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Transportation Secretary Visits PATH – "Great Ride" in Platoon Car

California's Secretary of Business, Transportation, and Housing, the Honorable Dean Dunphy, toured PATH's research facilities on the UC Berkeley campus and the Richmond Field Station on April 13, and personally tested PATH's longitudinal control cars by riding in one at freeway speeds on San Diego's Harbor Freeway on April 28. "Thanks for a great ride,"

for New Technology and Research John West, and Caltrans Chief, ATMIS and Systems Planning, Division of New Technology & Research Pat Conroy. Over a working lunch in Cory Hall, Dean David Hodges of the College of Engineering described the unique interdisciplinary nature of PATH research, and PATH Director Pravin Varaiya discussed PATH's accomplishments, plans, and goals, relating them to the national AHS development.



PATH Director Pravin Varaiya and the Hon. Dean Dunphy

After lunch, the Secretary and his entourage were given a demonstration of SmartPath computer-generated animation of AHS scenarios by researcher Farokh Eskafi, and a walk-through of the PATH electronic lab by researcher Bret Foreman and Professors Karl Hedrick's and Masayoshi Tomizuka's graduate students. After travelling to the Field Station, Professor Hedrick discussed PATH

he told test driver Scott Baysinger. Asked if he was nervous going 90kph (65mph) in a car controlled by a computer, sandwiched between two other computer-controlled cars four meters (13 feet) away, Dunphy replied "No, it's very smooth."

During his visit to Berkeley and Richmond, the Secretary was accompanied by Business, Transportation, and Housing Agency Undersecretary Jeff Reid, Assistant Secretary of Public Affairs Julie Stewart, and Special Assistant Ian Corrine; Caltrans Chief Deputy Director Andrew Poat, Caltrans Deputy Director for Maintenance and Operations Lee Deter, Caltrans Program Manager

experiments using magnetic markers for vehicle maneuvering control, and the visitors saw an electronically controlled tire-burst demonstration. They then took test rides on the RFS test track in both the longitudinal-control and lateral-control cars.

Participants agreed that the show and tell went off without a hitch, both in the Bay Area and San Diego. John West and Lee Deter of Caltrans told Director Varaiya that "it could not have been better," and the Secretary himself said he was very impressed.



**FAST – Freeway Automatic Shuttle Travel****Proposal for a First Evolutionary Step toward an Automated Highway System****H.-S. Jacob Tsao**
PATH

The impetus toward highway automation has so far come primarily from the immediate need to alleviate congestion on freeways by providing more highway capacity for cars. Of course, an automated highway system (AHS) designed to serve automobiles as its primary customers is by no means the only one. Other possible systems include a transit-oriented AHS, as well as systems designed to accommodate multiple major user groups. This article proposes a freeway van shuttle service, which we will call Freeway Automatic Shuttle Travel, or FAST, as the first step toward an AHS: that is, as the first service to feature fully automated hands-off feet-off freeway driving.

Such a service could further technological development of AHS and capture considerable public interest. It would be an excellent candidate for the 1997 AHS demonstration required by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and has a good chance of leading to a successful long-term AHS deployment supported by the general public.

The appeal of automated highway systems (AHS) lies in their potential for large improvements in highway capacity and safety without the need for significant right-of-way acquisitions. Operation on a freeway type of roadway has been assumed. Recently, Bishop et al. [1994] argued for the necessity to include the movement of people, as opposed to just vehicles (in terms of number of passing vehicles per lane per hour), as an additional performance objective for AHS. But such discussions are nothing but intellectual exercises unless the issue of how today's highway systems can evolve, in a planned and managed fashion, into mature AHS is also addressed.

Constraints on AHS Development

Several constraints dictate the gradual evolution of any automated highway system. The technology itself will mature gradually, and early automated vehicles may require that drivers undergo special training. The high costs of early vehicles will preclude their rapid deployment. The modification of existing infrastructure will be time-consuming. Finally, the commitment of automakers to manufacture and service automated vehicles, of the insurance industry to carry liability for them, and of the general public and special-interest groups to buy and travel in them, will all be gradual.

Technological Maturation

As has been the case with other developing technologies, vehicle automation, as well as the associated manufacturing and maintenance technologies will mature gradually. To ensure safe automated driving, automation-equipped vehicles may need to be inspected rigorously, perhaps even at onramps, and maintained frequently. This could be a disincentive for individuals to purchase a car with automation features. Such maintenance could, however be done more easily by a fleet operator with maintenance facilities.

Changed Driver Role

Resuming manual control of the vehicle after a period of fully automated driving will be a new task for drivers. Drivers may also need to actively monitor the operation of the automated vehicle. In the event of a system or other failure, they may have to take manual control of their vehicles for safety, especially during the early stages when automation technologies have not yet been perfected. Emergency handling could also be part of the new driver role.

These new roles may necessitate additional driver training, which may also disincline individual car owners to purchase automation options. It may even be possible that only trained professionals, e.g. professional drivers with special certification, would be qualified to take vehicles on an AHS during the early stages.

