

Research Updates in Intelligent Transportation Systems

Volume 8 No. 2
1999

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Program Manager

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.



High-Occupancy Vehicle/Toll Lanes: How Do They Operate and Where Do They Make Sense?

Joy Dahlgren, PATH

With the advent of electronic toll collection systems has come a new type of highway lane, free to high-occupancy vehicles, (HOVs), like a traditional carpool/bus lane, but also used by solo drivers who pay for the privilege. By combining these high-occupancy vehicle/toll (HOT) lanes with conventional mixed-flow lanes shared by all types of vehicles, highway operators get another tool in their never-ending struggle to reduce delay on congested roads. The new tool gains flexibility from electronic toll collection systems' ability to vary the toll with the time of day, or in response to congestion.

Interest in HOT lanes has mushroomed since the opening of the State Route 91 Value-Priced Express Lanes in Orange County in December 1995. These lanes have significantly reduced congestion. Fears that only high-income travelers would use the lanes have been dispelled by surveys of SR 91 travelers, which show that the lanes are used by people of all income levels and that time-varying tolls, once instituted, are viewed favorably by most people. The lanes have generated substantial toll revenues: \$12.7 million in 1997, to offset that year's \$9.1 million operating cost and the \$133 million capital costs. Toll rates vary by time of day, ranging from \$0.60 when demand is lowest to \$3.75 when demand is highest. High-occupancy vehicles initially paid no tolls but now pay a reduced toll.

In San Diego, the reversible HOV lanes on Interstate 15 were converted to HOT lanes in early 1998. These two reversible lanes operate in the peak direction only, and only during the peak hours: toward the city in the morning and toward the suburbs in the evening. Toll rates are not fixed by time of day, but vary with the congestion level on the main lanes. Reaction to these lanes has been favorable, but they are not as highly utilized as the SR 91 HOT lanes.

A variation on HOT lanes is used on the Katy freeway in Houston, Texas. There, two-person carpools can pay to use the HOV lanes during the peak hour, while three-person carpools pay no tolls. HOT lanes on Highway 1 in Santa Cruz, California, have just been approved by the regional planning agency. Additional HOT lanes have been studied in Sonoma County and Southern California.

The primary impetus for HOT lanes comes from advocates of congestion pricing, who believe that freeways are crowded because they are free, and that users do not pay for the cost they impose on other travelers by using the highway when it is congested. These advocates see HOT lanes as an easy first step toward more widespread pricing of congested roads. Further impetus has arisen from recent questioning of the effectiveness of HOV lanes. Converting underused carpool lanes into HOT lanes keeps the incentive to use carpools,

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Value-Priced Express Lanes (HOT lanes) on State Route 91 along the Santa Ana River in Orange County, just outside Anaheim.

Above: west-bound lanes, heading toward suburbs, are well utilized at 5 PM. Below: leftmost lane is HOV lane; lanes adjoining are toll lanes where toll varies with time of day.

while achieving full use of the lanes, and thus maximum delay reduction for the freeway as a whole. There is also the fiscal benefit of whatever revenue is generated by the lanes.

HOT Lane Performance Depends on Circumstances

There is a tendency to copy a success without analyzing why it succeeded. This is a mistake, because success is almost always context-dependent. The section of SR 91 where lanes were added, along the Santa Ana River, was very congested, and even after the new lanes went into operation, enough delay remained on the mixed-flow lanes to motivate large numbers of people to pay the HOT-lane toll in order to save time. But will HOT lanes be the best option on a less congested route? Are they always a more cost-effective alternative to HOV lanes? In what circumstances do they provide greater net benefits than mixed-flow lanes?

In an attempt to answer these questions a model of HOT lane and HOV lane operation was con-

structed to compare the effects on total person delay of adding a HOT lane, an HOV lane, or an additional mixed-flow lane to an existing highway in a variety of circumstances.

A HOT lane functions in many ways like an HOV lane. In both cases delay is reduced not only for those who use the lane during congested periods, but also for those remaining on the main lanes (because traffic switches to the HOV or HOT lane). However, as more people shift to these lanes, the delay on the main lanes is reduced, and people are less willing to pay (or, willing to pay less) to use the HOT lane. They also have less incentive to form a carpool in order to use the lane. Eventually an equilibrium is reached, when no additional people are motivated to use an HOV or pay a toll in order to use the lane. At what point this equilibrium occurs depends, of course, on how many people are required to form a legal carpool and on the amount of the toll. In both cases people will only be motivated to form a carpool or pay tolls *when the main lanes are congested*.

The most significant difference between the two types of lanes is that a HOT lane provides all travelers with a choice of levels of service—they can travel in congested traffic or they can pay a toll and travel without delay.

