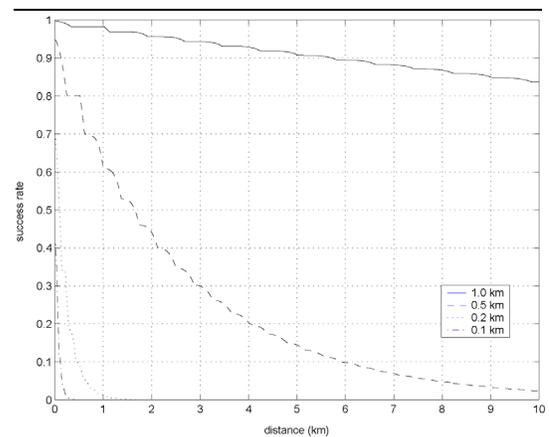


Figure 1: Success rates v.s. transmission ranges: penetration rate = 10% and four-lane road with density of 56 veh/km

For example, we evaluated the influence of different communication ranges on the information propagation as shown in Figure 1. As expected, longer transmission ranges yield better propagation results. The results in this figure are consistent in magnitude with those in the literature by simulation studies. This further argues for the assumption of instantaneous information propagation.

We also applied this model to study the impact of a gap in a traffic stream on information propagation. As shown in Figure 2, a gap at [0, 0.4 km] can seriously deteriorate the success rate (by more than 10 percentiles) for different locations of information sources.

In Figure 3, we show the influence of a shock wave on information propagation. Here, the information source vehicle runs into a congestion shock wave and slows down (from 104 km/h to 97 km/h). For a number of time instants, we consider the propagation distances of 95% success rate in both forward and backward directions. We can clearly see the bending effect of traffic density change on information propagation. This example shows that a small change in traffic density (60 veh/km vs 80 veh/km) can have substantial consequence on information propagation distances (4 km vs 27.1 km).

What do the researchers recommend?

This project demonstrated the effectiveness of the mathematical model for evaluating the performance of IVC in a traffic stream. Use of this model can significantly reduce the time required for evaluating the influence of communication ranges, market penetration rates, and traffic pattern on the success rate of information propagation. The model can be used for estimation of the performance of Autonet system. Continued efforts are needed to extend this analysis framework for studying other important issues related to IVC systems, such as communication capacity, and the impact of road network topology.

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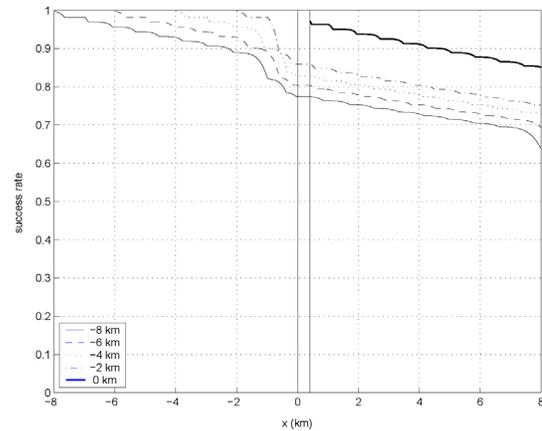


Figure 2: Success rates of information propagation for different locations of information :

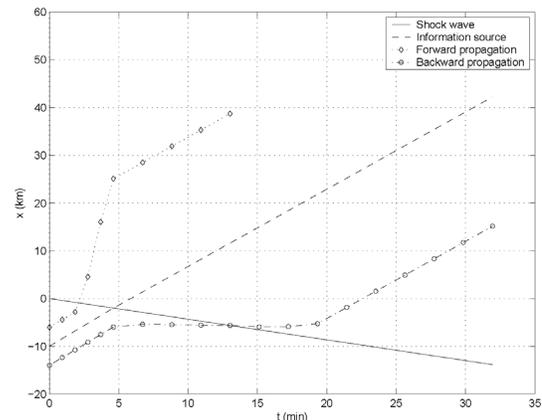


Figure 3: Information progress with 95% success rate in a shock wave

Mobile Throughput of 802.11b

Why was this research undertaken?

Simulation research has shown that a traffic information/management system based on P2P communication is feasible. However, significant additional study is needed to identify traffic management efficacy, limitations and hardware requirements. In particular, the ability of current wireless communication technology, e.g., 802.11b, to successfully transmit traffic information between vehicles moving at high relative speeds to each other is questionable.

What was done?

