Automated Following Demonstrated in San Diego

Throughout this summer, PATH advanced vehicle control systems (AVCS) researchers conducted a series of experiments and tests culminating in a demonstration of vehicle-follower longitudinal control technology in San Diego on August 24 and 25. Visitors from government, industry, and academia had an opportunity to ride in PATH test vehicles to experience the sensation of traveling at freeway speed in a tightly coupled pack. Encouraging test results illustrate the developmental potential of automated vehicles. As PATH intended, the demonstration rides in a four-car group gave the appearance of routine operation on an automated highway.

The Test Program

The San Diego tests were conducted in cooperation with Caltrans' New Technology Division, PATH's major sponsor, on the Interstate 15 High Occupancy Vehicle (HOV) lane. Caltrans District 11 built the eight-mile, separated two-lane facility in the center divider of I-15 as an example of modern highway engineering. The reversible HOV lane operates inbound for the morning rush and outbound in the evening. Between the hours of 10:00 AM and 1:30 PM, Caltrans operated the lane for PATH's benefit as a high-speed test facility. The road is nearly straight throughout its length and fairly level, but features one mild 1% grade and one moderate 3% grade at the north end. This profile is excellent for early development of longitudinal control systems.

Caltrans Engineer Randy Woolley managed all aspects of the facility for us, providing gate security, communications, inter-agency coordination, and a few creature comforts for the test staff. The cars were based in San Diego at the Caltrans District 11 Maintenance Facility, through the courtesy of Ross Cather and Bill Gant. District 11 provided gasoline, parking, and mechanical supplies.

PATH has developed four vehicles for longitudinal control experimentation and demonstration based on cars provided to PATH by the Ford Motor Company. The set consists of a 1989 Ford LTD Crown Victoria in the lead position and three 1990 Lincoln Town Cars with Teves ABS in the following positions. In May 1992, PATH demonstrated a very early vehicle-follower implementation based on these same four cars with the help of a subcontractor. Although the cars look much the same on the outside as they did then, everything inside is new: the test team has brought together experience with sensor systems, automotive hardware, real-time software, and applied control theory to create an integrated system. Accurate spacing control was

continued on page 8
California Transportation Management Centers: Past, Present, and Future

Hong K. Le
PATH
Randolph W. Hall
University of Southern California

Transportation Management Centers (TMCs) monitor changes in conditions of a transportation system and respond to them either reactively, as in incident management, or proactively, as in adaptive traffic signal systems. As new technologies are developed through research in Intelligent Transportation Systems (ITS), TMCs will assume increasingly more importance as command and control centers for transportation operations. They can provide a focus for cooperative and coordinated efforts to manage the transportation system. Future TMCs may disseminate real-time traffic conditions to the public, recommend vehicle route plans, implement emergency evacuation plans, monitor hazardous material routes, and coordinate intermodal transportation.

Many state and federal programs are actively developing new traffic management technologies. In 1990 alone, 105 freeway operations projects in the US were operating in a TMC setting or had the potential of becoming a TMC [1]. Now is an opportunity and important time to strategically assess TMC capabilities, and to envision ways that TMCs may evolve to incorporate new technologies. In this article, we briefly describe the history of TMC development, focusing on California, and then discuss some development possibilities, highlighting some potential barriers or cautions.

The earliest traffic management projects in the US began in the 1960s and 1970s, when new highway construction had already been surpassed by traffic growth. The Illinois Department of Transportation (IDOT) initiated the Emergency Traffic Patrol (ETP) program in Chicago to assist motorists with vehicle trouble in 1963 [1]; and the Minnesota Department of Transportation (MDOT) implemented isolated ramp metering in interstate 35E in 1970 [2]. In the early 1970s, the Washington State Department of Transportation (WSDOT) established a program to encourage ride-sharing and other transportation system management (TSM) measures, such as high-occupancy vehicle (HOV) lanes and park-and-ride lots. Successes in these early projects led to bigger projects that eventually evolved into TMCs. The IDOT Traffic Systems Center in Chicago was formed in the early 1970s; the MDOT Traffic Management Center (TMC) was built in 1972, and the Freeway and Arterial Management Effort (FAME) was established by WSDOT in 1987.

