Intellimotion

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PATH Projects in Progress

PATH – Partners for Advanced Transit and Highways – is a collaboration between the California Department of Transportation (Caltrans), the University of California, other public and private academic institutions, and private industry.
PATH's mission: applying advanced technology to increase highway capacity and safety, and to reduce traffic congestion, air pollution, and energy consumption.

CALIFORNIA PATH

Electronic Toll Collection at the Carquiñez Bridge

Jianling Li, PATH / University of Texas at Arlington

Over the last decade, many Intelligent Transportation Systems (ITS) technologies have grown from idea to reality. But because most ITS technologies are so new, there are few well-developed empirical databases on costs and benefits. ITS project evaluations are therefore likely to rely on estimates based on simulation models, so there is a pressing need for good data from ITS deployments and models that can be used to accurately predict the demand for and benefits of ITS applications. Such information is important for planning and implementing ITS programs, and in setting priorities for future deployments, especially in a financially constrained environment. To provide this information to decision-makers, PATH researchers have launched a series of studies on data collection and the benefit-cost evaluation of ITS projects. As part of these efforts, we have developed an analytical framework and used it to evaluate the FasTrak Electronic Toll Collection (ETC) system at the Carquiñez Bridge, where the Sacramento River joins San Francisco Bay. This article outlines the benefit-cost evaluation framework and procedures, and highlights the results of our evaluation of the Carquiñez Bridge ETC system.

The Carquiñez Bridge ETC project

The Carquiñez Bridge ETC system is a pilot project undertaken by the California Department of Transportation (Caltrans) to improve service on the state's toll bridges. It replaces the current Toll Registration, Audit and Collection (TRAC) system, a computerized process-control system, with an ETC system at the toll plaza. A dedicated ETC lane has been open since August 1997 to users who have established an ETC account with Caltrans, all other lanes are open for mixed electronic and manual toll collection, and another ETC lane is expected to open soon.

The ETC project has four major objectives: to reduce the overall toll collection cost; to provide an acceptable level of service for toll patrons; to provide information currently not available in the planning and operation of transportation facilities, while improving the quality of data now available; and to reduce traffic congestion, air pollution, and fuel consumption.

Evaluation framework and procedures

The Carquiñez ETC system was evaluated using the framework shown in Figure 1, which incorporates

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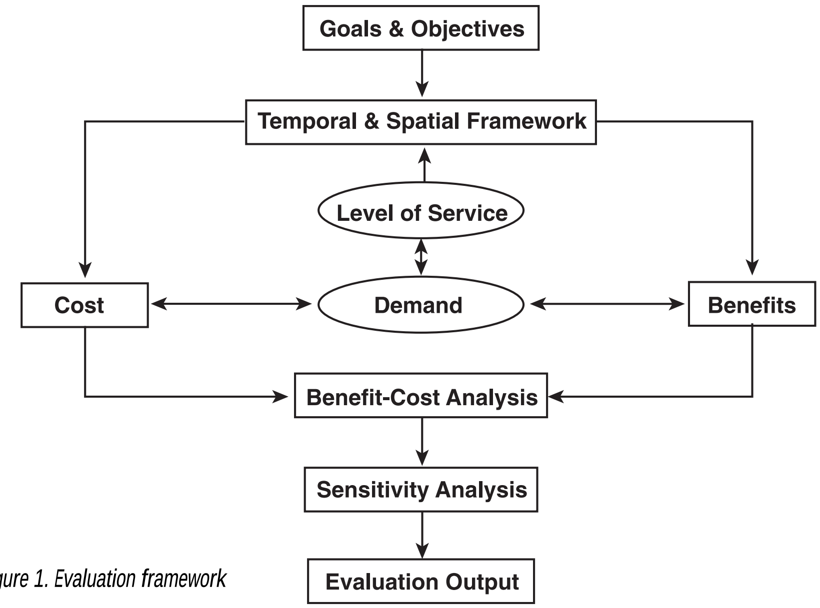

Figure 1. Evaluation framework

the principles of benefit-cost life-cycle costing. The major procedures in the evaluation process include:

- selecting evaluation criteria based on the goals and objectives of the ETC system;
- defining a temporal and spatial horizon for benefit and cost assessments;
- classifying and measuring cost differences between the baseline and the ETC system, as well as incremental benefits for affected parties;
- computing evaluation indices, such as net present value, benefit-cost ratio, and internal rate of return;
- conducting a sensitivity analysis to handle risk and uncertainty; and
- presenting analytical results.

The evaluation criteria include two sets of measures. One is a set of quantitative measures for direct benefits and costs, such as net benefits to the three groups affected: ETC users, the toll agency, and the community where the ETC facility is situated. This set includes benefit-cost ratios for the three groups. The other is a set of qualitative measures for indirect benefits such as travel convenience, data quality, induced effects, etc.

Because most ETC components have a life span of ten years, the temporal framework of our analysis — the evaluation period — was set at ten years. Because the bridge is geographically isolated from other bridges and highways, we assumed that the effects of the ETC system are limited to the bridge itself. (The nearest bridge, the Benicia-Martinez Bridge, is about nine miles upriver and will be equipped with the ETC system right after the completion of the project at the Carquiñez Bridge. The Carquiñez bridge ETC system is not expected to attract traffic from the Benicia-Martinez Bridge.)

Quantifiable costs and benefits were grouped into five major categories:

- direct monetary costs or savings,
- costs or savings associated with traffic accidents,
- time costs or saving,
- environmental costs or savings, and
- other costs and savings not included in the previous categories.

Direct monetary costs or savings include increments or decreases in the operating revenue, and life-cycle expense of the toll service and vehicles. Costs to users from accidents are expenses for vehicle repairs, medical expenses, wage losses, and expenditures due to personal injury or death. Costs to toll agencies from accidents refer to resources used for repairing property damage caused by accidents. Community costs due to accidents include those of support services such as police, emergency services, and insurance services provided by other sectors of society. Time cost is the time spent by users while using toll facilities. Environmental cost refers to community expenditures to repair any environmental damage. The differences in these costs between an ETC system and a manual toll system are benefits or disbenefits. Other non-quantifiable benefits include increases in travel convenience, data collection, improvements in data quality and service quality, and other induced impacts on travel demand, traffic congestion, productivity, etc.