The project investigated the capabilities of wireless local area networking (WLAN) technology for vehicle-to-vehicle and vehicle-to-roadside communication. An 802.11b (WiFi) card is inexpensive, and provides plenty of bandwidth. WiFi technology is being incorporated into PDAs, cellphones, and in Intel's Centrino laptop chipset. It requires very little imagination to suppose that drivers will soon have easy access to a computing device of some sort, which supports WiFi or a related technology. This project focused exclusively on vehicle-to-roadside communications. The work is part of a larger effort to benchmark the practical throughput of off-the-shelf wireless technologies. The work is on-going, with further vehicle-to-roadside and vehicle-to-vehicle tests planned.

The first step in testing wireless throughput was to install hardware both on the roadside and in a vehicle. Two Cisco AP 350 series wireless access points were mounted on buildings on the UC Irvine campus fronting Peltason Road. The access points were connected to building-mounted 13.9dBd antennas. The antenna specifications are as follows: 3dB Beamwidth, Degrees E-Plane 30, 3dB Beamwidth, Degrees H-Plane 34, Front to Back Ratio, dB 18, Gain dBd 13.9, and Impedance (ohms) 50.

Inside of the vehicle, wireless connectivity was achieved using a Lucent Orinoco Silver PCMCIA card plugged into a laptop computer. A 5db gain omni directional external antenna was mounted on the vehicle roof using a magnetic base. The laptop was also connected to the Testbed's extensible data collection unit (EDCU), in order to obtain exact positioning for the wireless signal readings.

The primary study area is shown in the accompanying figure. One antenna was mounted on the Multipurpose Science and Technology (MST) building, shown in the center of the figure, and the other was mounted on the Engineering Gateway (EG) building, just to the right of the MST building. Both of the directional antennas are pointed in a westerly direction along Peltason Road, more or less towards the crossing roadways on the left side of the figure. In order to test the

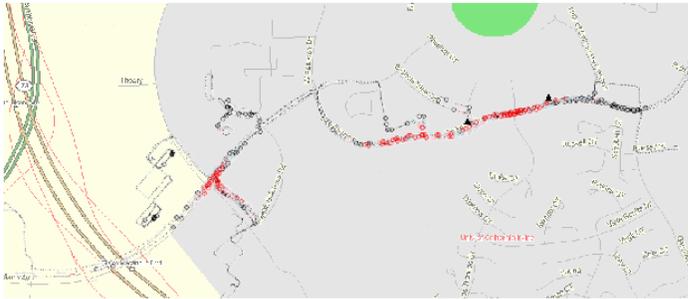


Study Area

wireless link capacity, the utility program Netperf was used. Netperf is designed to test various aspects of a network connection. In this case, it was configured to repeatedly conduct throughput tests with one-second duration. This resulted in one geocoded throughput measurement every two seconds.

Data were collected over several days. The maximum throughput observed was 4.62 Mbps, which compares favorably with WiFi used in an indoor environment. This maximum throughput value was measured while the vehicle was traveling at 30.7 mph, approximately 159 meters from the MST building access point. As can be seen from the figure, the connectivity is highly directional. This is for two reasons. First, the antennas are directional, and are pointing in a westerly direction along Peltason. Second, 802.11b requires a clear line of sight. Peltason road is quite hilly, and the roadside antennas are

completely obscured at the intersection of Peltason and Bison. However, at the intersection of California and Bison (near the crossing roads), there is a clear line of sight to the MST building once again.



Connectivity

Some simple regression tests were done to examine the relationship between line of sight, speed, and distance with the observed throughput. The regression results indicate that distance plays the most significant role in determining the throughput value. If all non-zero observations are included rather than just those clustered in the direction that the antenna is pointing (192 degrees), then the most important factor is the “degrees away from 192.” Interestingly, speed is less important than we expected. This is perhaps due to the fact that our tests were performed on streets with a speed limit of between 35 and 45 mph.

What can be concluded?

This project demonstrated that it is possible to establish a useful, high-bandwidth link between a moving vehicle and a roadside, directional antenna. The connection strengths were surprisingly high, with a signal of about 4 Mbps established at an intersection approximately 1 kilometer from the nearest antenna. While this connection was not maintained for very long due to the road geometry, at this communication rate it is possible to download a PDF file containing the UC Irvine campus map within 1 second. The biggest factor limiting throughput was maintaining a clear line-of-sight to the roadside antenna. As the road curved away or dipped down behind a hill, the throughput rapidly went to zero.