Vehicle Cost

Like most other products employing new and sophisticated technologies, e.g. computers, early automation-equipped vehicles will be expensive to purchase and to maintain. The high cost of such vehicles may hinder market penetration if individual car owners are the targeted purchasers. Such costs can more easily be absorbed by fleet operators, public or private. Only a small fraction would thus be passed onto individual travelers.

modification can be completed for automated driving from any entry point on an urban freeway network to another. Individual car purchasers may then be enticed to select an automation option.

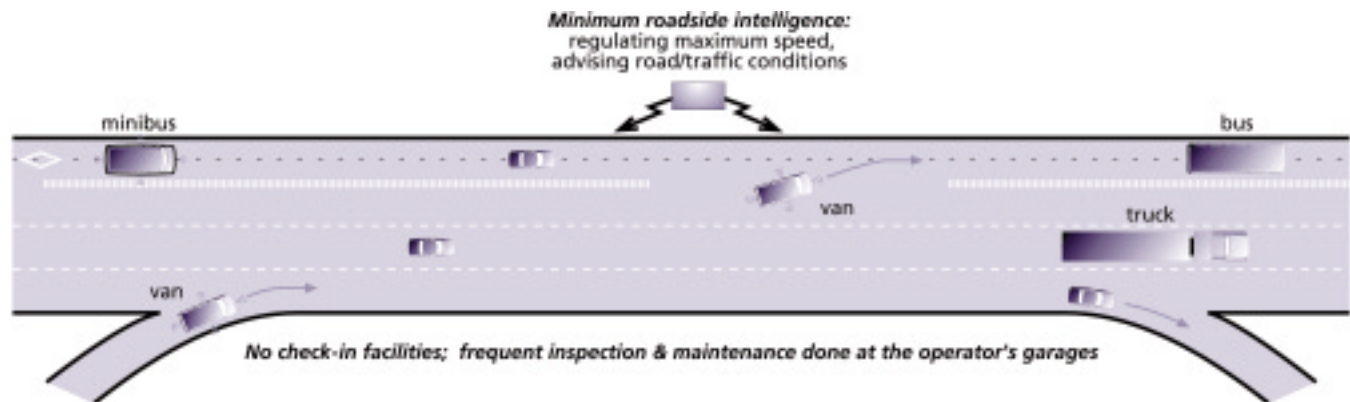
Auto Industry Commitment

Automakers will not commit their resources to making and servicing automation-equipped vehicles unless there is a profit to be made. They may prefer to enter the business of making automation-equipped vehicles with a small but certain niche rather than a larger but very uncertain one.

Insurance Industry Commitment

In many states, all vehicles are now legally required to carry liability insurance. This requirement will most likely remain or become more stringent after AHS development. The interest and attitude of the

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Infrastructure Modification

Some infrastructure modifications will likely be necessary for any AHS. Some roadside intelligence may also be required. If check-in at the onramp is necessary, additional land at highway-to-street intersections may be needed. Additional automated connector ramps will certainly be needed to provide continuous automated driving from one freeway to another. A likely scenario is the modification of infrastructure as demand warrants – in particular, to enable automated driving from one point on the freeway to another. Note that a modified point-to-point segment can be the freeway portion of a fixed popular route. Over time, infrastructure

FAST Shuttles Enter and Leave Freeway under Manual Control: Automatic Control Takes over on HOV Lane

LEGEND

- “waves” indicate FAST vehicles
- outlined minibus is automatically driven (hands-off, feet-off)
- zigzag arrows indicate communication direction
- dots at lane center indicate lane markers
- HOV lane is separated from general-access lanes by conspicuous markings (not physical barriers)
- Straight and curved arrows indicate direction of motion



PATH Research Presented

Below is a list of some of the conferences or workshops where PATH sponsored research was or will be presented.

American Automatic Control Council Seattle, WA, June 21-23, 1995

- Wonshik Chee, Masayoshi Tomizuka, Wei-Bin Zhang, and Satyajit Patwardhan from UC Berkeley "Experimental Study of Lane Change Maneuver for AHS Applications".
- Perry Li, Roberto Horowitz, Luis Alvarez, and Anne Robertson from UC Berkeley "Traffic Flow Stabilization".
- David Love, Masayoshi Tomizuka and H-C Lee from UC Berkeley "Longitudinal Maneuvering Control for Automated Highway Systems Based on a Magnetic Reference/Sensing System".
- J. Christian Gerdes and J. Karl Hedrick from UC Berkeley "Brake System Requirements for Platooning on an Automated Highway".
- Chien Chen and Masayoshi Tomizuka from UC Berkeley "Dynamic Modeling of Articulated Vehicles for Automated Highway Systems".
- Chien Chen and Masayoshi Tomizuka from UC Berkeley "Steering and Braking Control of Tractor-semi-trailer Vehicles in Automated Highway Systems".
- Jonathan Frankel, Luis Alvarez, Roberto Horowitz and Perry Li from UC Berkeley "Safety-oriented Maneuver for IVHS".
- Mooncheol Won and Sei-Bum Choi from UC Berkeley "Air Fuel Ratio Control of Automobiles Engine using Observer Based Sliding Mode Control and Gaussian Neural Networks".
- C.C. Chien and Youping Zhang from the University of Southern California "Autonomous Intelligent Cruise Control using Both Front and Back Information for Tight Vehicle Following Maneuvers".
- Diana Yanakiev and Ioannis Kanellakopoulos from UC Los Angeles "Longitudinal Control of Heavy-Duty Vehicles for Automated Highway Systems".
- Sei-Bum Choi and J. Karl Hedrick from UC Berkeley "Vehicle Longitudinal Control using an Adaptive Observer for Automated Highway Systems".
- Dattaprabodh Godbole, Farokh Eskafi, Ekta Singh, and Pravin Varaiya from UC Berkeley "Design of Entry and Exit Maneuvers of IVHS".
- John Lygeros and Dattaprabodh Godbole from UC Berkeley and PATH researcher Mireille Broucke "Design of an Extended Architecture for Degraded Modes of Operation of IVHS".
- Anuj Puri and Pravin Varaiya of UC Berkeley "Driving Safely in Smart Cars".
- Ching-Yao Chan of UC Berkeley "Open-loop Trajectory Design for Longitudinal Vehicle Maneuvers: Case Studies with Design Constraints".
- PATH researcher J. Karl Hedrick will cochair, with Alex Alexandridis from General Motors, the Friday morning session on Cruise Control.
- PATH researcher Steve Shladover will cochair, with Davor Hrovat from Ford Motor Company, the Friday midday session on IVHS III.