HOV lanes typically carry fewer vehicles than could be accommodated at free-flow speeds. This results from the fact that vehicle occupants come in increments of one. On many HOV lanes originally requiring three people per car, the requirement has been reduced to two in order to increase use, and the great majority of HOV lanes now require only two HOV occupants. In some cases, such as the Katy Freeway HOV lane in Houston, Texas, use is low when three occupants per car are required to use the lane, but is high enough to cause congestion when two-occupant vehicles are allowed. In theory, full use of HOT lanes can be achieved by setting tolls low enough to encourage drivers to switch to the HOT lanes, but high enough to maintain free flow.

Because HOT lanes require toll collection equipment, they have higher costs than HOV lanes. Both HOT and HOV lanes have higher costs than mixed-flow lanes because there must be some separation of the lanes and enforcement of the occupancy requirement.

Modeling the Effects of HOT, HOV, and Mixed-flow Lanes

Our model compares the effects of adding an HOV lane, HOT lane, or mixed-flow lane to an existing three-lane highway, as a fourth lane. The model uses an idealized freeway segment, as shown in Figure 1. There is a bottleneck at the downstream end. The neck is long and uniform, contains no entry or exit points, and extends beyond the area subject to congestion. The queue builds up and dissipates during the peak period as shown in the lower section of Figure 1. The model assumes that all travelers are equally likely to use an HOV (it can be demonstrated that this assumption gives the upper limit on the number of people who might shift to HOVs). The initial congested period, before the lane is added, is assumed to be three hours, with travel time building at a constant rate until the middle of the congested period, and then falling at a constant rate until the end of the congested period. The model calculates average person-delay over the *initial* congested period, maximum delay, and the number of vehicle trips. Given these data, the *relative* emission levels can be estimated on the basis of vehicle hours, vehicle miles, and vehicle trips. Of course, actual emissions depend on additional factors, including the vehicle mix, the maximum speeds, and the number and magnitude of accelerations. But for comparative purposes, relative emissions can be estimated on the basis of average trip end emissions, average per-mile emissions on the portion of the trip that is not congested, and average hourly emissions in the freeway segment subject to congestion. Average hourly emissions of CO₂ and hydrocarbons, based on speed and acceleration patterns typical of each average speed, are remarkably constant over the range of speeds experienced on congested freeways.

Six cases were modeled to show how the relative performance of the three types of lane varies with circumstances. The circumstances that varied in these cases were:

- Initial percent of people in HOVs (Initial percent of HOVs): 10.2% (5%), 20.3% (10%), 45% (20%)
- Initial maximum delay moving through the bottleneck: 15 minutes and 45 minutes

HOT lane utilization was assumed to be 1800 vehicles per lane per hour. Maximum flow for mixed-flow lanes was assumed to be 2000 vehicles

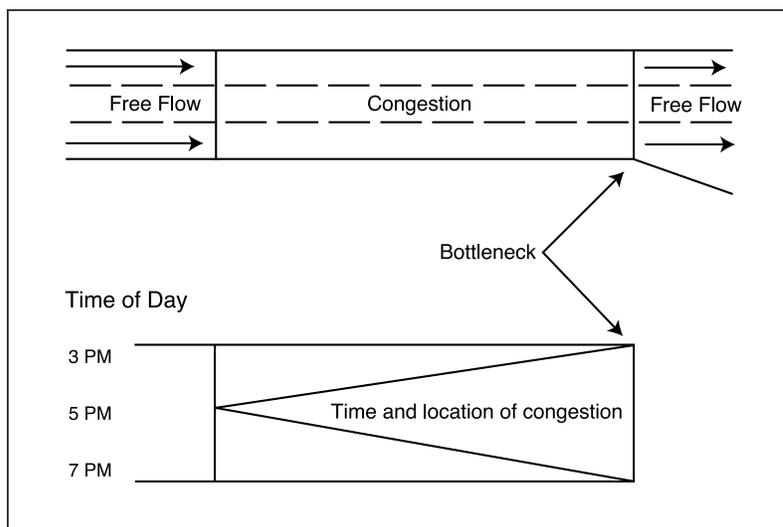


Figure 1. Evolution of congestion over the peak period.

per lane per hour. The carpool occupancy requirement was assumed to be two people. It was assumed that all HOVs would use the HOV lane, and that no non-HOVs would use it.