The implications of these tests for possible applications are clear. If we continue to use the same directional antennas, it is possible to conduct short transactions with moving vehicle that are in range. These transactions might include downloading a map, or a short session requesting the nearest available parking to an intended destination. However, transactions that require long sessions, such as attending a lecture wirelessly or checking email, are not possible with this kind of connection.

What do the researchers recommend?

There are several aspects of the vehicle to roadside connection, which still need testing. For example, the test protocol did not repeatedly attempt to establish a connection with the base station. That is, a single period of testing would include a single connection event. After that, the wireless antenna would be assigned an IP address and could concentrate on testing throughput. It would also be interesting to test the time required to negotiate the initial connection throughout the test area. The tests were also performed with very little ambient interference. While there are 50 or more open WiFi access points in the study area, they are all use low power omni-directional antennas, and did not offer any significant interference.

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Implementation Tests of a Peer-to-Peer (P2P) Network for Incident Exchange

Why was this research undertaken?

The existing paradigms for vehicular traffic monitoring and control have a strong infrastructure bias—data are collected centrally, processed, and then redistributed to travelers and other clients in response to requests. There are a number of research efforts to decentralize traffic state monitoring by leveraging advanced local area wireless technology. One version of such a traveler-centric system is called Autonet. Work to date consists of a preliminary *implementation* of some of the key Autonet concepts as well as some field measurements.

One of the key gaps limiting the broad adoption of Intelligent Transportation Systems (ITS) technologies by drivers is the lack of usable real-time data. According to a 2002 national survey of ITS technology adoption [ITS Joint Program Office, 2004], only about 30% of all signalized intersections on arterial streets had any form of electronic surveillance. Even if every *highway* were fully and accurately monitored, drivers attempting to plot an alternate route around an incident would be unable to evaluate conditions on the arterial street network.

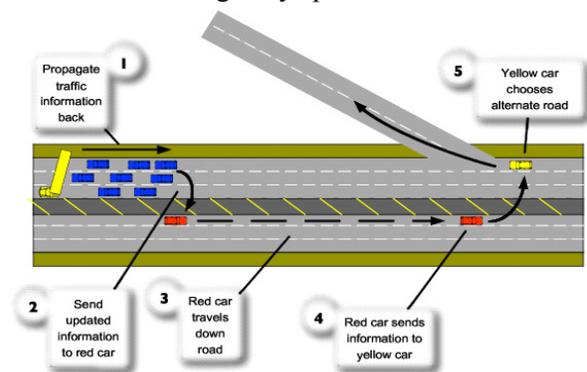
Automobile manufacturers have been installing more and more computer electronics and control systems into their cars, with high end models commonly sporting in-dash, GPS-based mapping systems. The contrast between the high cost and low penetration rate of *infrastructure* based traffic monitoring, and the declining cost and increasing capabilities of *in-vehicle* electronics devices implies that we should explore the abilities of the latter to augment or even replace the former. We suspect that a *decentralized, vehicle-based* traffic probe system may be cheaper, faster, and easier to implement than the centralized monitoring and traffic probe systems defined in the National ITS Architecture.

What was done?

An in-vehicle client with an informative GUI has been developed. This client continuously listens for other clients, and exchanges knowledge about network incidents once contact is made. We demonstrated that knowledge about traffic conditions can be propagated successfully using this system. The client programs were also used to test the actual throughput possible for messages sent from one vehicle to another using 802.11b wireless hardware. These measurements establish the maximum throughput at about 4,000 incidents for two vehicles moving in opposite directions at highway speeds.

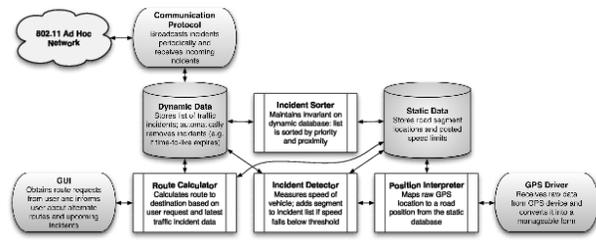
The main result of this project was to design the basic features of an Autonet system, and to then implement an Autonet peer that could perform the most important of those features.

The guiding scenario is shown in the figure. This picture shows a vehicle passing a traffic jam, collecting information about that jam from the affected cars, and then “carrying” that information upstream. At some point, the information would be used by travelers upstream of the incident to decide their optimal course of action, in this case, to exit the highway. This scenario led to a specification of the system requirements, which in turn led to a software architecture, shown in the accompanying figure, and an implementation.