Benefit-Cost Analysis

Based on historical data provided by Caltrans on traffic volume at the bridge, and drawing from existing national statistics, we projected future annual traffic demands, estimated annual direct costs and benefits over the 10-year evaluation period, and discounted them to fiscal year (FY) 1995 dollars. Basic assumptions used for calculations of traffic growth, market share of ETC usage, toll transaction time by type of payments, travel speed, and the design configuration of the bridge are shown in Table 1. The sum and distribution of the direct costs and net benefits during the evaluation period are shown in Table 2.

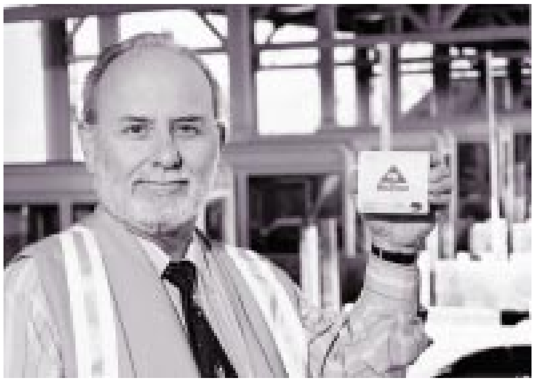

Photo: Carquiñez Bridge Toll Captain Norman Crow with ETC transponder.

Table 1. Basic assumptions.

Items	Assumptions
Annual traffic growth rate	3%
Annual growth rates of ETC transactions	FY 97/98 – 6%
	FY 98/99 – 15%
	Thereafter – 5% annually
Seconds per cash transaction	10
Seconds per ticket transaction	4.5
Seconds per ETC transaction	2.4
Normal travel speed	55 mph (88 kph)
Ramp distance to/from toll plaza	0.2 miles (0.3 km)

Table 2. Distribution of direct costs and net benefits by party. FY95. (Dollars in thousands.)

	Total	Toll Agency	ETC Users	Community
Direct Costs	$2,885	$2,543	$342	$0
Benefits	$13,664	$342	$13,299	$23
Benefit/Cost Ratio	4.7	0.1	38.9	N/A
Net Benefits	$10,779	($2,201)	$12,957	$23

Several findings can be observed from the analysis:

- Overall, the ETC project would result in a net present value of $11 million and a benefit-cost ratio of 4.7 over the evaluation period.
- Distribution of direct costs and net benefits is quite uneven, with the ETC users the clear winners. Collectively, the ETC system would not only reduce their travel time and fuel consumption, but also increase their travel convenience. The net benefit to ETC users would be about $13 million in FY95 dollars if transponders were provided by the toll agency, with or without a deposit requirement. (Caltrans currently provides transponders, with a $30.00 deposit requirement for each, the approximate cost of the transponder. Users who prepay their tolls by credit card may get up to three transponders without paying a deposit.)
- Although the ETC system would save the toll agency labor and operation costs in later years, it would cost the agency about $2.2 million in constant dollars during the evaluation period, because the operating cost saving and revenues would not offset the initial capital investment for the ETC system. However, the agency's ability to set flexible tolls would be enhanced, and it would have access to more data — potential benefits that are not included in this analysis.
- The ETC project would also generate environmental benefits for the community (although their magnitude would be relatively small).

Sensitivity Analysis

A sensitivity analysis was also conducted to assess the possible effects of changing assumptions on net benefits and the distribution of benefits and costs (see Table 3). Results indicate that if the ETC market

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Table 3. Net benefit results of sensitivity analysis. FY95. (Dollars in thousands.)

Scenarios	Total	Toll Agency	ETC Users	Community
Original Assumptions	$10,779	($2,201)	$12,957	$23
Change in Market Share [a]	$25,425	$2,488	$22,889	$48
Change in Market Share [b]	$25,626	($2,228)	$27,807	$48
Change in Time Value	$7,078	($2,201)	$9,256	$23
Change in Fuel Consumption	$11,282	($2,201)	$13,446	$38

Note: [a] Assuming that ETC users pay for the ETC transponders.
[b] Assuming that ETC users rent the transponders from the toll agency.

Control Design for a Floating Offshore Airbase

Jim Misener, Dan Empey, PATH

Snaking around PATH headquarters at the Richmond Field Station, northwest of the UC Berkeley campus, on San Francisco Bay, is a half-kilometer asphalt test track that on any given day may see use by Buicks, Hondas, a Freightliner tractor/trailer—even a Caltrans snowplow—in various stages of automated control. But if you wander the hallways these days, you'll hear talk of advanced vessel control. Vessels? Craft designed to navigate on water, in this world-renowned center of vehicle control?

Three to five electronically connected vessels will link together at sea to form a mile-long floating runway.

Vessels, as in seagoing. We are now in the seventh month of a fifteen-month project sponsored by the Office of Naval Research, which in collaboration with the Naval Facilities Engineering Service Center has contracted PATH to perform control design, evaluation, and a physical demonstration of multiple, "electronically connected" semi-submersible bargelike vessels, each about as long as the biggest aircraft carrier afloat.

This notional system of semi-submersible vessels is called a Mobile Offshore Base (or MOB). In concept, three to five of these vessels will link together at sea to form a mile-long (1.6 km) floating runway. Together they will be able to store perhaps 5 million cubic feet of materiel, and carry up to 20,000 combat-ready troops. Such a system would dramatically reduce the difficulty of mounting a military operation where no friendly country or nearby island can serve as a base for action. The self-propelled MOB barges would steam independently toward some point at a speed of 15-20 knots, rendezvous 100 km offshore, assemble in tandem to form the runway, submerge about halfway (for stability) and then proceed with their mission. Some concepts call for them to be mechanically linked, some link them electronically (due to torsional forces created by high seas), and others use a hybrid approach, linking them mechanically during low sea states and electronically once environmental disturbances increase.