ITS AMERICA

Washington, D.C., March 15-17, 1995

Along with a combined Caltrans booth featuring PATH, Southern California ATMIS Testbed (UC Irvine, Cal Poly San Luis Obispo) and Caltrans' Smart Traveler Kiosk, the following PATH sponsored research was presented.

- PATH researcher Mark Miller "Report on Research on Societal Implications by AHS Pre-Cursor Teams".
- UC Davis ITS researchers Prasuna Reddy, Paul Jovanis and Ryuichi Kitamura "Advanced Interfaces for a Multi-Optional Real-Time Ride Share System".
- UC Davis ITS researchers Prasuna Reddy, Kenneth Vaughn, Mohammed Abdel-Aty, Ryuichi Kitamura and Paul Jovanis "Design of a Recurrent Neural Network for Analyzing Route Choice Behavior in the Presence of an Information System".
- UC Davis ITS researcher Mohammed Abdel-Aty "Understanding the Effect of ATIS on Commuters' Route Choice Decisions".
- PATH Deputy Director Steven Shladover "Highway Automation Using Platoons".
- PATH researcher Sei-Bum Choi and Professor J.K. Hedrick "Comparison of Engine Models and Distance Sensors for Vehicle Longitudinal Control: Analysis and Test Results in PATH".
- Professor Alice Agogino, Kai Goebel and Satnam Alag of UC Berkeley "A Framework for Intelligent Sensor Validation, Sensor Fusion and Supervisory Control of Automated Vehicles in IVHS".

- Hong Lo, Mark Hickman and Stein Weissenberger from PATH, Bin Ran from the Massachusetts Institute of Technology, and Jim Larson from Rockwell International "Route Planning and Guidance: Potential Benefits and Implications for Public-Private Partnerships".
- PATH researcher Mark Miller "An Examination of Environmental Issues Associated with Automated Highway Systems".
- Professor Matthew Barth from UC Riverside "Automated Highway System (AHS) Vehicle Emissions: Preliminary Analysis".
- UC Irvine graduate student Stefano Stefan "Intelligent Transportation Systems: Technology Assessment and Directions for Social Science Research".
- Steven Shladover, PATH Deputy Director, presided over the AHS Issues session.
- Graduate student Jie Yu and Athanasios Sideris both from UC Irvine "Combined Vehicle Motion Control—A Gain Scheduling Approach".
- Bin Ran from the Massachusetts Institute of Technology and PATH researcher H.-S. Jacob Tsao "Toward a Macroscopic Formulation Approach for Dynamic Traffic Flow on an AHS".
- PATH researchers Youngbin Yim and Mark Miller, and ITS researchers Paul Hellman and Mohammad Sharafsaleh "Infrastructure Deployment Issues Associated with Automated Highway Systems in Urban Areas".
- PATH Program Manager Stein Weissenberger headed the session "Field Operational Test and Their Evaluations: A View from the Trenches" in which PATH researcher Youngbin Yim participated.
- "Estimates of Fuel Savings from Platooning" by M. Zabat, N. Stabile, and F. Browand was published in the proceedings.



UC Berkeley Industrial Liaison Program March 9, 1995

Mark Hickman presented "A Comparable Systems Analysis of San Francisco's BART: Lessons for Automated Highway Systems"

1995 Geographic Information Systems in Transportation (GIS-T) Symposium

Reno, Nevada, April 2-5, 1995

Mark Hickman presented "Organization and Use of Spatial Data at California Transit Agencies".

ASCE First Congress on Computing in Civil Engineering

Washington D.C., June 1994

M. Abdel-Aty. "Studying Route Choice Behavior Using Computer Aided Telephone Interviews and GIS".

5th National Transportation Planning Methods Application Conference

Seattle, April 1995

Mohammed Abdel-Aty. "A New Approach To Route Choice Data Collection: Multi-phase, CATI Panel Surveys Using A GIS Database".