California developed in parallel. In 1971, an experimental closed circuit television (CCTV) project was installed on the San Francisco-Oakland Bay Bridge to reduce detection time for stalls and accidents [3]. When traffic demand continued to increase, an HOV and bus lane was introduced. In 1974, a computer-controlled ramp metering system was devised, one of the first in the US. The Bay Bridge TMC has continued to grow—presently, magnetic vehicle detectors are installed at 1200 foot intervals in each of the bridge's five lanes, and optical sensor detectors at 600 foot intervals, for incident detection. There are plans to further extend the scope of surveillance by installing CCTV along the lower deck of the Bay Bridge.

In Southern California, a three-year federally funded project started a TMC in the Los Angeles area in 1971. Portions of the Santa Monica, San Diego, and Harbor Freeways were electronically monitored via loop detectors, and real-time traffic flow data were transmitted to the TMC. This early program also funded three California Highway Patrol (CHP) helicopters and a freeway service patrol program. Over the years, this TMC has expanded tremendously. To date, the TMC monitors over 340 center-line miles of freeways via more than 20,000 loop detectors and operates over 800 ramp meters [5].

These early successes led to the installation of other TMCs in California. Caltrans currently operates seven TMCs: District 3 (Sacramento), District 4 (the Bay Bridge and Vallejo), District 6 (Fresno), District 7 (Los Angeles), District 8 (San Bernardino), District 11 (San Diego), and District 12 (Santa Ana). A new TMC in Oakland—the Cornerstone Project—is being planned in District 4. Although TMC capabilities vary, most of them focus on surveillance, incident management, and ramp metering.

There are also TMCs operated by city or local governments, which are primarily concerned with arterial traffic surveillance and control. In 1984, the first California city TMC—the Automated Traffic Surveillance and Control (ATSC) System—was established by the Los Angeles Department of Transportation to control arterial traffic during the Olympic Games. The initial installation encompassed 116 intersections and 396 detectors in an area of four square miles. Information was transmitted to the ATSC System for monitoring and generating adaptive signal timing plans [4]. Currently, there are 800 signalized intersections under ATSC control, and there are plans to include all 4,000 signalized intersections in the city by 1998. Favorable evaluation of the ATSC System stimulated similar work in the cities of Anaheim, Irvine, San Diego, and San Jose. To ascertain the conditions of existing TMCs, we visited seven Caltrans

and three city TMCs and interviewed their staffs to assess:
• existing TMC functions
• coordination among TMCs
• coordination with other agencies
• facilities, software and databases, and
• communication media.

Our study indicated that California has made great strides in developing its TMCs, especially through the close coordination of the California Highway Patrol (CHP) and Caltrans. These efforts have laid the groundwork for major advances in traffic management.

Despite these accomplishments, California's TMCs have yet to fulfill their potential as nerve centers for the vast array of traffic management functions. How best to integrate a greater scope of advanced ITS functions into TMC operations is yet to be determined. Long-range vision and cooperative effort are needed to develop California's TMCs into a distributed network of closely coordinated agencies, and to ensure that their talents can be effectively combined.

To support the effort of coordinating and organizing TMCs, we have elsewhere [7] introduced the concept of Computer Integrated Transportation (CIT). We envision an integrated network of public and private transportation organizations, each with

Intellimation
PATH Research Presented

Singapore

The International Conference on Advanced Technologies in Transportation and Traffic Management, organized by the Centre for Transportation Studies, Nanyang Technological University, Singapore, and supported by the Public Works Department, Singapore, and the Institute for Transportation Studies, UC Berkeley, was held May 18-20, 1994, in Singapore. PATH researchers presented the following papers:

Rae-Li Chen and Stephen G. Ritchie, "Neural Network Model for Automated Detection of Lane-Blocking Freeway Incidents."