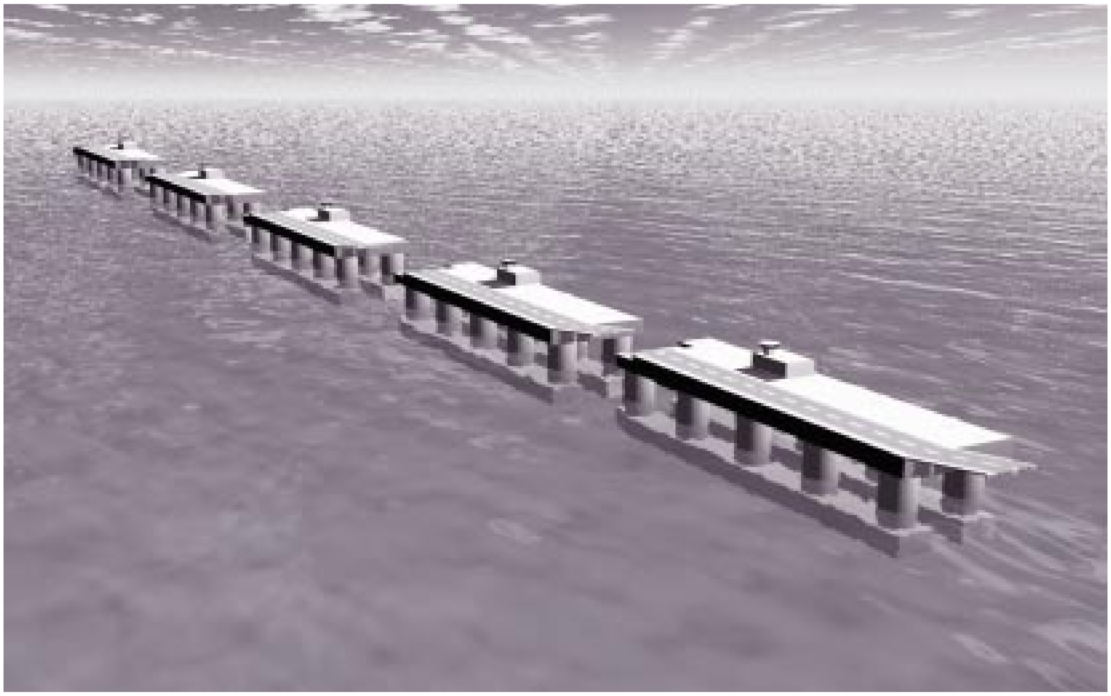
Jim Misener is a Principal Development Engineer at PATH.

Dan Empey is a Senior Development Engineer at PATH.

Why has the ONR chosen PATH? Some aspects of the MOB project are quite Intelligent Transportation Systems-like, especially vessel control, which in the semi-submersible world (of oil rigs, for example) is called dynamic positioning, or DP. Moreover, MOB vessels must "assemble" and "disassemble" in close coordination, not unlike vehicle platoon join and split manuevers. This brings issues that PATH has long studied to the fore — in adaptive feedforward control, string stability, and in the overarching control architecture. The project also involves elements of a field best described as simulation of hybrid dynamic systems composed of multiple agents. This is an ideal application of our SHIFT programming language for describing dynamic networks of hybrid systems (www.PATH.berkeley.edu/SHIFT -- discussed in its SmartAHS implementation in Intellimotion 5.4, December 1996). SHIFT offers the proper level of abstraction for describing complex systems whose operation cannot be captured by conventional models. It is ideally suited to evaluate various concepts and ultimately, to test the feasibility of dynamic positioning on the MOB. The project also has a strong experimental component that will involve the testing of subscale physical models at the Richmond Field Station.

During our fifteen-month period of performance, we will develop the dynamic postioning control method for the MOB (along with our subcontractor, Scientific Systems) and provide a tool template to uniformly evaluate competing concepts. We will also use SHIFT to virtually demonstrate (by computer) the MOB control and evaluation method and to physically demonstrate our implementation of DP by controlling a string of closely spaced, subscale MOB models.

A host of PATH and UC Berkeley researchers are involved: from the principal investigator, PATH Director Karl Hedrick, to other UC Berkeley faculty members, such as Dean Bill Webster, Professor of Naval Architecture and Ocean Engineering, and their graduate students, among them Anouck Girard, Brian Kaku, and Steve Spry. PATH researchers working on the project are Akash Deshpande, Dan Empey, Natasha Kourjanskaia, Misha Kourjanski, and Jim Misener. We also have two contractors: Scientific Systems, to develop nonlinear dynamic positioning control methods for the Mobile Ocean Base, and João Sousa, visiting UC Berkeley from the University of Porto and working with us to develop our SHIFT simulations.



Artist's conception of Mobile Offshore Base. Several semi-submersible self-propelled barges, each the size of the U.S. Navy's largest aircraft carrier, would link together at sea to form a mile-long runway.

We are working concurrently along four development thrusts:

- Thrust 1 is to develop a broadly applicable and innovative DP distributed control architecture and accompanying detailed controllers.
- Thrust 2 is to provide an "open architecture" simulation and evaluation method, suitable for all MOB concepts.
- Thrust 3 will be to demonstrate the controller and evaluation method through computer-based simulation on a government-selected MOB concept.
- Thrust 4 will be to demonstrate string stable control through a physical demonstration of subscale MOB models.

The two demonstrations will implement key products from the first two development thrusts. The simulation demonstration (Thrust 3) is an end-to-end virtual test of the delivered DP controller and evaluation software, and the physical demonstration (Thrust 4), using government-supplied hardware, will serve as an important proof of principle in the application of stable control of a string of MOBs.

Thrust 1-Dynamic Positioning Control. The development of DP for the MOB will require resolution of issues in which module dynamics far different from any seen in a terrestrial vehicle play a central role. The elements that present the greatest challenge are estimation of the hydrodynamic forces that result from platform motions and the platform's response to water waves, and prediction of the forces produced by thrusters acting in this environment.

We are working on characterizing the hydrodynamic environment, which has some interesting disturbance components, all of which require modeling:

- The effects of the wind speed and direction of the forces and moments acting on a vessel are non-negligible.
- The principle of superposition may not be applicable.
- Added mass coefficients are not constant and are independent of the wave circular frequency.
- The environmental disturbances induced by the motion of each vessel affect the motion of other vessels operating in close proximity.

Together with with our Scientific Systems subcontractor, we have begun design of a DP system for a single MOB. Our primary control approach is with a Model Predictive Controller based control design approach. For the purposes of controller design, only the dynamics associated with surge, sway, and heading are considered.