International Ergonomics Association (12th Triennial Congress)

Toronto, Canada,

August 15-19, 1994

"Simulation Tests of Driving Performance with Selected Route

Guidance Devices" presented by Raghavan Srinivasan.

Applications of Transport Telematics and IVHS (First World Congress)

Paris, France, Nov. 30-Dec. 3, 1994

"Effect of In-Vehicle Driver Information Systems on Driving Performance: Simulation Studies" presented by Paul Jovanis.

6th IEEE International Symposium on "Personal, Indoor and Mobile Radio Communications" (PIMRC '95)

Andreas Polydoros, Prokopios Panagiotou, Achilles Asastasopoulos, Te-Kai Liu, Chung-Ming Sun, and Ramez Gerges, "Integrated-Layer Packet Radio Study for AHS".

at left

*PATH researchers,
Mark Hickman
and James Bret
Michael, at ITS
America*

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Conferences

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3rd IEEE Mediterranean Symposium on "New Directions in Control and Automation"

Andreas Polydoros, Prokopios Panagiotou, Achilles Asastasopoulos, Te-Kai Liu, Chung-Ming Sun, and Ramez Gerges. "Communication Technologies for AHS".

Colloquium on Investigating the Transit Needs of a Non-Driving Disabled Population

The University of Michigan, March 17, 1995
Professor Reginald G. Golledge of UCSB's Department of Geography presented "GPS, GIS, and PGS: Assistive Technology to Enhance Navigation and Mobility Skills of Non-driving Disabled Populations".

University of New South Wales

Australia, April 13, 1995
Professor Reginald G. Golledge. "Assistive Technology as a Mobility Aid for Blind People".

Annual Meeting of the Association of American Geographers

Chicago, Illinois, March 16, 1995
Professor Reginald G. Golledge. "Disability, Barriers, and Transportation".

Society of Automotive Engineers (SAE) International Congress

Detroit, Michigan, Feb. 27- Mar. 2, 1995
Mike Zabat of USC presented "Drag Forces Experienced by 2, 3, and 4-Vehicle Platoons at Close Spacings" co-authored by M. Zabat, N. Stabile, S. Frascaroli, and F. Browand.

ASME Winter Annual Meeting 1995

San Francisco, CA
W. Chee, M. Tomizuka, S. Patwardhan, and W. Zhang. "Lane Change Maneuvers for Automated Highway Systems: Control, Estimation Algorithms and Preliminary Study".

Northwestern University Transportation Center and Dept. of Economics

Evanston, Illinois, Nov. 17, 1994
Kenneth A. Small of UC Irvine presented "A Discrete Choice Simulation Model of Urban Highway Congestion Incorporating Travel Reliability".

Annual Meeting of the Regional Science Association International

Niagara Falls, Ontario, Nov. 18-19, 1994
Pia Maria Koskonoja of UC Irvine presented "Socio-Economic Attributes of Commuters and Unreliable Commuting Time".
Kenneth A. Small and Robert B. Noland presented "A Discrete Choice Simulation Model of Urban Highway Congestion Incorporating Travel Reliability".

Western Regional Science Association Conference

San Diego, CA, February 1995
Robert B. Noland of UC Irvine presented "Commuter Responses to Travel Time Uncertainty Under Congested Conditions: Expected Cost, Information, and Flexible Scheduling".

UC Irvine's Institute of Transportation Studies

May 1995
Robert B. Noland of UC Irvine will present "Commuter Responses to Travel Time Uncertainty".

Intelligent Transportation Systems and the National Information Infrastructure

Harvard, Kennedy School of Government, July 13, 1995
Randolph Hall "Public and Private Roles in the Delivery of Travel Information".

Workshop on Operations and Management of Information Networks

National Institute of Standards and Technology, Gaithersburg, Maryland, April 11-12, 1995
PATH researcher Bret Michael was one of five panelists to discuss issues regarding the integration of network management services.

Automated Highway System Performance Objectives and Characteristics Workshop

Fort Lauderdale, FL, April 12-13, 1995

PATH attendees included Steven Shladover, Wei-Bin Zhang, Mark Miller, Jacob Tsao, and Bret Michael. The purpose of the workshop was to obtain feedback from stakeholders on the draft document titled "Automated Highway System (AHS): System Objectives and Characteristics."

ISSCC

San Francisco, CA, February 1995

UC Berkeley researchers C. Lu, B.E. Boser, and M. Lemkin "A Monolithic Surface Micromachined Accelerometer with Digital Output".

Japan Society for the Promotion of Science

UC Berkeley ITS Director Adib Kanafani gave two seminars on IVHS development and on the PATH Program in Japan. At the University of Kyoto, Prof. Kanafani presented "Recent Developments and Issues in IVHS", and at the University of Tottori, he presented "On the Economics of Traffic Information Systems".

Thurgood Marshall Academic High School

On Friday March 17, Mireille Broucke spoke in San Francisco for the opening ceremony of the San Francisco school district's project entitled "Housing and Transportation for the Bay Area in the Year 2020".

First IFAC (International Federation of Automatic Control) Workshop on "Advances in Automotive Control"

March 13-17, 1995, Ascona, Switzerland

Prof. Karl Hedrick gave a talk on "Vehicle Control Issues in Automated Highway Systems" and a summary of his work in the "Vehicle Dynamics Laboratory".