Our model used a queuing analysis to calculate demand for the highway and the delay for each traveler. The proportion of those travelers wanting to enter the highway during each minute of the congested period who chose to use the new lane was estimated using a logit choice model. This choice model had only two parameters, one that described the effect of the highway travel time differential between the new lane and the other lanes, and another that captured all of the other determinants of HOV use. The latter was based on the proportion of people choosing HOVs when the time differential was zero, before the HOV lane was added. Unfortunately, no studies of the sensitivity of HOV use to travel time savings as a result of HOV lanes could be found. Therefore the model used a value for sensitivity to travel time of -.05 per minute of round trip in-vehicle travel time. This is at the high end of all such values found in the literature, and therefore shows HOV lanes in the most favorable light. The delay on each type of lane for people wanting to use the freeway during the next minute was then calculated, and the proportion choosing to travel via HOV during the next minute was calculated using the new travel time differential.

Clearly, travelers do not have minute-by-minute estimates of travel time. However, over the course of days, traveling at similar times or under similar delay conditions, travelers estimate the highway travel time they will save in an HOV and weigh that

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Steering Control In Vehicle-Following Collisions

Ching-Yao Chan, Han-Shue Tan, Bruce Hongola, PATH

Accidents cause deaths, injuries, and property damage, and have significant hidden social costs as well. Traffic safety is thus a critical issue in transportation research, especially work aimed at improving future transportation systems. Our research studies the feasibility of applying crash-mitigation control in the critical seconds just after a collision. The objective is to determine if automatic steering control can be effectively applied to maintain the colliding vehicles' original paths after the initial impact. This article gives an overall review of our design approaches and simulation results.

Our research studies the feasibility of applying steering control in the critical seconds just after a collision.

A vehicle-following collision, in typical highway driving conditions, can result in significant shift and rotation in vehicle movements. This in turn may send the colliding vehicles into the paths of vehicles near them on the highway, with devastating consequences. Our work is a first step in studying the feasibility of using feedback controllers after a collision as a post-impact handling strategy. A look-ahead controller, consistent with the same generic control law used in PATH experimental demonstrations, was tested in the simulation of many variations on a basic two-vehicle rear-end collision scenario. The controller was found to be effective, illustrating a simple yet robust control law that can be applied to a wide

range of system conditions. Its effectiveness also implies that steering control functions can serve as a driver-assistance or automated function to mitigate the potential damage of crashes.

Introduction

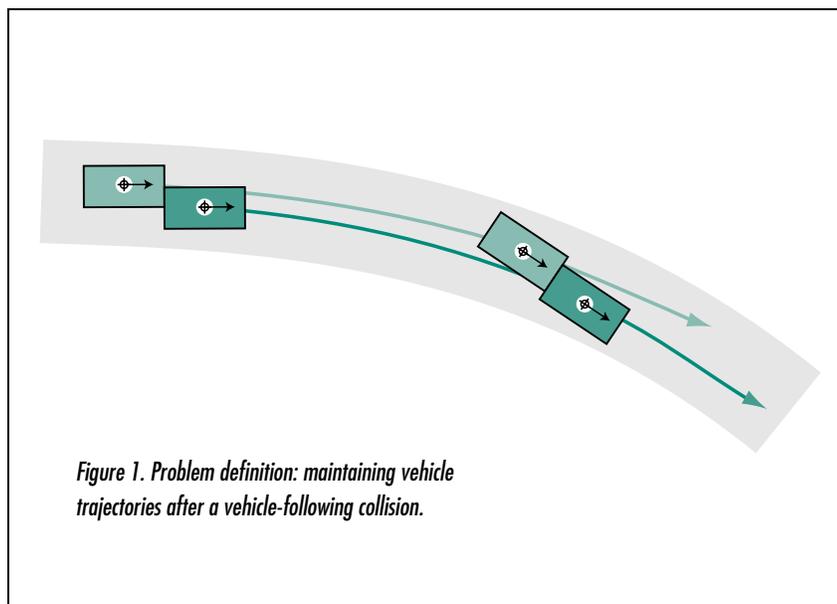
In recent years, PATH researchers have demonstrated automated vehicle control systems that steer vehicles at highway speeds along a designated path with precision and robustness (Tan et al., 1998). Even under emergency conditions, such as a tire blowout, the control systems have been demonstrated to keep the vehicle effectively on track (Patwardhan et al. 1997). PATH researchers have also investigated the effects of vehicle collisions under close-following conditions (Chan, 1998; Chan and Tan, 1999). It was found that without control, vehicles would veer from the original path within one to three seconds after the initial collision. It was also shown in simulation using an ad hoc approach that vehicles involved in a collision could be kept within a designated lane by applying steering control.

Problem Definition

Consider this situation: two vehicles are traveling along a straight or curved road, one closely behind the other. The vehicle in front, traveling at a slower speed, is rear-ended by the vehicle behind. Both vehicles are front steering, and both steering systems are still functional after the collision.