Thus far, the controller has been tested in the simulated presence of wind disturbances; testing in the presence of environmental disturbance due

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Precision Docking Demonstration at Houston

Han-Shue Tan, Bénédicte Bougler, Hung Pham, and Dan Empey, PATH

"It works!" ...and the feeling was great! After the tenth consecutive time the Buick LeSabre automatically parked at almost exactly the same spot, 1.5 centimeters from and parallel to the curb, we were so excited that not even the 100 degree temperature nor the 95 percent humidity at Houston could dampen our spirit. We had always known that the system would work, but seeing it was still astonishing.

Facing page, top: Houston Metro General Manager Bob MacLennan (in white shirt) and staff ride in demo car. MacLennan: "This is great."

Facing page, bottom: Precision lateral control always positions vehicle precisely 1.5 cm from the curb, never touching it. Not touching the curb saves wear and tear on tires.

The journey started last December. Houston Metro was interested in having PATH simulate automated precision bus docking, in which a bus consistently pulls up to a bus stop at precisely the desired distance to the curb, using PATH's magnetic marker guidance system and one of our LeSabre test cars.

The PATH automated steering control system, although initially designed for highway driving, is generically a high gain robust control system and is therefore a candidate for fulfilling the tasks involved in automated docking, of which the two key requirements are precision and consistency. We soon realized that by altering the "stopping" characteristics of the original algorithm, we could create a unified automated steering control algorithm that would perform high speed driving on the highway, high-g maneuvering on sharp curves, and precision docking when stopping. By December 1997, we had installed a sequence of magnetic markers at a Houston Metro bus station and were ready to test our theory. But the discovery of a strong magnetic background noise field in the bus station pavement postponed the implementation. Subsequently, we determined that either lowering the magnetometers on the vehicle or using stronger magnets in the pavement could solve such noise problems. After repositioning the magnetometers and modifying the signal processing algorithm, we went back to Houston in the first week of September 1998 to demonstrate the effectiveness of our docking system. The plan was to automatically steer the vehicle laterally across one lane and park it parallel to the curbside, at a 1.5-centimeter distance, without ever touching the curb—and to do it consistently regardless of any loading conditions.

The results matched our expectations. After we finished the software debugging at Houston, the vehicle performed every docking process with the same precision and consistency, either under full automation, with steering, throttle, and brake controlled by computer, or semi-automation, with speed controlled by the driver. Figure 1 shows the desired docking trajectory, as well as front and rear sensor measurements during the 10 consecutive fully automated docking runs. These runs were conducted with 0 to 4 passengers (including one test run with 3 passengers sitting on the back of the trunk) at the Houston Pinemont Park and Ride bus station curbside. It is clear from Figure 1 that once the docking curve starts, at marker number 25, the tracking performance is so consistent that only two trajectory lines (one for front and one for rear) are distinguishable. By magnifying Figure 1 from marker number 52 to 62, as shown in Figure 2, it can be seen that the variation at every marker point is within 5 millimeters peak to peak. These variations are almost undetectable to human eyes observing from the curb. In practice, a bus could automatically latch on to the magnetic markers upon approaching the bus station and

Photo strip: PATH-automated Buick pulls up to bus stop with precision and consistency.

perform either fully automated or semi-automated docking. As our demonstration showed, automated docking exceeds human performance in precision and consistency.

On September 9, 1998 we demonstrated the precision docking maneuver to Bob MacLennan, General Manager of the Houston Metro system, and members of his staff. Bob rode the demo several times and at the end said "This is great, where do we go from here?"

Potential applications of the PATH magnetic marker guidance system for bus operations are many, including docking, automated bus daily maintenance, and "Bus Rapid Transit." We look forward to successful collaboration with Houston Metro in the future. ■

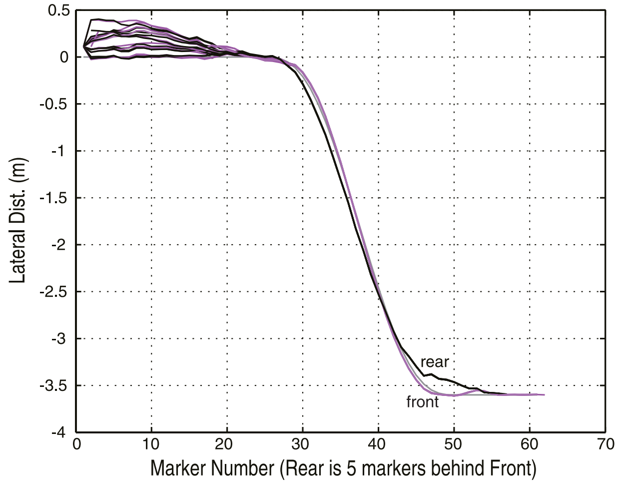

Figure 1

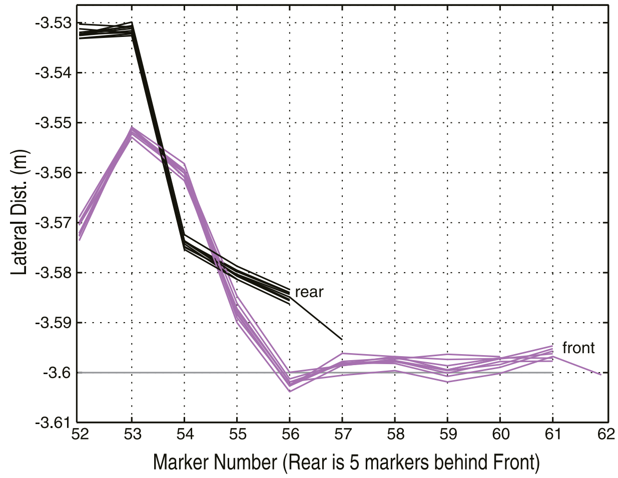

Figure 2

Video of this demonstration is available online at:
www.path.berkeley.edu/PATH/Publications/Videos/

PATH Program-Wide
Richmond Field Sta
November 5

Over a hundred PATH researchers, around forty Caltrans personnel, and a dozen or so representatives from private industry and academia convened at PATH headquarters in November for two rainy but illuminating days of presentations and discussion. Participants came from six University of California campuses, the Lawrence Livermore lab, the University of Southern California, Cal Poly San Luis Obispo, SRI International, Nissan R&D, and elsewhere. Caltrans sent people from five districts, plus strong delegations from Traffic Operations and the New Technology and Research Program.