Transportation Science Section Meeting of the Institute For Operations Research and Management Science (INFORMS)

Los Angeles CA, April 1995

Jim Moore from USC presented his research on "Artificial Intelligence Approaches to Rapid Estimation of Network Flow".



PATH on Video

Camera crews from various TV news and documentary outfits have been taping sporadically at the Richmond Field Station for months, and their footage is beginning to show up on TV.

PATH research efforts have been featured in three documentaries broadcast recently:

CNN's *Future Watch*, which aired on April 4, included footage of the platoon cars in San Diego.

PBS's *Future Quest*, shown locally on April 25, and narrated by Jeff Goldblum, whose role as a mathematician in *Jurassic Park* seems to have qualified him as a commentator on technological trends, featured interviews with Director Varaiya, Program Director Steven Shladover, researchers Wei-bin Zhang, Delnaz Khorramabadi, and former researcher Bobby Rao; SmartPATH animation; and lateral car footage.

Future Transportation, shown on Japanese television, focused on ITS, but also showed interviews with Steven Shladover and researcher Han-shue Tan, plus action shots of the lateral-control car on the RFS test track.



New PATH Test Track Off and Running



Han-shue Tan
PATH



After finishing the first automatic steering experiment on PATH's new test track at Golden Gate Fields race track, PATH engineer Satyajit (Pat) Patwardan and I sat in the test car admiring the view. Imagine: clear sky with a few white clouds, blue ocean with a little breeze, the Golden Gate Bridge on the horizon, and San Francisco as a background—it would be hard to find a more beautiful place to conduct vehicle experiments. We had been working on this project since last August, and a month before we had spent day after day on our knees in the rain, checking and rechecking and re-rechecking the magnetic polarity of every one of 923 markers. Now, after lots of work, lots of luck, and lots of help, we finally had the new test track PATH has needed for years.

During the past several years, PATH engineers have been conducting a variety of experiments on advanced automatic vehicle control systems using a short test track at the Richmond Field Station. We have been implementing new sys-

tem concepts, validating analytical results, and giving demonstrations to visitors from federal, state, and foreign governments, from private industry, and from other universities. We have successfully implemented and demonstrated a lateral control system based on magnetic marker reference/sensing systems and have achieved significant experimental results. But the restricted geometric boundaries of the Richmond track make it difficult to perform such advanced vehicle lateral control experiments as high speed lane-keeping control, lane-change maneuvers, and tire-burst control, as well as integration of lateral and longitudinal controls. With fences a few feet away from the test vehicle, it is virtually impossible to safely explore the performance and robustness limits of the designed systems. A longer track was needed, with the safety space necessary for conducting lateral experiments, and a second lane for lane-change maneuvers, in a convenient location for logistic support.



at left and below

Han-shue Tan and Satyajit Patwardhan inspecting the magnetometer on the test vehicle; the Golden Gate Fields parking area with the layout of magnetic markers

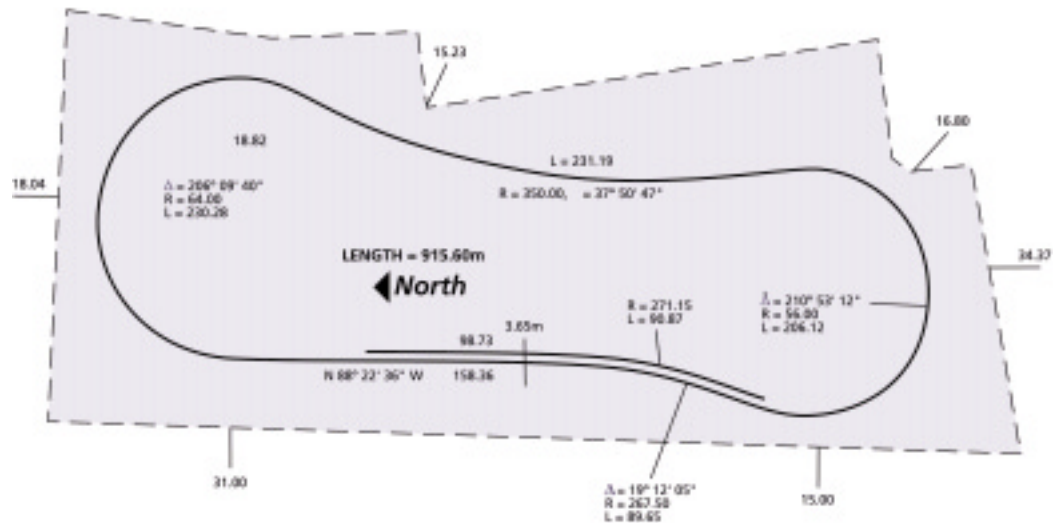


Wei-Bin Zhang suggested using an immense parking lot at Golden Gate Fields, a horse-racing track just three miles from the Richmond Field Station, as a test facility. PATH has used this parking lot, which is the size of fifteen football fields, for open loop tire-burst experiments in the past. The initial response from Ladbroke Racing Company, which operates

Golden Gate Fields, indicated that installation of the magnetic markers in the parking lot would be possible as long as the markers would not be visible and the installation would not affect the life cycle and the smoothness of the pavements. Mr. Zhang did all the initial planning, and got Caltrans' permission for the work.