When selecting a controller for this problem, the following questions are posed to judge the effectiveness of steering control in the defined situations:

- Can the vehicles stay within the designated lane after the collision? This condition is measured by checking the lateral displacement of the center of gravity of each vehicle. A vehicle is defined to depart from a lane when the center of gravity moves more than 0.9 meters off the lane center.
- Does the yaw angle of either vehicle deviate from the desired angle and diverge continuously without being corrected? This typically indicates a spin-out. A vehicle is defined to have lost directional control when the yaw deviation is greater than 45 degrees.



- When a vehicle experiences disturbances caused by a collision, can the deviations in lateral position and heading angle converge to a desired range? The allowable errors in positions and heading angles depend on the damage to the vehicles. For example, an offset of rear-wheel angles will cause the heading angle of a vehicle to stay in a non-zero state even though the vehicle continues to move in a straight line.

Simulation Models And Controller

The effects of a collision were treated as external disturbances to the vehicle states. Mathematical models were formulated and analyzed to establish the potential changes to the vehicle states. The appropriate values for the control gains were selected in various scenarios to achieve satisfactory results.

This study was conducted using SMAC (Simulation Model of Automobile Collisions), a model of collision and vehicle dynamics. SMAC was initially developed by Calspan Corporation for the National Highway Traffic Safety Administration (NHTSA). Revisions were added to the code so that a controller could be implemented (Chan, 1999).

The vehicle models presented in the case studies below represent a modern passenger sedan used in recent PATH experiments. Other vehicle models were also evaluated in our study, but are not presented here due to limitations of space. The dynamic characteristics of vehicles affect the selection of optimal control parameters and should be considered in the design process.

The controller chosen for this study was adapted from an empirically verified design that has been extensively tested. The primary objective of the controller is to bring the vehicle back to the center position of a designated lane without use of sophisticated control algorithms. The following generic steering control law is proposed:

$$U = -G (\Delta Y + L \Delta \Psi)$$

- Where
- U = steering input (angle at wheel)
 - G = control gain
 - L = look-ahead distance
 - ΔY = lateral deviation
 - $\Delta \Psi$ = heading angle deviation

The lateral deviation or offset is measured from the center of gravity. The heading angle deviation, in



a straight-line lane, is equivalent to the yaw angle. The control gains are adjusted by changing G and L. A time-delay routine was built into the controller models to account for the possible effects generated in discrete sensing or actuation cycles.

In addition to the aforementioned adjustments to the controller, the rate of change of the steering angle is limited to 30 degrees/sec. This reflects a restraint on the bandwidth or power of the steering actuator. Also, the demanded wheel angle is monitored throughout the simulation so that the steering angle does not become excessive. ΔY is in meters, and U and $\Delta \Psi$ are in radians.

Evaluation Of Control Effectiveness

In the examples presented here, some common parameters and conditions are specified:

- At the beginning of each simulation, the leading vehicle is traveling at 20 m/sec and the trailing vehicle at 30 m/sec at a distance of 12.5m behind.
- The leading vehicle is offset to its right by 0.45m prior to the collision. This is to represent a relatively bad misalignment of vehicles, to create yawing motions of the two vehicles as the collision progresses.
- Both vehicles are proceeding with zero yaw angles at the beginning of the simulation. Steering actions are initiated as the vehicles enter the curved portion of the road (in the curved-road simulation).

Figures 2a and 2b show a collision occurring on a straight road. Without steering control, the vehicles veer from their original lanes within a few seconds (Figure 2a). On the other hand, when steering con-

PATH researchers have demonstrated automated vehicle control systems that steer vehicles at highway speeds along a designated path with precision and robustness.