Thursday, November 5

- Welcome Address/Overview - Karl Hedrick, PATH Director
- Caltrans New Technology and Research Program: The Role of R&D - Greg Larson, Caltrans Liaison to PATH
- US DOT Intelligent Vehicle Initiative (IVI) - Robert Ferlis, FHWA

Technical Sessions I

AVCSS - Fault Detection and Management Systems - Chair: Jim Misener

- Robust Fault Detection and Identification for an Automated Highway System: Theory and Applications - Jason Speyer
- Fault Detection in Human-Augmented Automated Driving - Theodore Cohn, Jay Barton, and Masayoshi Tomizuka
- Fault Detection and Diagnosis for the PATH/AHS Longitudinal Control: Simulation and Implementation - Adam Howell, Karl Hedrick

ATMIS - Surveillance - Chair: Robert Tam

- Advanced Image Sensing Methods for Traffic Surveillance and Hazard Detection - Art MacCarley/ Brian Hemme
- Development of an Intelligent Loop-Based Traffic Surveillance System - Stephen Ritchie
- Laser-Based Detection System for the Measurement of True Travel Times - Joe Palen

Technical Sessions II

AVCSS - Parallel Sessions:
A. Communications - Chair: Chin-Woo Tan

- Fault Diagnosis for Intra-platoon Communications - Tunc Simsek, Raja Sengupta
- Optimized Vehicle Control/Communication Interaction During Platoon Maneuvers in an AHS Environment - Sonia Mahal, Yu-Han Chen, Karl Hedrick
- Address Resolution Protocol for One-Lane Automated Highways - Soheila Bana, Pravin Varaiya

B. AHS Safety - Chair: Pete Hansra

- AHS Link and Coordination Layer Control for Emergency Vehicle Maneuvering - Roberto Horowitz
- Steering Control in Vehicle-Following Collisions - Ching-Yao Chan
- Safety and Capacity Analysis of Automated Highway Systems - Datta Godbole

ATMIS - Advanced Transportation Information Systems - Chair: Mark Miller

- Accessible Transit for Blind Travelers; Use of Talking Sign Technology - Reginald Golledge
- TravInfo Evaluation; Survey Results - Y.B. Yim
- TravInfo FOT: The Traveler Information Center (TIC) Evaluation - Mark Miller

e Research Meeting
tion, UC Berkeley
5-6, 1998

Friday, November 6

- Welcome Address - Roy Bushey, Program Manager, Caltrans New Technology and Research Program
- Traffic Operations: R&D Opportunities - Hamed Benouar
- The PHOENIX Project - Greg Larson

Technical Sessions III

AVCSS - Vehicle Control - Chair: Han-Shue Tan
- Brake Torque Measurement and Emergency Braking - Michael Uchanski, Karl Hedrick
- Control of Automated Heavy-Duty Vehicles (Joint Presentation by UCLA and UC Berkeley): (UCLA) Ioannis Kanellakopoulos, Yaolong Tan, Andreas Robotis; (UCB) Masayoshi Tomizuka, Pushkar Hingwe, Meihua Tai, Jeng-Yu Wang

ATMIS - Evaluations - Chair: Mohammed Al-Kadri
- Assessing the Benefits and Costs of Information: An Exploratory Analysis - David Gillen
- The Design of a Performance Monitoring System for Caltrans District 12 - Pravin Varaiya/Karl Petty
- Evaluation of the Anaheim Adaptive Control Field Operational Test- Mike McNally

Technical Sessions IV

AVCSS - Parallel Sessions:
A. Modeling and Simulation Tools for AVCSS - Chair: Aaron Steinfeld
- Regulation Layer Software Integration - Akash Deshpande
- Mixed Semi-Automated/Manual Vehicular Traffic - Petros Ioannou
- Sensor Modeling and Fusion, and its Applications to Fault Diagnosis for AVCS - Alice Agogino

B. Platoon Aerodynamics - Chair: Ching-Yao Chan
- Transient Aerodynamics of Uniform Platoons - Omer Savas
- Digital Particle Image Velocimetry (DPIV): Measurements of the Air Flow Between Close Following Vehicles - Mustapha Hammache, Bogdan Marcu, Michael Park, Fred Browand
- Experimental Investigation of a High Drag Regime for Two Closely Spaced Vehicles - Bogdan Marcu, Matteo Paci, Mustapha Hammache, Michael Park, Fred Browand
- Field Observations of Air Flow in the Wake of a Single, Full Size Vehicle - Mark Michaelian, Bogdan Marcu, Mustapha Hammache, Fred Browand

ATMIS - Traffic Management/Car-Sharing - Chair: Joy Dahlgren
- CarLink: A Smart Car-Sharing System, A Study of Behavioral Adaptation - Susan Shaheen
- Incident Management: Process Analysis and Improvement - Randy Hall
- The I-80 Experiment: Real-Time Algorithms for Travel Time Estimates and Incident Detection - Alex Skabardonis

Electronic Toll Collection at the Carquiñez Bridge

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From top: Dedicated FasTrak ETC lane on bridge roadway; Driver passes through ETC toll booth without stopping; Transponder (in lower right of windshield) identifies car with ETC account.

share were assumed to be 35 percent higher than the original assumption, the total net benefits would be about $25 million in FY95 dollars, more than doubling the net benefit under the initial assumptions. The total benefit-cost ratio would be about 9.4. How the net benefits would be distributed, however, would depend on who pays the cost of ETC transponders. If the cost were borne by ETC users, all three groups would be better off. The ETC users would still be the major beneficiaries, with a net benefit of $23 million over the entire evaluation period. The toll agency, on the other hand, would save about $2.2 million in constant dollars for operations over the entire evaluation period, compared to the baseline. In spite of some reduction in interest generated from transponder deposits, the toll agency would have a net benefit of $2.5 million, accounting for about 10 percent of the total net benefit. Hence, the net present value of benefits would be more evenly distributed. Otherwise, the toll agency would bear slightly more financial responsibility for the project than under the previous assumptions.