Sarosh I. Khan and Stephen G. Ritchie, "Incident Detection on Surface Streets Using Artificial Neural Networks."

Asad Khatib, "Advanced Public Transportation Systems: A Taxonomy and Commercial Availability."


Brussels


The Hague


American Control Council

The following research papers from PATH-supported projects were presented at the American Control Council's 1994 meeting in Baltimore June 29-July 1.

W.S. Chen and M. Tomizuka, "Lane Change Maneuver of Autonomous for Automated Highway Systems."

H. A. Pham, J. K. Hedrick, and M. Tomizuka, "Combined Lateral and Longitudinal Control of Vehicles for Intelligent Highway Systems."


Stockholm


VNIIS


International Symposium on Advanced Vehicle Control

Prof. Tomizuka will also present a paper at the 1994 International Symposium on Advanced Vehicle Control, organized by the AVIC '94 Organizing Committee and the Vehicle Motion Control Committee of the Technical Board in JSME (Society of Automotive Engineers of Japan, Inc.). It will be held October 24-28 in Tokyo City, Japan. The paper title will be "Theory and Experiments of Tire Blow-Out Effects and Hazard Reduction Control for Automated Vehicle Lateral Control" which he co-wrote with Sanjay Patwardhan, Wei-Bin Zhang, and Pete Devlin.

American Society of Mechanical Engineers

B. Michael gave an overview of the work performed to date by PATH researchers on "System Safety of Software-Controlled Autonomous Highways" and identified system safety issues in terms of vehicles, roadway infrastructure, command and control, and communications during this April 22 conference. The central theme presented was that determining which of the AHIS subsystems are safety-critical is a difficult task.

CALL for PAPERS

Fourth International Conference on Applications of Advanced Technologies in Transportation Engineering

June 23-26, 1995

Cupri, Italy
Artificial Intelligence Approaches to Rapid Estimation of Network Flow

James E. Moore II
University of Southern California

Predicting transportation network system states for the purpose of comparing alternate network structures and making choices is a key concern of transportation engineers and urban planners. Monitoring trends in transportation systems and investments on transportation systems is a primary goal, and the rapid estimation and prediction of traffic flows is a problem of central importance. Furthermore, the 1989 Loma Prieta and 1994 Northridge earthquakes affected California transportation priorities in ways that made prediction for the sake of network management more important than ever.

Researchers at the University of Southern California have been experimenting for the past five years with artificial intelligence approaches to various transportation modeling problems. The approach appears to be successful in applying versions of artificial intelligence matrices to model traffic flow identification problems, including constrained optimization problems. The research described here relies on associative memory approaches derived from the artificial intelligence field to predict changes in transportation network flows.

A simple synthetic system (summarized in Figure 1) demonstrates the utility of associative memory for estimating transportation flows. The Frank-Wolfe algorithm is executed to generate user equilibrium travel costs and flows.

Caltrans and cooperating agencies are now facing a complicated set of structural retrofit decisions. Retrofit criteria and decision-making procedures have been steadily improving both at the Headquarters and District levels. Unfortunately, it took two major earthquakes to improve decision making at the political level. A considerable amount of traffic data has been generated as a result of the Northridge quake. Obviously, such large scale changes in the state of the network are very rare. Extra traffic counting was done by Caltrans District 7 and the Los Angeles Department of Transportation as part of the effort to define alternate routes and generate alternatives for travel. A unique opportunity now exists to use these traffic counts and travel time estimates to compute associative memory models.


"A highway system is a complex network of vulnerable links. Bridge structures are by far the most critical links because of their vulnerable to damage when subjected to earthquake loads. It is increasingly important to evaluate seismic reliability of the lifetime from a network systems point of view. Each critical element, or bridge, must be considered as part of a global system."

She is correct. A rudimentary version of what Gilbert is suggesting is reflected in Romero's 1994 estimate for the Governor's office of the costs associated with the shutdown of Los Angeles' I-10 freeway following the Northridge quake.