AUTONET Scenario

The implementation was installed on a number of laptops. Each laptop was equipped with a GPS antenna to provide location and speed information, and a WiFi card to allow the peers to communicate with each other. Each peer was equipped with a common network model, based on the freely available TIGER/Line file data for Orange County. This provided a common framework for exchanging incident information. In repeated trials, we demonstrated the ability to transmit incident information between vehicles, and to have incident information be carried from one vehicle to another just as depicted in the basic scenario discussed above.



Implementation Schematic

What can be concluded?

In addition to providing a proof of concept test, the initial Autonet peer implementation served a second purpose: the ability to benchmark the capabilities of off the shelf communications hardware and protocol stacks. In order to explore the feasibility of the Autonet idea, the proper approach is to implement a large-scale traffic simulation, and to slowly ratchet up the adoption rates. However, such simulations would be difficult to program without solid evidence about the capabilities of each wireless client. Using the initial Autonet peers, we were able to demonstrate the ability to transmit data in a highway setting between two oncoming cars, each traveling at 70 mi/h. The results are summarized in the accompanying table.

| | 40 mi/h | 55 mi/h | 70 mi/h |
|--------------------------|---------|---------|---------|
| # of incidents exchanged | 5,996 | 4,295 | 3,556 |
| Time within range | 23 s | 18 s | 10 s |
| Round trip time | 71 ms | 80 ms | 81 ms |

This project demonstrated that a decentralized, vehicle based real-time traffic information system is technically feasible. We designed the necessary system architecture, implemented that architecture, and then tested our implementation on the road. We were able to transmit incidents in real time between moving vehicles using our software and off the shelf hardware.

Test Results

What do the researchers recommend?

A large question is how useful such a system will be if it is adopted by the general public. To answer this question, the next step is to expand simulation studies using the empirical capabilities of the prototype device as a starting point. Through simulation, it will be able to determine the relationships between adoption rates, information flow, and system awareness, which in turn will lead to traveler-centric applications such as route planning and incident avoidance.

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Implementation of a Tool for Measuring ITS Impacts on Freeway Safety Performance

Why was this research undertaken?

Reduced congestion and smoothed traffic flow are likely to improve safety, as well as reduce psychological stress on drivers. Using data from the Testbed, we have begun to document the relationship between safety and improved traffic flow. Recent developments indicate that the time is right to refine and implement analytical tools that can be used in real-time monitoring of the safety level of the traffic flow on any instrumented segment of freeway. As opposed to tools that measure freeway performance in terms of throughput or travel time, the data indicate that the key elements of traffic flow affecting safety are not only mean volume and speed, but also variations in volume and speed. We further determined that it is important to capture variations in speed and flows separately across freeway lanes, and that such information is useful in differentiating types of crashes.

What was done?

The objective of this joint effort between the Testbed and PATH is to implement a real-time tool for safety analysis. The overall project goal is to calibrate and verify a tool that translates traffic flow, as measured by ubiquitous single loop detectors, into safety performance in terms of expected numbers of crashes by type of crash per exposed vehicle mile of travel. This tool can be used in monitoring the safety performance of freeway operations and to evaluate and document improvements to safety arising from such ITS deployment as system-wide ramp metering (SWARM), freeway service patrol (FSP) and other incident response measures, and driver information.

In work conducted thus far, we lay the groundwork for the development of a performance tool that gauges the level of safety of any type of traffic flow on a California freeway. The inputs to this tool are data from single loop detectors, so the tool can be implemented wherever such data are monitored or simulated. Our analyses are based on loop detector data for each of the freeway lanes for a short period of time preceding each of over 1,700 accidents in our case study. This case study covers the six major freeways in Orange County for a six-month period in 2001. The results have uncovered an extensive set of statistical parameters that capture those aspects of traffic flow that are strongly related to accident potential.

In this work we recognize that loop detector data at a specific time and place cannot be converted to speed, because it is not possible to know effective vehicle length at such a detailed level (that is, the mix of long and short vehicles is unknown at a specific place for a short period of time). Consequently, we avoid using any direct speed or density measures among the parameters. These parameters include not only central tendencies (means and medians), but variations, and measures of systematic and synchronized traits that capture patterns in short period of loop detector data. Such patterns include breakdown from free flow to congested operations or recovery back to free flow, and differences in traffic conditions across lanes. We demonstrate that the parameters can account for speed and density, even though these are not used directly. Moreover, the parameters account for important differences among the types of accidents that occur under different type of traffic flow.

What can be concluded?