To test the effect of time-value assumptions on benefit calculations, we changed our assumptions about the hourly value of time to travelers. The original assumption set hourly time value at $12.75 for auto and bus travelers and $33.41 for truck drivers. Due to lack of information on traveler profiles, such an assumption may overestimate hourly time value, and the effect of the ETC project. To investigate the magnitude of such an effect, we substituted a more conservative time value for the previous assumption: $9.00 per hour for auto and bus travelers and $23.40 per hour for truck drivers. The analysis shows that changing the assumption of time value would not change the distribution of net benefits to the toll agency and the community, although it would reduce both total and ETC users' net benefits. ETC users would still be the primary beneficiaries.

Assumptions regarding fuel consumption also affect the analytical outcomes. For example: we have estimated fuel consumption for vehicles paying the toll manually at 25 miles per gallon (8.9 km/l) typical for vehicles traveling on city streets. This may be low, especially for light-duty trucks, sport utility vehicles, and large cars, considering that vehicles must accelerate to highway speed after they stop to pay the toll. A higher fuel consumption value (15 mpg = 5.3 km/l) for manual vehicles would result in higher estimates on fuel saving and vehicle emission reduction for ETC vehicles. A 40 percent increase in the fuel consumption estimate for vehicles stopping to pay the toll would lead to about a 65 percent increase in the estimates for both fuel saving and emission reduction for vehicles using ETC. However, since fuel saving and emission reduction account for only about 6 percent of the total benefits, changing the assumption about fuel consumption would cause an increase of about 4 percent in total benefits. That is, the change would not have a significant effect on the outcome of benefit estimates or the distribution of net benefits among the three groups.

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Control Design for a Floating Offshore Airbase

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to currents and waves is in progress. We have also begun systematically testing the controller's performance on multiple MOBs.

Thrusts 2 and 3: Simulation, Evaluation, and Virtual Demonstration. To validate our simulations so that they will accurately reflect real-world conditions, it is important to ensure that all important hydrodynamic phenomena have been identified and incorporated into the SHIFT model. This will be accomplished by carefully comparing SHIFT simulation predictions with the performance of experimental models. When this validation is complete, SHIFT can be used with confidence to evaluate particular control system designs through exhaustive simulations of the MOB in a variety of environmental conditions and for a variety of operational scenarios. These evaluations will be used to modify and refine the control system design.

Up to this point we have been working on establishing the SHIFT-based framework for DP control development and evaluation. We first developed the simulation architecture, shown in Figure 1. Then, in order to provide the infrastructure for our subsequent work, we implemented the simulation architecture block diagram in SHIFT.

We next implemented a generic six-degree-of-freedom model of the physical layer dynamics in our SHIFT simulation framework for the purpose of performance evaluation. The next step will be to populate this model with hydrodynamic characterizations performed by Bill Webster and his students.

Thrust 4: Physical Demonstration. We will conduct our physical experiment in two phases. The first phase involves a small scale (2 m or 6-foot long), economical set of models to capture the basic hydrodynamic performance of the MOB modules and to capture a representative performance of the thrusters. (It is not possible to model real thruster performance well on this scale.) The purpose of this first-phase model set is to validate that all of the relevant hydrodynamics have been captured in the SHIFT model. Our models will be based on a generic design developed by the US Naval Academy. For the initial testing, three modules should be sufficient to validate the control concepts and SHIFT simulation.

The second phase involves experiments on a much larger-scale model set to model thruster performance more accurately. The goal of this second phase will be to design a control system for realistic thruster performance. Ideally, it will be conducted in the controlled environment of a model testing basin such as the Offshore Technology Research Center in College Station, Texas, or the David Taylor Maneuvering and Seakeeping Basin at the

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The first phase involves a small scale set of models (2 m or 6 feet long) to capture the basic hydrodynamic performance of the MOB modules.

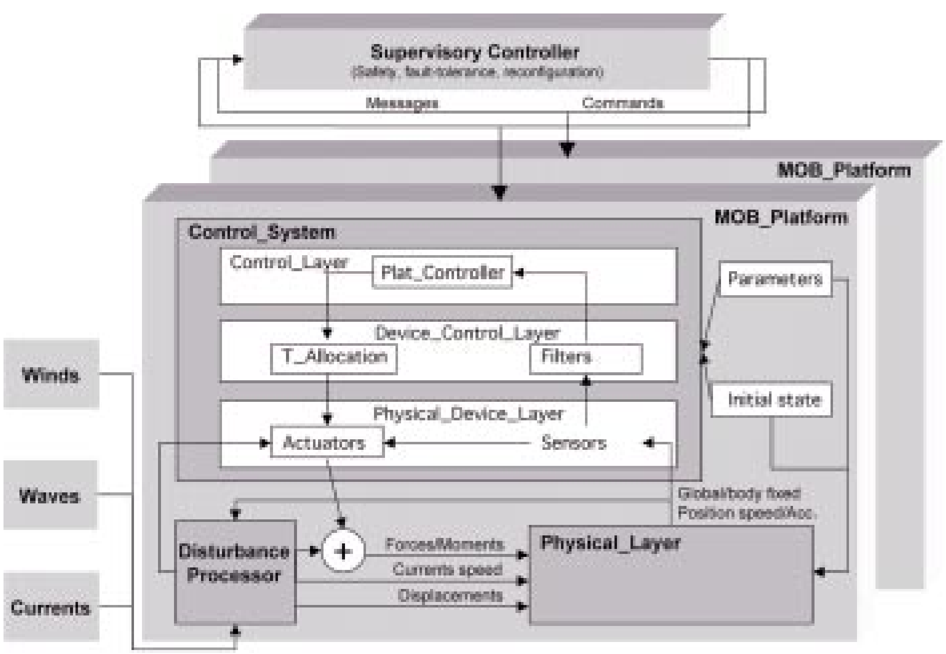

Figure 1. Block diagram of SHIFT simulation architecture.

PATH Presentations

Recent and Upcoming Presentations of PATH Sponsored Research

1998 IEEE International Conference on Systems, Man, and Cybernetics. Hyatt Regency, La Jolla, California, October 11-14, 1998.
• Carlos Sun, Stephen Ritchie, Kevin Tsai, "An Application of Intelligent Surveillance System for Transportation Management and Information" was presented at a special invited session on Simulation and Modeling for Intelligent Transportation Systems.
• Pravin Varaiya, "Hierarchical Control Architecture" (Plenary Lecture).