Daily cost of I-10 shutdown

| Value of commuters' delay/day of I-10 closure | $548,918 |
| 287,551 vehicles × 70% × 25 hours/day/vehicle/day | $13.75 wage/hour |
| 25 hours/day/vehicle/day | $55,210 |
| Value of lost work | $79,077 |
| 79,077 vehicles × $1.10/gallon | $1,103,295 |

This is not the entire story. Effects on the remainder of the network are missing. Caltrans existing retrofit criteria, as good as they are, do not treat systems information even at the level presented by Romero. Caltrans uses Average Daily Traffic Counts as a retrofit criteria, but these counts reflect the importance of a given structure only in the context of current system flows. Historical ADT cannot account for flow effects in a disrupted system. An improved traffic network model will make it feasible to anticipate flow effects and combine these effects with existing Caltrans retrofit criteria.
Automated Following in San Diego

(continued from page 1)

achieved solely by the use of appropriate engine commands to generate either accelerating torque or deceleration through compression braking. This constitutes a desirable progression of development by verifying the robustness of the basic control approach prior to adding the complication of brakes. PATH's next major hardware effort involves the design, fabrication and integration of a high-bandwidth brake actuator. At that point we will implement boundary layer switching schemes within the existing control algorithm software to provide stable, conservative braking capability.

While the process of achieving smooth and accurate control is extremely complex, and involves a significant field engineering effort, the basic control concept is straightforward. In controlling a group of cars, one can operate according to a fixed headway strategy, where the time increment between vehicles is set, or alternatively, one in which the following distance is fixed. PATH's work on this strategy: vehicles travel together in a closely spaced group, with the lead car setting the pace and those following working to maintain a precise, precisely defined following distance. This requires real-time information regarding following distance, relative velocity, longitudinal acceleration, throttle position, and also the state of the preceding vehicle.

Through AVCS simulation and theoretical work, control requirements for stability of individual vehicles and strings of vehicles have been defined. Dr. Sei-Hun Choi has developed and implemented a nonlinear sliding control law design in PATH's longitudinal follower software. Dr. Choi uses a highly detailed multi-surface engine map which takes into account manifold gas dynamics into account and ensures smooth overall control. The control scheme is based on the work of Professor Karl Hedrick and student researchers at the UC Berkeley Vehicle Dynamics Laboratory.

Following-distance and relative-velocity data are obtained through the use of separate frequency modulated continuous wave (FM/CW) and pulse Doppler radars operating in the K-band at about 24 GHz. These units were custom-designed and constructed for PATH by O'Connor Engineering of Benicia, California. Joe O'Connor personally assisted in the on-site integration and tuning process to produce functional radar sets within a short span of time. The relatively simple analog approach provides 0.3 m resolution between 1.5 and 50 m range. PATH elected to purchase radar and perform signal processing in our software package. Since radar raw output is inherently noisy due to quantization, glint, crosstalk, clutter, and many other effects, some form of processing is necessary. Dr. Choi experimented with several methods, such as Kalman filtering, before deciding on an adaptive data fusion approach utilizing relative velocity data to estimate distance measurements. The resulting observer delivers the advantages of an extremely low-pass filter but avoids the phase lag problems associated with such approaches. The observer values provide the primary data input for the control software.

Strong stability, which is essential to successful close following, can be ensured through feedforward control whereby velocity and acceleration information from the lead vehicle is relayed via data link to all followers. A tone ring communications system based on the work of Professor Pravin Varaiya and his student William Li was selected for the test program. Proxin spread-spectrum radio transceivers broadcasting at 902-928 MHz provide a 128 kbps data rate and deliver updates every 50 msec. An intelligent radio interface card featuring a 10 MIPs 80186 processor running embedded firmware allows the Proxin radio to be controlled by the vehicle computer.

Data from the engine management system, transmission, ABS, accelerometers, and ranging sensors are channeled into the vehicle computer at 80,000 based industrial PC running at 33 MHz. This machine features an ISA bus, 8 MB memory, and real-time operating system from QNX Software Systems Limited.