Many tasks had to be completed before the first experiment could be conducted. A use permit had to be issued by the City of Albany, where the track is located, which meant that Satyajit Patwardhan and I had to be questioned at a public hearing; a contract had to be negotiated between the Real Estate Services of the University of California and Ladbroke's; the test course and the magnetic marker coding strategy had to be designed, a trailer to tow the experimental lateral vehicles had to be purchased, and the permanent magnetic markers had to be installed.

Satyajit designed the test course, trading off the geometric limitations of the parking lot with a strong



emphasis on safety. The total length is 1106 meters. There is at least a 4-lane-width distance between the course to the nearest objects outside, such as perimeter fences or walls. Moreover, the course is always tangent to those outside objects. The 923 magnetic markers are spaced 1.2 meters apart. The course is very challenging, with a maximum designated speed of more than 80 kph (22m/s, or 50 mph) on a 300-meter straightaway, and the smallest radius of curvature of 56 meters. It should provide grounds for a very dramatic demonstration of the lateral-control cars' effectiveness. One researcher who drove it repeatedly in his own manual-controlled car said that his coffee cup would slide off the dashboard at 40 kph (25 mph) on the sharp curve. There is also a second lane available for lane-change maneuvers.

Magnetic codes, based on putting either the north or south magnetic pole of the marker up, are installed at 24 locations on the course. The code contains information about current or upcoming road curvatures, which enable the vehicle's preview con-

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New Test Track

continued from previous page



trol software to anticipate roadway features. It can be read by a vehicle traveling either clockwise or counterclockwise. The initial coding strategy of the magnetic markers was suggested by Wei-Bin Zhang, and was finalized two days before the installation with great effort from Satyajit Patwardan.

ing any coding error after the markers have been epoxied in, the magnetic polarity of each marker has been most painstakingly verified. On April 10, 1995, just one week after our initially scheduled completion date, with the sound of the jackhammer still ringing in our ears, the new track was ready.

The installation of the permanent magnetic markers involved five steps: surveying the test course, purchasing the magnets, drilling holes on the course, installing the magnets into the holes, and patching the holes with a quick-drying epoxy. Because the racing season was on, PATH only had access to the parking lot on Mondays and Tuesdays except for the last week of March and the first week of April. We thought this would be our greatest obstacle until the rain kept falling on us. The survey was done by the Aliquot Company with less than half a centimeter error requirement. It was scheduled during the first two weeks of March, but continuous rain prevented its completion until the last working day of the month. The 4000 magnets (four per marker) arrived just in time for installation. The Penhall company drilled and patched the holes from April 5th to 10th, and Satyajit and I installed the magnet markers ourselves to ensure the correctness of all the codings. Several graduate students from Professor Masayoshi Tomizuka's and Karl Hedrick's research groups volunteered their time

In order to take full advantage of the beautiful view, we have made many experimental plans for the coming year. Robust lane-keeping control up to 80 kph (22m/s, or 50 mph) tire-burst control up to 65 kph (18 m/s or 40 mph), lane-change maneuvers up to 75 kph (20 m/s or 45 mph), and combined

lateral and longitudinal control tests have all been proposed. Hopefully those experimental results will further enhance our knowledge and experience about the development of automatic vehicle control systems.

Many other people have contributed to this project, and we would like to thank them all: Ms. Nannette Woodson and Ms. Barbara Cooper from PATH for their persistent help and infinite

knowledge in the purchasing matters. For their assistances and advice on various topics, Ms. Barb Evans from UC Real Estate Services, Ms. Sui Chen from the College of Engineering Office of Research Support, Ms. Bonnie G. Wynn from the Planning, Design and Construction Department, Mr. Larry Bell from the Richmond Field Station. For their endurance of noise, rain, dirt, and the nice bay view, graduate students Sujit Saraf, Chieh Chen, Hung Pham, Wonshik Chee, and Pushker Hingwe. Also, PATH engineer Peter Devlin for his constant reminder of the safety issue; and Deputy Director Dr. Steven Shladover for his patience for delay and tolerance for mistakes. Finally, Mr. Randy Woolley and Mr. Sompol Chatusritipitak from Caltrans for their support and directions.



top to bottom

the lateral control vehicle (w/magnetometer raised for transit); magnetic marker being placed into position; Han-shue Tan overseeing the installation of markers



and effort for the hard labor of installation, which took four days, from 6:30 am to 4:30 pm every day except when occasionally stopped by rain. Because there is coding throughout the course, and because of the great difficulty involved in correct-



PATH Visitors

Senior Engineer Nobuo Momose and Kenneth Yoshioka from Mitsubishi Motors America toured the Field Station on March 20, and also gave a seminar where they introduced some very new technology that Mitsubishi will offer on the Japanese market. Mr. Momose discussed INVECS II technology, which can adjust the characteristics of various control systems to suit the traffic condition and the user's driving style. Mr Yoshioka discussed the Preview



Distance Control System, which uses a video camera and laser radar, and the Preview Traction Con-

trol System, which uses navigation data to preview road curvature and perform pre-curve velocity control.