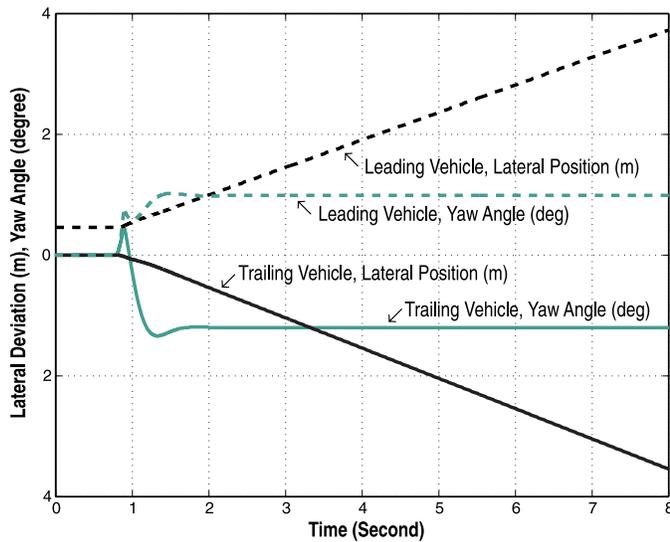


Figure 2a

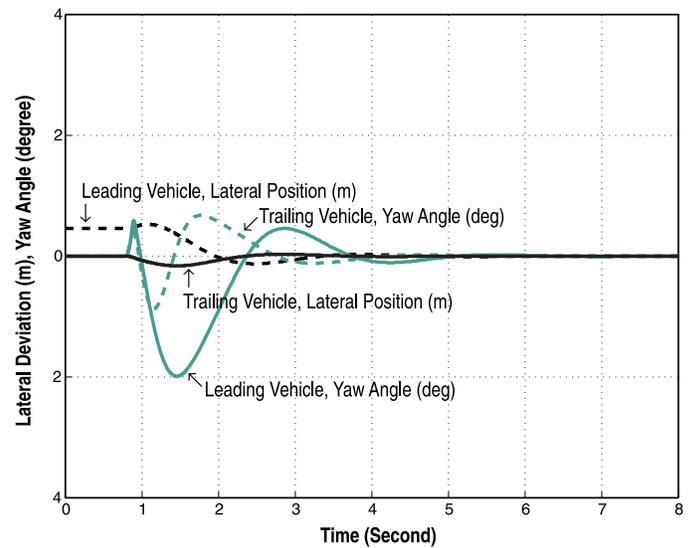


Figure 2b.

Figure 2. Collision on straight road.
2a. No steering control—vehicles veer from lane within seconds.
2b. Steering control—vehicles stay in lane.

control is activated right after the collision, the position and heading angle errors are corrected and the vehicles stay in their lane (Figure 2b).

Figures 3a and 3b show a collision on a curved road. The scenario starts with a straight section and then a circular arc curves to the right with a radius of 400 meters. The collision occurs just as both vehicles enter the curved section. Steering inputs were applied at the beginning of the simulation, but no braking was applied to either vehicle. Included in this scenario is a one-degree offset to the front wheels of the trailing vehicle and the rear wheels of the leading vehicle. The offset was added to the wheel angles right after the collision, and represents a bias caused by structural damage due to the collision. A time delay of 0.1 second was incorporated into the controller. Figures 3a and 3b show that with steering control, the two vehicles follow the curved trajectory successfully. Although time delay typically implies sluggishness in system responses, a delay of up to 0.1 second was well tolerated in tested scenarios. The tolerance of a reasonable time delay indicates that the steering control function could be potentially activated with a crash-sensing device as an automated or driver-assistance system.

Conclusion

The generic controller was shown to be robust and effective in a wide range of simulated conditions. This result was significant because a robust controller is essential to steering control applications

when such systems are open to the uncertainties and variations in operating parameters that characterize highway driving. The robustness of the controller needs to be further evaluated under various sensing systems and potential sensing failures. Moreover, a combined strategy of applying active braking or throttle control in conjunction with steering inputs may be necessary in maneuvering colliding vehicles in certain situations. These remain topics for future work.

Note

The simulation program and related documents are available on the PATH web site at www.path.berkeley.edu/PATH/Research/SMAC. The software was typically run on a PC platform, but was ported to a UNIX machine, where simulation and animation can be executed in sequence. The descriptions of these features are given in Hongola and Chan, June 1999.

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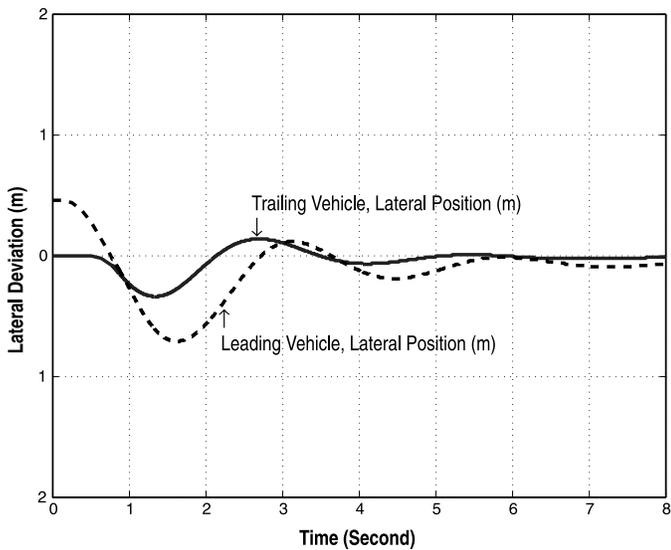


Figure 3a.