Software engineer Leon Chen of the PATH research staff selected QNX after an appraisal process and implemented it in all test vehicles. The operating system provides a Unix model tasking and development environment including a POSIX-compliant microkernel with networking support. Software developed by PATH includes device drivers that provide analog and digital I/O capabilities, hardware timing, and token ring communications. Higher level program modules support the sliding mode engine control task, supervisory velocity tracking, and a server that provides interprocess communications and data interchange between computer programs. Many integration issues were encountered by the engineers during the course of development. Working closely with Sei-Hun Choi over a period of months, Leon incorporated hundreds of modifications to the PATH software to improve reliability and performance.

All hardware on the project was the responsibility of PATH's mechanical engineer Peter Devlin who, along with technician Eric Johnson, integrated each subsystem into the test cars at the Richmond Field Station. The cars feature 110VAC power, cooling for the vehicle computer, throttle actuators via a laboratory stepper motor, and many other modifications. Mr. Devlin selected Superior Electric stepper motors, which resist the high-temperature under-hood environment and deliver 1000 steps/second with resolution of 0.9°/step. He also developed a successful ultrasonic ranging sensor based on Polaroid components. These devices are 3-in. round on all cars and used to calibrate the radar measurements. PATH has concluded evaluation of these devices, noting that the sonar also functions at speed, suggesting that ultrasonic ranging approaches might prove feasible.

The four month longitudinal test series was directed by the author, who provided system engineering support and test planning, and investigated all aspects of test safety, assisted by test engineer Ramji Narendran, a PATH controls researcher.
The Demonstration

PATH's demonstration consisted of two traversals of the eight-mile-long I-15 HOV lanes, first southbound and then northbound. The south and tournamendt afforded the chance for riders to change places and test the ride in another car.

The driving profile included a mixture of steady cruising and speed-change maneuvers. Since the experimental vehicles are not yet equipped with automatic brake actuation, speed was controlled by use of the throttle alone. This means that deceleration was limited to that provided by aerodynamic drag and engine braking. The speed of the lead car was governed by a predefined profile stored in its control computer.

The test started with the cars under manual control. At 45 mph, at the bottom of the 3% grade, the lead car switched into automatic throttle control mode, followed by cars 2, 3, and 4 in turn. The group accelerated to 65 mph while climbing the moderate hill, then cruised at speed for a mile or more. After slowing to 45 mph, the cars began a brisk acceleration to 65 mph while maintaining close spacing. Figure 3 shows typical speed data for all four vehicles; individual speeds are virtually indistinguishable. The ride ended in a reverse of the starting sequence, with Car 4 switching off and manually braking first, followed by the rest.

On the northbound return, similar events were featured, with link-up at 25 mph and the ride ending with a deceleration from 65 to 45 while descending the 3% grade. This maneuver represents the approximate limit of deceleration capability using aerodynamic drag and engine braking alone. PATH-sponsored aerodynamic research predicts that vehicles traveling in close proximity to one another derive significant benefits in drag reduction and improved fuel economy. This aerodynamic phenomenon is seen in our test cars, which slow only gradually when coasting.

The desired following distance was set at 4 meters or about 13 feet. This distance was selected to provide passengers with some sensation of short-headway vehicle following, while remaining well within the capabilities of the technology implemented on the test vehicle. Figure 2 shows all of the vehicles maintained that spacing with considerable accuracy, with nominal deviation of less than 0.25 m. At 65 mph, this spacing corresponds to a headway of about 0.3 seconds.

The PATH demonstration cars are research tools, not intended for use by the general public. The success of the tests and demonstrations is dependent upon the knowledge and experience of test drivers Baytinger, Chen, Devlin, Johnson and Narenzand. The drivers are responsible for steering the cars and for transferring control to and from the automatic mode at the correct times and within the hand-over limits imposed by the vehicle follow-up system. They must also be able to detect any anomalies and the machine's performance, so that if necessary, they can safely terminate a run. They maintain voice control to notify each other of any problems and to coordinate transitions to and from automatic control. At PATH's systems mature, extensive experiments will be conducted at shorter spacing to evaluate the associated engineering issues. Further refinement should make the transition between manual and automatic modes simple, seamless and transparent, requiring no special expertise or training. Through development can provide the user-friendly features expected of a consumer product while ensuring reliability and safety even in the event of abnormal operating conditions.