IFAC Workshop on Intelligent Components for Vehicles, Seville, Spain, March 23-24, 1998.
• Masayoshi Tomizuka, "Advanced Vehicle Control System (AVCS) for Heavy Duty Vehicles for Automated Highway Systems (AHS)" (Plenary Talk).

Fourth ECPD International Conference on Advanced Robotics, Intelligent Automation and Active Systems, Moscow, Russia, August 24-26, 1998.
• Masayoshi Tomizuka, "Intelligent Control of Road Vehicles for Automated Driving: PATH Architecture for Automated Highway Systems and Vehicle Lateral Control Research Conducted at California PATH Program" (Plenary Talk).

Fourth International Symposium on Advanced Vehicle Control (AVEC'98), Nagoya, Japan, September 14-18, 1998.
• Masayoshi Tomizuka, "Vehicle Lateral Control for Automated Highway Systems" (Keynote Speech).

Future Transportation Technology Conference and Exposition, Costa Mesa, California, August 11-13, 1998.
• Arnab Bose (presentor), Petros Ioannou, "Issues and Analysis of Mixed Semi-Automated/Manual Traffic" (SAE Technical Paper Series No. 981943).

Aachen Proc. Traffic and Mobility-Simulation, Economics and Environment Conference, Aachen, Germany, September, 1998.
• Carlos Daganzo, "Remarks on Traffic Flow Modeling and its Applications".

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• Ronald Koo, Youngbin Yim, "Travel Behavior of Morning Commuters: a Case Study of US 101 Corridor". Presented by Youngbin Yim.

INRIA Colloquium, Rocquencourt, France, June 3, 1998.
• Pravin Varaiya, "Towards a Layered View of Control".

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• Pravin Varaiya, "Automated Highway Systems".

Association of Commuter Transportation Annual Meeting, San Francisco, California, September 1, 1998.
• Conrad Wagner and Susan Shaheen, "Car Sharing and Mobility Management: Facing New Challenges with Technology and Innovative Business Planning".

Fall 1998 INFORMS Conference, Seattle, Washington, October 25, 1998.
• Randolph Hall, "Efficient Transit Service through the Application of Intelligent Transportation Systems".

School on Computational Aspects and Applications of Hybrid Systems, Grenoble, France, October 19, 1998.
• Pravin Varaiya, "Optimal Control and Verification of Hybrid Systems" (Invited Lecture).

Workshop on Learning, Control and Hybrid Systems, Bangalore, India, January 4-8, 1998.
• Pravin Varaiya, "SHIFT—A Language for Simulating Interconnected Hybrid Systems".

Raytheon Systems Company, El Segundo, CA, August 1998.
• Ioannis Kanellakopoulos, "Autonomous Vehicle Systems in Control Research and Education" (Invited Seminar).

Department of Computer Science, University of Crete, Heraklion, Greece, October 1998.
• Ioannis Kanellakopoulos, "Sensors and Controls for Autonomous Vehicles" (Invited Seminar).

Ford Motor Company, Advanced Vehicle Technology Division, Dearborn, Michigan, November 1998.
• Ioannis Kanellakopoulos, "Nonlinear Control for Advanced Vehicle Systems" (Invited Seminar).

Center for Automation Science, Ecole Nationale des Mines de Paris, Fontainebleau, France, November 1998.
• Ioannis Kanellakopoulos, "Autonomous Vehicle Systems in Control Research and Education" (Invited Seminar).

Bay Area Rapid Transit District CarSharing Workshop, Oakland, California, September 3, 1998.
• Susan Shaheen, "Smart CarSharing in the San Francisco Bay Area: CarLink".

New Mobility Workshop, Institute of Transportation Studies-Davis, Davis, California, November 3, 1998.
• Susan Shaheen, "CarSharing and CarLinking: The North American Experience".

PATH Magnets to Guide AHMCT's Advanced Snowplow for Caltrans

Gerald Stone, PATH

Late in September, Caltrans District 3 road crews finished installing 5,206 magnetic markers—6.25 kilometers' or 3.9 miles' worth—over Donner Summit on Interstate 80. Two hours later plows and sanders were already at work as the season's first snow fell. Soon the plows will be following the magnets. The magnet installation is the first step in a series of experiments that will use PATH's magnetic marker guidance system to guide Caltrans snowplows through whiteout conditions at Donner Summit, which frequently gets heavier snowfall than any other roadway in the lower 48 States.

"We're hoping for increased safety for the drivers, and a two- to fourfold increase in plowing speed in whiteout conditions," said transportation engineer Mike Jenkinson, project manager for Caltrans' New Technology and Research Program. "An increase from three miles an hour to above ten doesn't sound like much, but that would mean we could open the road sooner. And Highway 80 is the main artery into California."

Technical development for the Advanced Snowplow Project involves a partnership between the Advanced Highway Maintenance & Construction Technology (AHMCT) Research Center (http://www-ahmct.engr.ucdavis.edu/ahmct/) at the University of California—Davis (UCD), and PATH. A third partner, the Western Transportation Institute of Montana State University, will evaluate the performance improvements the system provides.

AHMCT researchers have already completed the system integration on a Caltrans snowplow. This work includes installation of two arrays of seven magnetometers, which will read the magnetic fields of the markers, placed in the center of I-80's westbound lane. An onboard computer will calculate the plow's position and trajectory, and display it to the plow operator on a screen in the cabin. The driver will be able to use the display as a reference even in a whiteout, rather than relying on seeing snow-stakes placed along the side of the road, which can be difficult or impossible to see during heavy snow, or when covered by drifts. The system also includes AHMCT's radar-based collision warning system to alert the driver of stalled vehicles and other obstacles. PATH conducted software integration and implemented the magnetic sensing system on the snowplow, and PATH and AHMCT jointly developed the Human-Machine Interface that displays the plow's position.

Magnet installation on I-80 over Donner Pass. Top: Drilling holes for magnet placement. Bottom: Sealing holes after magnets have been placed.