Eight Factors were found to account for approximately 79% of the variance in the original variables. In order to evaluate the effectiveness in describing derived parameters (speed and density), each of prohibited scaled measures was regressed on a set of forty-four variables, made up of the eight Factors, plus eight factor quadratic terms (the products of two like Factors), plus twenty-eight factor interactions (the products of any two different Factors). The regression results (not shown) for the means and standard deviations of occupancy and the ratio of volume to occupancy for each of the three lanes indicate

that the Factors do very well to explain all of the prohibited variables that are proportional to traffic flow density and speed. The conclusion is that all of the original variables are sufficiently described by the eight Factors.

A summary of the main results of the analysis of accident propensity as a function of traffic flow is presented in the table below, in which the solid red cells indicate that the probability of the accident characteristic being present increases with the factor score, and the hatched green cells indicate a decreasing probability with an increase in the score. Each of the eight Traffic Flow factors is effectively related to at least two of the four sets of accident characteristics. This sensitivity bodes well for continued research into the development of hazard functions in the eight-dimensional space of the Factors and their second-level interactions.

What do the researchers recommend?

Work is needed to test the model’s ability to distinguish locations and conditions with high accident rates from those with low accident rates. By quantifying the safety benefits accrued from smooth and efficient traffic operations, Caltrans should be able to incorporate safety measures in assessment of performance gains resulting from ITS deployment. Another application will be to forecast the safety implications of proposed projects by evaluating the levels of safety implied by traffic simulation model outputs. The safety aspects of costs and benefits can be assessed by comparing the levels of safety estimated by the tool for traffic flows before and after implementation of a treatment, such as a component of an intelligent transportation system (ITS) or infrastructure project. It can also be used to forecast the safety consequences of doing nothing. It is meant to complement performance measurement systems that focus on travel times and delay (e.g., PeMS).

| Factor | Interaction | Accident Characteristic | | | | | | | | | | | | | | | |
|-----------------------------|-------------|-------------------------|--------|----------------|----------|------------|-------|--------------------|-----------|--------------|------------|-------------------|---|---|---|----|--|
| | | Severity | | Collision Type | | | | Collision Location | | | | Involved Vehicles | | | | | |
| | | PDO | Injury | Sideswipe | Rear end | Hit object | Other | Off road left | Left lane | Middle lanes | Right lane | Off road right | 1 | 2 | 3 | 4+ | |
| 1 Outer lanes congestion | 6 | | | | | | | | | | | | | | | | |
| | 7 | | | | | | | | | | | | | | | | |
| | 6 | | | | | | | | | | | | | | | | |
| 2 Volume level | 2 | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | |
| 3 Synched. Conditions | 3 | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | |
| 4 Curb lane perturbation | 2 | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | |
| | 6 | | | | | | | | | | | | | | | | |
| 5 Volume variation | 5 | | | | | | | | | | | | | | | | |
| | 6 | | | | | | | | | | | | | | | | |
| 6 Conforming curb volumes | 1 | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | |
| | 5 | | | | | | | | | | | | | | | | |
| | 7 | | | | | | | | | | | | | | | | |
| 7 Systematic volume changes | 1 | | | | | | | | | | | | | | | | |
| | 6 | | | | | | | | | | | | | | | | |
| 8 Synchronized outer flow | 6 | | | | | | | | | | | | | | | | |
| | 8 | | | | | | | | | | | | | | | | |

Summary of Results

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Development of a Tool for Measuring Non-recurrent Congestion Impacts of Accidents

Why was this research undertaken?

Although it has been speculated that non-recurrent congestion caused by accidents, disabled vehicles, spills, weather events, and visual distractions accounts for one-half to three-fourths of the total congestion on metropolitan freeways, there are insufficient data to either confirm or deny this conjecture. When considering the extreme difficulty of estimating accident likelihood due to the definitional properties of non-recurring congestion, the most important potentially soluble factor in the development of accident management strategies is to identify and to quantify the conditions affecting the total delay by accidents. Most of all the quantification of the total delay by an accident is required as basic information for the purpose of accident management strategies as well as is used as a performance measure to evaluate transportation policies and planning level analyses associated with design of transportation systems or preparation of operating plans for safety. However, in order to collect the real data regarding the total delay, there is a need for a specially designed detection system that detects long freeway sections and records the traffic condition on them for long periods. Thus the objective of this study is to develop temporal and spatial methods to quantify the accident delay as well as to identify the causal factors affecting the total delay caused by accident, based only on loop data.

What was done?