These interdisciplinary seminars are usually held every Wednesday at noon in 3110 Etcheverry Hall on the UC Berkeley campus. For an invitation, please contact Mireille Breuksch, mire@robotics.eecs.berkeley.edu. PATH seminar announcements are available on the PATH Mosaic homepage, which can be accessed via Mosaic by entering the URL http://www-path.eecs.berkeley.edu/5000/ or by clicking on Robotics Related Sites on the UC Berkeley home page.

Intelligent Sensor Validation, Sensor Fusion, Fault Diagnosis, and Optimal Decision Making using Uncertainty for Reliability and Safety Enhancement applied to Vehicle Control Framework

Prof. A. Agogino, Kai Goebel and Satnam Alag
Mechanical Engineering, UC Berkeley
July 20

In order to perform its basic functions (longitudinal control, lateral control, platooning, and such maneuvering techniques as lane changing or exiting the automated lane), an Intelligent Transportation System (ITS) requires a large number of sensors for control at the platoon level, engine level, and for sensing and communication between the vehicles and the ITS main controller. For all subsystems to work well and reliably the ITS requires high sensor data fidelity.

Generally, however, sensor readings are uncertain, and deterministic relationships between the sensor readings and the system being monitored do not exist. Our project aims at accounting for sources of uncertainty and propagating them to the final diagnosis of the system state. An inconsistent sensor reading could be a result of a system or a process failure, and it is important to distinguish between these types of failure. In either case it is important to be able to implement alternative policies in real-time to handle unexpected situations or maximize the overall safety and reliability of the ITS system.

This talk outlined our methodology for addressing the above issues. We have a hierarchical structure consisting of intelligent sensor validation and sensor fusion techniques at the regulation layer. Based on the results of the sensor validation and fusion, fault diagnosis of the vehicle state is carried out. All these are used via an intelligent decision advisor to forecast potential hazards and provide recommendations to the platoon level and the regulation layer controller on potential maneuvers and other actions.

The Dynamics of Braking in an ITS Environment

Chris Gerdes and Prof. J.K. Hedrick
Vehicular Dynamics Lab
Mechanical Engineering, UC Berkeley
August 3

Central to the concept of platooning is the reliable ability to stop them. Limit, or emergency, braking maneuvers dictate safe spacing distances, whereas the ability to track, control braking profiles determines spacing errors and passenger comfort. The demands of limit braking and vehicle following on the hardware, however, differ not only from each other but also from the demands placed by a human driver. Starting from some qualitative objective that a braking system must meet in terms of equi-optimality maneuvers, vehicle following, passenger comfort, and ease of implementation, this talk addressed the mechanics of braking in an ITS context. Limit braking is tied to such factors as the tire-road interface, the vehicle's braking efficiency, and the dynamic response of the actuator/breaking system. Of those, most are dictated by external factors, leaving only the actuation and brake system at the discretion of the designer.
unique responsibilities, working toward a common goal of facilitating travel across all modes of transportation. The mission is to achieve effective coordination of the overall transportation system while respecting the individual responsibilities of participating agencies. To this end, we organized a series of focus group sessions, in which strategies for GIF were presented to TMC managers and staff for their comment and discussion. Afterward, a follow-up survey was administered at each TMC, to assess future directions for California TMCs.

Throughout the study, we encountered considerable enthusiasm for Intelligent Transportation Systems (ITS). Participants were nearly unanimous in their belief that ITS has improved their working relationships with other agencies. While they generally felt that a centrally organized organizational structure was more practical, participants agreed that leadership-based structures might be viable in the future, provided that the benefits could be demonstrated. In most cases, participants felt that new ITS systems should be aligned along the lines of current agency responsibilities. With respect to internal organization, the ultimate structure would depend on costs analyses and technical feasibility, and not so much on institutional considerations.