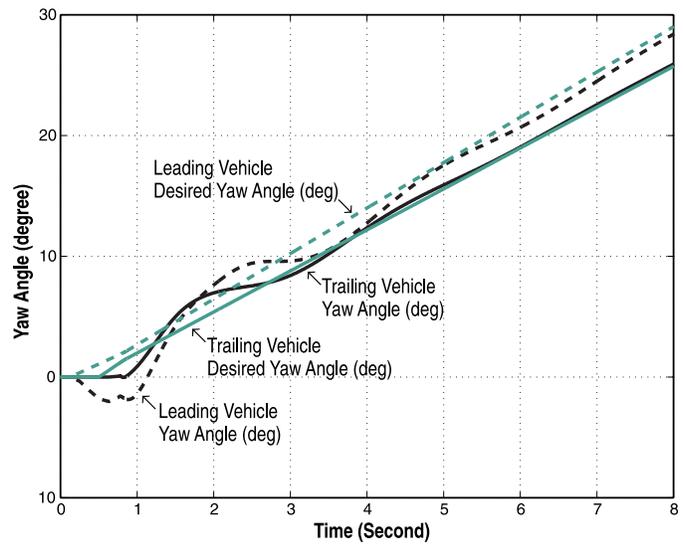


Figure 3b.

Chan, C. and H-S Tan. 1999. A Robust Controller for Lane-Tracking in Vehicle-Following Collisions. 1999 American Control Conference, San Diego, California.

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Figure 3. Collision in curved road with steering control applied 0.1 second after collision.

3a. Change in distance from center line.

3b. Change in yaw angle.



Project Update

The Mobile Offshore Base (MOB) project has moved into a new phase with the construction of scale model modules (platforms). PATH will soon be conducting an experiment using three 1/150 scale platforms to test feasibility, system stability,

and controller performance. The platform shown here (being worked on by Bart Duncil) is the first of the three test models being built by PATH. It will eventually be equipped with four independently steerable underwater thrusters (ducted propellers) and sensors to locate the module in relation to the others. The whole set of three modules will be floated in a 50' x 70' x 2' deep tank and controlled via an "umbilical" cord to a "shore side" computer. We expect to start testing the first complete model in November.

PATH at Demo '99, Transportation Research Center

Steve Shladover, PATH

To the chagrin of many PATH researchers, it sometimes seems that the letters "R" and "D" are less associated with "Research" and "Development" than with "Repeated Demos." There is a continuing demand for "tire kicking" demonstrations of vehicles with ITS capabilities, the latest of which was held at the Transportation Research Center of Ohio on July 26-28. PATH established a record: it is the only organization to demonstrate vehicles in the last three international demonstrations of advanced vehicle control and safety systems, AVCSS (Demo '97 in San Diego, Demo '98 in Rijnwoude, Netherlands and now Demo '99).

At Demo '99, PATH was one of ten organizations providing demonstration rides in AVCSS-equipped vehicles. The PATH demonstration showed our precision docking capability, using a Buick LeSabre

to represent a transit bus. The docking demonstration showed our ability to repeatedly stop the vehicle with a lateral accuracy of 5 mm and a longitudinal accuracy of one foot (30.5 cm), which we are improving. To our knowledge, no other system has demonstrated a comparable docking accuracy. All of the visitors to Demo '99 had the opportunity to ride in the fully-automated Buick, and to closely observe it from the "bus stop" we installed to make the accuracy and repeatability of the demonstration evident (Video of the docking demonstration is available on the PATH Web at <http://www.path.berkeley.edu/PATH/Publications/Videos/>).

Demo '99 was our first use of surface-mounted magnetic markers for guidance, rather than magnets placed in holes below the road surface. Each neodymium magnetic marker was encased in a



Above, PATH demo booth after Ohio summer thunderstorm.

Right, automated docking demonstration drew media and visitors.



Center, Ohio

plastic hemisphere, 75 mm in diameter and 35 mm high, and these hemispheres were then placed on top of our survey marks on the pavement. These magnetic "Botts dots" made it possible to set up the demonstration in a short period of time, and without imposing any damage on the road surface. This method, developed by Dan Empey and Bart Duncil, should make it possible to give future demonstrations in areas where drilling holes for magnets would be impractical or impolitic.

PATH's docking demo at Demo '99 was made possible through much hard work by Han-Shue Tan and Bénédicte Bougler, as well as Dan and Bart, and with the assistance of the Buick Motor Division of General Motors in shipping and maintaining the demonstration vehicle.