Dr. Axel Fuchs, Manager, Joint Projects, for Daimler-Benz Research and Technology North America, visited the Field Station on April 25 with two colleagues: Senior Vice President Dr.-Ing. Michael Krämer, from Stuttgart. and Dipl.-Ing. Christian Fröh, from Daimler-Benz of Brazil.

On May 5, Satyajit Patwardan gave a tour and test rides to Dr. Werner Schiehlen, visiting Miller research professor at UC Berkeley's Department of Mechanical Engineering; Takashi Iwasaki, Assistant manager, Chassis Component Engineering Dept., at Toyota Motor Corporation's Higashifuji Technical Center (Japan); and Professor Hidenori Kimura of the Department of Mathematical Engineering and Information Physics, Faculty of Engineering, University of Tokyo.



top to bottom

*Steven Shladover
with Dr.-Ing.
Michael Krämer,
Dr. Axel Fuchs,
Dipl.-Ing. Christian
Fröh, Han-shue
Tan;*

*Han-shue Tan with
Kenneth Yoshioka
and Nobuo Momose*



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FAST

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insurance industry must be taken into consideration. Incremental introduction of automation features that have proven safe may be required. Frequent and rigorous vehicle inspection and maintenance may be required as well. At least initially, insurance premiums could be very high, which could discourage individuals from buying the insurance, and the automated car. Fleet operators, however, could more easily afford the insurance, and again could spread the additional cost to individual users.

Acceptance by Special Interest Groups and the General Public

A smooth and successful development of AHS will require work by the research and development community to win the support of various interest groups (especially environmental groups), and eventually acceptance by the general public. Features of AHS that appeal to such groups should be emphasized, especially user services. Among these are increased safety, comfort, and convenience, coupled with reduced environmental impacts, travel delays, and the overall cost of travel.

Freeway Automatic Shuttle Travel – FAST

An automated highway system is frequently envisioned, especially on television, as one in which streamlined cars are wafted speedily to their destinations by an all-seeing, infallible computer, while passengers read the newspaper or nap. An AHS should more properly be considered as any integrated system of sensor, communication, computer, and control technologies applied to the goal of automating the movement of vehicles and people.

Even if automobile automation is the ultimate goal, it need not be the first step. For example, conventional mass transit based on full-size buses may not be convenient and economically attractive enough to lure sufficient ridership for its survival, especially in the sprawling suburbs designed for solo driving. But highway automation technologies can easily be tailored to automate the highway driving of a van/mini-bus shuttle system. This, together with other

transit technologies, may eventually lead to an automated transit system.

The automated shuttle service proposed here—FAST—would:

- provide non-stop passenger transportation from one activity center to another,
- make a small number of stops at each activity center to pick up and drop off passengers, and
- use mainly freeways for the entire trip.

The familiar airport-to-downtown shuttles currently available at most metropolitan airports are good examples of similar services. Others include the suburb-to-downtown commuter bus services available during peak hours in most metropolitan areas. A freeway shuttle could also link one suburb to another if demand is sufficient and local pick-up and drop-off are made convenient enough for riders. The size of the shuttle vehicle could vary from a full-size bus to a mini-bus or van. However, smaller vehicles may be preferable because the resulting automation technologies may be applicable, with some modification, to both full-size buses and automobiles; because emergency control of smaller vehicles may be easier, or collision impacts may be minimized during emergency maneuvers in the event of vehicle or system failures; and because the demand for such a shuttle service may grow only gradually.

Initial Operation

We propose the following possible operating scenarios for FAST. For simplicity, let us focus on a shuttle service between two activity centers and make the following assumptions:

- There are no automated onramps or offramps at the two activity centers. But there is a continuous high-occupancy-vehicle (HOV) lane in each direction connecting the two centers.
- Markers—paint markings, magnetic markers (nails or tape) or other devices—are installed for vehicle lane-keeping, as well as for encoding roadway geometry and perhaps speed limits. There is no other required infrastructure support or roadside intelligence.
- Shuttle vehicles are autonomous and sufficiently

equipped for safe automated lane travel, i.e. cruising along a lane without lane changes including both Adaptive Cruise Control (ACC) and automatic lateral control for lane-keeping. Note that safe automated lane travel requires the vehicle's ability to learn the speed limit and to determine the maximum safe cruising speed, which may depend on driving and traffic conditions. No vehicle-to-vehicle or vehicle-to-roadside communication capability is necessary. Roadside-to-vehicle communication for broadcasting the speed limit and other driving and traffic conditions is optional.

During initial deployment, FAST operation would be very simple. It is summarized as follows:

- A driver would be in the driver's seat throughout the trip, and in control while the vehicle is off the HOV lane.
- Upon entering the HOV lane and reaching a safe distance behind the vehicle ahead (which might be manually driven) the driver invokes automatic control and relinquishes manual control.
- During automated driving, the driver supervises the automated driving, watches for possible debris in the road, and reacts to dangers caused by manually controlled traffic in the HOV lane or neighboring lanes, or to possible vehicle or system failures. Should any occur, the driver takes back control of the vehicle. If the HOV lane gets blocked, the driver takes over and changes lanes to bypass the blockage.
- When approaching the destination, the vehicle requests resumption of manual control. The driver then takes control and drives the vehicle off the freeway to complete the journey.
- Shuttle vehicles will be maintained and certified periodically, and frequently checked for fitness for automated driving. These checks will be done in the operator's maintenance facilities and away from the freeway onramps.