Despite enthusiasm for ITS, significant obstacles lie ahead. Participants were worried about the ability to fund and maintain ITS. They were worried that parochial interests might stand in the way of improved coordination. They were worried that some agencies were not sufficiently supportive of innovation and change. And they were concerned that the benefits of ITS might not be documented, which could stand in the way of future deployments.

Although participants focused on the deployment of ITS, their comments are also relevant to ITS research. Overall, we observed that the following factors have profound implications for ITS implementation and research. Each demands careful deliberation at a strategic level, and possibly changes both in how transportation agencies are organized and how they relate to each other.

**Timeline**—Nearly across the board, participants focused on short-range applications of ITS, mostly in the time frame of five years or less.

**Coordination**—Transportation management requires the coordinated effort of multiple agencies, and multiple decisions within agencies. Unfortunately, it appears that some of these organizations suffer from divided responsibilities. Information is not necessarily linked to actions.

**Broadcast Orientation**—ITS, as they exist today, disseminate information via broadcast technologies (changeable message signs, radio stations, etc.), and collect information in aggregate (mostly via loop detectors). ITS presents the opportunity for targeting information collection and dissemination to individual vehicles, drivers, or travelers. Evolution from a broadcast orientation to a "narrowcast" orientation is a major challenge.

**New Technologies**—While all participants were enthusiastic toward ITS within the context of their current functions, there was some hesitation about expanding their functions.

**Mutual Interest**—If ITS are truly to fulfill the mission of enhancing mode transitions, the needs and interests of the various involved parties should be understood and appropriately incorporated.

**Cooperation**—There is no established mechanism or channel for building cooperation. Each joint effort is established on a case-by-case basis, and often demands great leadership and political will to overcome the institutional barriers. A mechanism, incentive, or catalyst is needed to encourage cooperation.

A continuation of this project, which is now underway, will focus on non-automobile TMCs and supporting agencies. The goal will be to identify ways to coordinate transportation across all agencies involved in transportation, within the framework of Computer Integrated Transportation, and to identify a preferred organizational structure.

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**References**


For further information see PATH Working Paper UCB-ITS-PPP-93-17.

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**Visitor to PATH Headquarters**

Joaocht Nicolai, Head of the Traffic and Transportation Systems Department of Daimler-Benz AG (Berlin), who is currently researching road and rail traffic trends in the US, visited PATH on September 26. He discussed traffic safety, ATMS, and other PATH activities with researchers Bruce Hongolf, Jean-Luc Yeguace, Bret Michael, Mark Miller, and Y-B Tin.
PATH on Paper

Below is an update on some recent PATH publications:
A price list that includes research reports, working papers, technical memoranda, and technical notes can be obtained from the Institute of Transportation Studies Publications Office, University of California, 109 McLaughlin Hall, Berkeley, CA 94720.
510-642-3538, Fax: 510-642-1246

PATH Research Reports

UCB/ITS/PRR/94/17 Fault Detection and Avoidance Control for Competitive Guidance of Vehicles in Automated Highways. Sanyi Wang, North Carolina State University, August 1994, $5.00

UCB/ITS/PRR/94/18 Improving Transit Performance with Advanced Public Transportation System Technologies. Hank Heinen, Abraham Ouedraogo, Daniel Pydovitch, August 1994, $5.00

UCB/ITS/PRR/94/19 An Assessment of RWS/ATS Technology Impacts on Energy Consumption and Vehicle Emissions of Transit Bus Fleets. Sylvain C. Allard, Jr., AIAA Airline, August 1994, $5.00

PATH Working Papers


UCB/ITS/PRR/94/12 The Optimal Transmission Model: Network Traffic. Carlos F. Ojeda, August 1994, $5.00

UCB/ITS/PRR/94/13 Single Channel RWS Communication Architecture. Jean-Paul A. V. Labe, September 1994, $7.00