As Intellimotion goes to press, the snowplow is being tested at PATH'S Crow's Landing test facility in the Central Valley. It will join Caltrans' winter operations fleet on I-80 at Donner Summit in early December. The plow will also be tested this winter by the Arizona Department of Transportation on Interstate 180 through Kendrick Park. Data will be collected throughout winter 1998-99 to evaluate the effectiveness of the guidance system. ■

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Commuter Response to Traffic Information on an Incident, Ronald Koo, Youngbin Yim, September 1998, $5.00
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Los Angeles FOT Spread Spectrum Radio Traffic Signal Interconnect Evaluation Task: Final Report on Full Deployment, Victor O. K. Li, Senthil Sengodan, Tat-keung Ken Chan, Lei Zhuge, October 1998
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* *Available on-line at: http://www.path.berkeley.edu/Publications/PATH/index.html*

Control Design for a Floating Offshore Airbase

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Naval Surface Warfare Center Carderock Division in Maryland. However, accurate modeling of thruster performance may require models so big that the experiments can only be performed in an open setting, such as a lake.

When choosing the model scale many factors need to be considered: purpose of the experiment, viscous drag forces, handling of the model, model function, and size of the test facility. For the first phase of the physical experiment, relatively small models (1/150 scale) should suffice. This scale is small enough to allow three model MOB modules to be floated in a 12m x 15 m x 1m (40' x 50' x 3') pool at our Richmond Field Station facility, but large enough to carry the appropriate control computer, thrusters and actuators. A model of this scale is also just large enough to be tested in a model basin without encountering surface tension or capillary wave problems. There are drawbacks to models this small, the main issues being propeller (thruster) scaling, capillary waves, and viscous drag forces.

Because of the lack of viscous effects, if scale model thrusters are smaller than a certain diameter, they do not perform like full-scale thrusters. Experience indicates that thrusters less than 10 cm (4 inches) in diameter do not have the correct scale thrust characteristics; for our 1/150 scale model, the thruster diameter is more like 4.7 cm (1.9 inches). This does not mean that a 2-inch diameter thruster is useless, rather that the thrust characterization (e.g. thrust vs. propeller RPM) will not scale up correctly. Our thrusters will therefore have to be designed to achieve correct thrust levels rather than correct scale. Viscous drag is more difficult to characterize, but ship models are almost universally tested in water, and experimental and theoretical methods exist for correcting the model results for the viscosity of water. In our case the problem is slightly simpler due to the fact that the MOB vessels will not be moving through the water at any appreciable speed when linking up, and the scaling of Reynolds number effects will be accordingly reduced.

The second-phase model of the MOB platform will be almost 24 meters (80 feet!) long.

If the model scale is dictated by the need to provide for correct thruster scaling, a scale of about 1/66 will be needed. This will produce individual MOB modules 4.1 meters (13.6 feet) long, weighing about 1040 kilograms (2,290 lbs.). Such a model may be difficult to test indoors in a testing basin, since the assembled MOB platform will be almost 24 meters (80 feet!) long, assuming a runway length of nearly 1500 meters. It might be possible to test such an assembly in a large model basin such as the David Taylor Seakeeping Basin, but it may be necessary to conduct the test in a natural body of water. So in the near future, in additon to seeing automated land vehicles on PATH researchers' computer screens, you can expect to see automated ocean-going vessels. And in addition to seeing automated cars, trucks, and snowplows running at the Richmond Field Station, you can expect to see some automated semi-submersible platforms. But don't expect to see the RFS test track underwater—yet. ■

PATH Database

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Electronic Toll Collection at the Carquiñez Bridge

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Implications

Issues of who loses and who benefits are crucial in decision-making. The findings of this study suggest that in assessing costs and impacts of ITS projects, it is important to measure not only their total costs and benefits, but also the distribution of those costs and benefits. An overall positive net benefit does not necessarily indicate that the net benefits to all the affected parties are positive. Our findings also reveal that different assumptions and modeling techniques will lead to different inputs for the calculations of costs and benefits, which can alter the outcomes of evaluation and affect decision making. ITS project evaluators should be fully aware of these limitations.

This being said, our analysis indicates that the Carquiñez Bridge ETC project should realize most of its objectives. It should provide a higher level of service for toll patrons, facilitate traffic flow on ETC toll lanes, reduce vehicle emissions and fuel consumption, and boost the quantity and quality of data. However, if the demand for ETC use and operating cost reduction is smaller than forecast, savings in toll collection and an increase in operating revenue may not offset the initial capital investment.

Finally, our findings suggest that in the absence of a need to expand capacity, encouraging ETC usage while reducing cost is essential for cost recovery and benefit increase for toll agencies. Toll agencies should make every effort to market ETC and reduce costs. To promote ETC usage, toll agencies may consider increasing the toll on manual toll lanes. Innovative strategies such as involvement of or partnership with industry, financial institutes, and other private sector groups should be developed to reduce or eliminate the costs of transponders to toll agencies.

References

For the complete evaluation of the Carquiñez ETC system see Li, Jianling, David Gillen, and Joy Dahlgren. 1998. Evaluation Analysis for Decision Support: An application to the Electronic Toll Collection System at Carquiñez Bridge. In press.

Members of the research team on ITS benefit-cost evaluation projects include PATH ATMIS Acting Program Director Joy Dahlgren, UC Berkeley Professor of Civil Engineering David Gillen, UCB graduate student research assistant Elva Chang, and University of Texas at Arlington Professor Jianling Li.

Intellimotion

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Publications Manager	Bill Stone
Editor	Gerald Stone
Art Director	Esther Kerkmann
Multimedia Specialist	Jay Sullivan

For more information or comments about this newsletter, please write, call, fax, or e-mail the address below.

PATH Publications
1357 South 46th Street, Bldg. 452
Richmond, CA 94804-4603
Tel: 510/231-9495 FAX: 510/231-9565
e-mail: bstone@uclink2.berkeley.edu
http://www.path.berkeley.edu

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CALIFORNIA PATH
Partners for Advanced Transit and Highways

Director	Karl Hedrick
Deputy Director, AVCSS Program Manager	Steven Shladover
Interim ATMIS Program Manager	Joy Dahlgren
Caltrans Management Liaison	Greg Larson

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