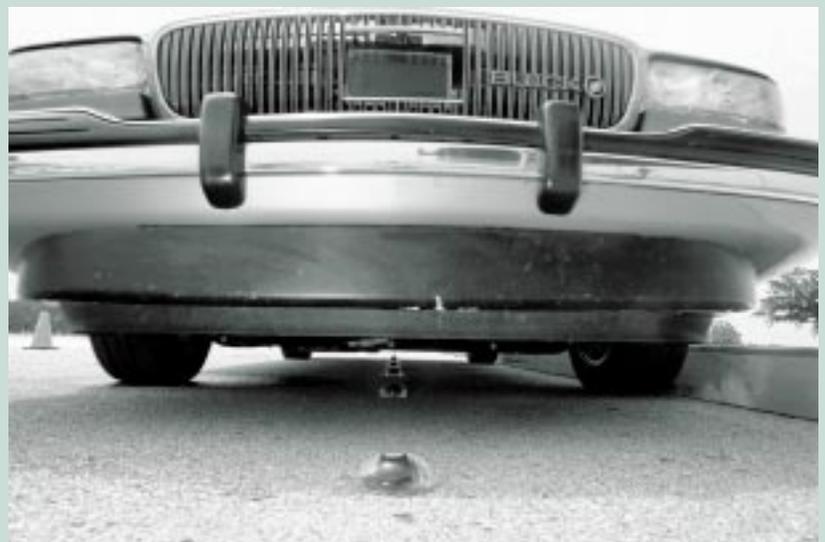


Above and left, bird's eye view of precision docking. The Buicks consistently stopped at the "curb" with longitudinal accuracy of one foot, lateral accuracy of 5mm.

Below, worm's eye view of magnetic "Botts dots." Rare-earth magnets encased in plastic hemispheres laid out magnetic path for demo vehicles to follow.

Left, Han-Shue Tan describes precision docking demo to FHWA's Robert Ferlis, PATH Caltrans liaison Greg Larson, Arizona Department of Transportation's Steve Owen.

Below, PATH engineers Han-Shue Tan, Bénédicte Bougler, and Dan Empey at demo track.



High-Occupancy Vehicle/Toll Lanes: How Do They Operate and Where Do They Make Sense?

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against the other benefits and costs of HOV use. It was assumed that the toll could be set so that the HOT lane would be fully utilized when there was congestion on the main lanes.

HOV Lanes Perform Better Than Mixed-flow Lanes When Delays are Long and the Initial Proportion of People in HOVs is High

Table 1 shows how sensitive the performances of the three types of lanes are to circumstances. When there are initially very long delays, such as 45 minutes, and 20% of people are in HOVs (10% of vehicles are HOVs) before the lane is added, then HOV lanes perform better than mixed-flow lanes. But when the initial delay is only 15 minutes, a new mixed-flow lane performs better than or as well as an new HOV lanes. HOV lanes perform well when the initial delay is high and when the initial proportion of HOVs is high because the high delay

motivates people to shift to HOVs and the high proportion of HOVs means that the HOV lane will be well utilized.

HOT Lanes Perform Better than HOV Lanes When the Cost of Toll Facilities and the Initial Proportion of People in HOVs are Low

Because HOT lanes generally can achieve higher utilization than HOV lanes, the overall delay with a HOT lane is less than with an HOV lane. But if the initial proportion of HOVs is high, the delay differential between a HOT lane and an HOV lane is low and may not motivate many people to use the toll lane. With few travelers using the toll lane, the benefits of the delay reduction may not be enough to offset the cost of the toll collection facilities.

Mixed-flow Lanes Perform Better than HOT Lanes when the Cost of Toll Facilities is High

If both types of lane were fully used, there would be no difference in total delay for all users. But we assume that use of the HOT lane is limited to 1800 vehicles per hour in order to maintain free-flow speeds. So, people using the HOT lane suffer less delay and people using the other lanes suffer more delay than if all lanes were mixed-flow lanes. The primary benefits of an HOT lane over an additional mixed-flow lane come from providing travelers with more choice. If the tolls went to the travelers in the mixed-flow lanes, this would be simply a market situation in which travelers could trade time for money, making everyone better off. But of course, the tolls go to the owner of the facility and may not be used to compensate the people in the mixed-flow lanes. Nevertheless, to the extent that all travelers use the HOT lane some of the time or value having the *option* to use the HOT lane, they benefit from having a choice.