UCB/ITS/PRR/94/14 Simulation Modeling of the South Texas Freeway. Samuel E. Brown, David W. Brown, and David A. May, September 1994, $13.00

UCB/ITS/PRR/94/15 Vehicle Longitudinal Control for the CAT, S. Y. Kim, October 1994

PATH Technical Notes

Tech Note 9401 Council of Disruptive Events Systems in Temporal Logic. Ashok Deshpande, Prasoon V. V. T. V. August 1994, $7.00

Tech Note 9405 Current Control and Safety Measures in Temporal Logic. Ashok Deshpande, Prasoon V. V. T. V. August 1994, $5.00

Tech Note 9406 Concept of an Advanced Two-way Communications System for the New Region of the Fuji Region. R. H. Heineke, Harder A. M. Bier (University of Central Florida), Randolph W. Hall (University of Southern California), September 1994, $5.00

PATH Seminars

continued from page 11

These components are furthermore shown to be the determinants of a vehicle's ability to simultaneously maintain close spacings and passenger comfort. The model of brake dynamics developed at U.C. Berkeley and the current method of brake actuation were discussed in terms of this model. Severe limitations, imposed by the inclusion of the vehicle's vacuum assist unit, were discussed with this approach.

Such limitations seem paradoxical in light of the fact that humans drive cars every day and seem to control them quite adequately. To resolve this point, human driver behavior is discussed briefly and contrasted with the needs of autonomous vehicle operation. Each control limitation found in the vacuum assist is paired with a biological reason why humans either fail to notice or, in some cases, require such limits.

The seminar concluded with a look at a proposed method for brake actuation and the future direction of brake research in the Vehicle Dynamics Lab.


Bret Michael

Associate Research Engineer, PATH

August 31

Dr. Michael introduced a methodology for assessing the performance of safety-critical automotive vehicle-control system software. The methodology is based on three elements: (i) formal system analysis and decomposition, (ii) directed Monte Carlo testing, and (iii) statistical analysis of the results. By applying this methodology to PATH's experimental, fully automated, cooperative system for lateral vehicle control, an estimate of system performance under a wide variety of conditions is obtained. Researchers concluded that the test strategy used was shown to be effective for finding anomalies or incorrect system behavior. An experiment in progress, involving the use of formal methods to direct the restructuring and decomposition of the PATH experimental vehicle-control system software, was also briefly discussed. This work is being conducted in collaboration with Dr. Andrew Sagal of EES, Sunnyvale, CA.

Vehicle Longitudinal Control Using an Adaptive Observer for Automated Highway Systems

Sei-Bum Choi

PATH visiting post-doctoral student

September 14

Dr. Choi summarized data fusion, controller design and experimental work done recently for the longitudinal control of a platoon of autonomous vehicles. Alternative sub-models of an engine and a transaxle were used to achieve the goals of precise speed control with smooth ride quality. Researchers have developed adaptive observers to estimate vehicle-to-vehicle spacing and closing rate. The estimated values are used in a sliding mode based controller. The developed control strategies have been implemented on the test vehicles and four-vehicle control has been performed, a major step towards highway speed profiles using throttle position control alone.

Ranging Sensor Specification for Longitudinal Control

Bill David

PATH Senior Development Engineer

September 21

This talk covered the performance requirements and design characteristics of a ranging sensor for longitudinal control, and specifically how these numerous requirements translate into an engineering specification. The development and availability of a clear and unambiguous specification is vital to the success of the ranging sensor as a practical system for longitudinal control. The presentation gave participants an understanding of the relationships between the various sensor system parameters and an overall background that can be used in sensor selection.
Coming Soon...

Report on PATH Program-wide Research Meeting

Transportation Modeling for the Environment

Testing New Lateral Control Software

AHS Initial Deployment

PATH's Role in Federal Systems Architecture Program

Silicon Microsensors for AHS

... and more!

Intellimation is a quarterly newsletter edited and designed by the California PATH Publications Department. For more information or comments about this newsletter, please write, call, fax, or e-mail the address below.

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