FAST Advantages

The advantages of this shuttle-based initial development strategy, particularly with respect to its automobile-based counterparts, include:

- simple technology and operation (with respect to the technology required for fully automated AHS),
- safe introduction of the new driver roles for transition, monitoring, and emergency response,
- sharing of the high cost of early-generation automation-equipped vehicles by transit users,
- incremental service expansion synchronized with infrastructure modification,
- initial niche market for automakers,
- reduced risk for insurance carriers, and
- easier acceptance by special-interest groups and the general public.

Further development

Once the following conditions have been met, FAST could safely implement "driverless driving" on freeways.

- Dedicated onramps and offramps are widely available and the HOV lane is completely or virtually completely separated from its neighboring lane by physical barriers.
- An "emergency cord," similar to those on trains, has been installed on each vehicle so that any passenger can pull it to stop the vehicle in the event of vehicle or system failure.

"Driverless driving" would work as follows:

- The driver would get off the automation-equipped vehicle at the onramp. Freeway driving would be entirely automated, without a driver's supervision. At the offramp, another driver would get on the automation-equipped vehicle and complete the trip.

With no driver on board, highway automation would realize a major saving in labor cost, as many other automation technologies already have. The absence of a driver during freeway travel in this advanced deployment stage is an issue that requires further study and debate. The fact that at least two fully automated, driverless rapid-transit systems (i.e., urban rail systems) already exist, in Vancouver, Canada, and Munich, Germany, is cause for hope.



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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 510-642-3558, FAX: 510-642-1246.

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UCB-ITS-PRR-94-28	Vehicle Longitudinal Control Using Discrete Markers, David W. Love, Masayoshi Tomizuka, December 1994, \$7.00
UCB-ITS-PRR-95-01	A Handbook for Inter-Vehicle Spacing in Vehicle Following, Y. Sun, P. Ioannou, January 1995, \$7.00
UCB-ITS-PRR-95-02	Design and Implementation of Digital Radio Communications Link for Platoon Control Experiments, Wei-Yi (William) Li, January 1995, \$7.00
UCB-ITS-PRR-95-03	Vehicle-Based Control Computer Systems, David M. Auslander, January 1995, \$7.00
UCB-ITS-PRR-95-04	Longitudinal Control Development for IVHS Fully Automated and Semi-Automated Systems - Phase I, J.K. Hedrick, D.H. McMahon, D. Swaroop, V. Garg, J.C. Gerdes, D.B. Maciuc, T.T. Blackman, P.P. Yip, January 1995, \$14.00
UCB-ITS-PRR-95-05	Freeway Service Patrols Evaluation, Alexander Skabardonis, Hisham Noeimi, Karl Petty, Dan Rydzewski, Pravin P. Varaiya, Haitham Al-Deek, February 1995, \$15.00
UCB-ITS-PRR-95-06	A Machine Vision Based Surveillance System for California Roads, J. Malik, S. Russell, March 1995, \$5.00
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UCB-ITS-PRR-95-08	Hierarchical Hybrid Control of Automated Highway Systems, Datta Godbole, March 1995, \$16.00
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UCB-ITS-PRR-95-10	IVHS Safety: Multiple Collisions in Automated Highway Systems, Anthony Hitchcock, April 1995, \$7.00
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UCB-ITS-PWP-95-4	TravInfo Field Operational Test Evaluation Plan, Randolph Hall, Y.B. Yim, Asad Khattak, Mark Miller, Stein Weissenberger, May 1995, \$8.00
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PATH Technical Notes

Tech Note 95-01	ATCOMM/XL Hardware Driver Software Documentation, Herb Huang, Bret Foreman, January 1995, \$5.00
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Tech Note 95-03	Validating the Basic Cell Transmission Model on a Single Freeway Link, Wei-Hua Lin, Dike Ahanotu, March 1995, \$10.00
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University of Michigan

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Freeway Automatic Shuttle Travel references

Bishop, J.R., G.M. McHale, and W.B. Stevens. 1994. "A Snap Shot of the Automated Highway Systems (AHS) Precursor Systems Analyses (PSA) Early Research Results," Proceedings of IVHS America Fourth Annual Meeting, Atlanta, Georgia, April, 1994.

Tsao, H-S. J. 1995. "Constraints on Initial AHS Deployment and the Concept Definition of a Shuttle Service for AHS Debut," to appear in IVHS Journal (1995).

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1357 South 46th Street
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Editor	Bill Stone
Assistant Editor	Gerald Stone
Art Director	Andrew T. Watanabe
Contributing Designer	Matt Abarbanel
Editorial Assistant	Sara Martinez de Osaba

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PATH Publications
1357 South 46th Street, Bldg. 452
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Tel: 510/231-9495
FAX: 510/231-9565
e-mail: bstone@uclink2.berkeley.edu

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