The objective of this project was to develop and apply an analytic procedure that estimates the amount of traffic congestion (vehicle hours of delay) that is caused by different types of accidents that occur on urban freeways in California. Binary integer programming is applied for estimating temporal and spatial extent of delay caused by freeway accidents. The basic idea to estimate the congested area by an accident originated from the speed difference between under normal flow condition and under accident condition.

Our analysis involved a case study of accidents that occurred on freeways in Orange County in 2001. Two datasets were combined to accomplish the objective of the study: (1) accident data from the Traffic Accident Surveillance and Analysis System (TASAS), which covers all police-investigated accidents on the California State Highway System, and (2) traffic flow data from the Vehicle Detection System (VDS), received directly from the Caltrans District 12 front-end processor (FEP) using the UCI Testbed Intertie with Caltrans District 12. The non-recurrent delay caused by the case study accidents is estimated based on inferred link speeds derived from loop data and a binary integer programming formulation to identify the temporal and spatial region affected by the accident.

Using non-recurrent delay computed for a sufficient sample of accidents, a statistical model was estimated that describes non-recurrent delay as a function of day of week, time of day, weather, and the observable (e.g., from emergency calls and/or aerial or on-scene observation) characteristics of the accident. These accident characteristics, which are available to Freeway Traffic Management Systems, include time of day, number of involved vehicles, whether a truck is involved, and collision location (by lane or side of road). This statistical model can be used to inform a manager as to the expected delay associated with an accident as soon as the accident is reported and its characteristics are observed. This can in turn be used in improving resource allocation.

Computations of non-recurrent delay were successfully performed for 870 accidents that occurred on weekdays throughout the period of March through December 2001 on the six major Orange County non-toll freeways.

What can be concluded?

The median total delay for these 870 accidents is 86 vehicle hours, the lower bound of the mean is 184 vehicle hours, and the lower bound of the standard deviation is 246. As indicated by the difference between the median and the high standard deviation relative to the mean, the distribution of non-recurrent delay is highly skewed to the right (i.e., toward high values of delay), as expected. A regression model was developed that can forecast the expected amount of non-recurrent delay for different types of accidents that occur at different times. Our results indicate that the following accident characteristics are crucial in identifying those accidents that are likely to cause the most delay: (a) how many vehicles are involved in any accident occurring during the weekday AM peak, and whether the accident is in the left lane or not, (b) how many vehicles are involved in an accident occurring in the midday period, and whether there is a truck involved in the accident, (c) which lane a PM peak period accident is located in, and whether or not it is a single-vehicle accident, (d) whether or not a truck is involved in any accident, and finally, (e) whether or not the accident occurs on Friday.

The most important predictor of delay is whether the accident involves two vehicles and occurs in the midday period. This combination indicates an accident that would generally occur in heavy traffic that is moving at relatively high speeds. It would also be an accident that occurs prior to buildup of the afternoon rush hour, so that lingering effects are typically likely to influence steadily increasing levels of traffic. The next most important indicators are whether a PM peak period accident was located in the interior or left lanes, and whether an AM peak period accident involved multiple vehicles.

The accident that is likely to cause the greatest delay is an AM peak period accident involving three or more vehicles, which multiplies the base level of delay by a factor of more than seven. Other indicators of extensive delay is whether a PM peak period accident is in the left lane or off-road left, whether a AM peak period accident involves two-vehicles, or whether a PM peak period accident is in the interior lane(s). Reduced levels of delay are expected for truck-involved accidents and for AM peak-period accidents in the left lane. However, if a truck is involved in an accident that occurs in the midday period (weekdays, 9:01 a.m. through 3:29 p.m.), more non-recurrent delay can be expected. Also, single-vehicle accidents that occur in the PM peak period will lead to more delay, because such accidents are typically more severe (over 30% of PM peak period single-vehicle accidents are injury accidents, compared to about 25% of PM peak period multiple-vehicle accidents).

What do the researchers recommend?

Eventual application of the results reported here can give managers an estimate of the total non-recurrent delay due to each of these accidents, as soon as they are spotted and basic characteristics are known. These results can also be useful for the performance evaluation of accident management systems by quantifying accident congestion in terms of total delay to evaluate the benefit of accident management systems accrued from efficient traffic operations. Additionally, they can be used by public sector transportation

With further testing and refinement, the modeling procedures developed could be incorporated as a layer in the ATMS map display that, once an accident and its essential characteristics are observed, would display the likely spatial and temporal extent of the congestion expected from the accident.

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