Policy Implications

Figure 2 shows the circumstances in which each type of lane performs best. It shows that if an HOV lane is underused, it would be a good candidate for conversion to an HOT or mixed-flow lane: an HOT lane if the cost of the toll facility was reasonably low and a mixed-flow lane otherwise. (Converting

Table 1. Delay for Alternate Types of Lanes

1a. Initial Maximum Delay—15 minutes						
Initial percent of people in HOVs	Add mixed flow lane		Add HOV Lane		Add HOT lane	
	Maximum Delay	Average Delay	Maximum Delay	Average Delay	Maximum Delay	Average Delay
10%	0	0	5.7	2.0	0	0
20%	0	0	1.9	0.6	0	0
45%	0	0	0	0	0	0

1b. Initial Maximum Delay—45 minutes						
Initial percent of people in HOVs	Add mixed flow lane		Add HOV Lane		Add HOT lane	
	Maximum Delay	Average Delay	Maximum Delay	Average Delay	Maximum Delay	Average Delay
10%	11.2	4.5	15.7	6.3	11.5	3.7
20%	11.2	4.5	9.8	3.6	8.7	2.7
45%	11.2	4.5	5.8	1.8	5.8	1.8

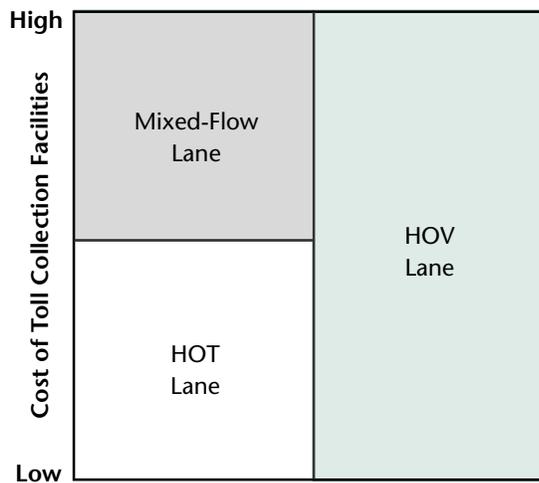


Figure 2. Circumstances in Which Each Type of Lane Performs Best

an underused HOV lane on an *uncongested* section of highway will not, of course, reduce congestion.) It is possible that in high growth areas, increasing demand and congestion will eventually motivate enough HOV use to fully utilize the HOV lanes during certain periods. Conversion of HOV lanes to HOT lanes would preserve the option for the lane to operate as an exclusive HOV lane during these periods, while still allowing it to be fully utilized during periods when there is less HOV use.

There are now 760 lane-miles of HOV lanes in California with more under construction or planned. In 1997 only 4 of the HOV lanes in Los Angeles and Ventura Counties carried more than 1200 vehicles per lane during the peak hour, and they likely carried fewer vehicles during the other hours in the peak period. This is well below the capacity of 2000+ vehicles per hour capacity of a typical mixed-flow lane. In the San Francisco Bay Area, only six sections of HOV lanes, roughly 20% of all such sections, carried more than 1200 vehicles during the peak hour. Of course, HOV lanes do not exist in isolation. They are part of a larger network that may contain multiple bottlenecks, so increasing capacity in one location may cause a new bottleneck downstream and reduce capacity in another location. Furthermore, the presence of an HOV lane in one location in the network may affect the use of HOV lanes on connecting or alternate links. Therefore, before any change in status is made, the effects of the change on the whole network must be examined. Nonetheless, it seems likely that some of California's underutilized HOV lanes would perform better as HOT lanes, and would offer good sites to learn more about how

road pricing affects travelers and revenues. Where appropriate, an experimental conversion of underutilized HOV lanes to HOT lanes could be instituted, including a strong evaluation component so that maximum learning could take place in the process. This could reduce congestion in the short run and provide information to guide investment and management decisions in the long run.

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PATH Presentations

Recent and Upcoming Presentations of PATH Sponsored Research

6th World Congress on Intelligent Transport Systems, Toronto, Ontario, Canada, November 8-12, 1999.

- Mark A. Miller, (Jacob Tsao), "Testing a Decision-Oriented Framework to Understand ITS Deployment Issues: Lessons Learned from the TravInfo ATIS Project".
- Steven Shladover, "Progressive Deployment of Vehicle-Highway Automation Systems".
- James A. Misener, Chuck Thorpe, and Ron Hearne, "Enhancing Driver-Assist Sensors: Background and Concepts for Sensor-Friendly Vehicles and Roadways".

1999 IEEE/IEEJ/JSAI Conference on Intelligent Transportation Systems, Tokyo, Japan, October 5-8, 1999.

- Ching-Yao Chan, Han-Shue Tan, "Application of a Robust Steering Controller in Emergency Situations".

2000 SAE International Congress and Exhibition.

- Art MacCarley, "Advanced Image Sensing".

14th IFAC World Congress, Beijing, China, July 1999.

- Meihua Tai and M. Tomizuka, "Robust Lateral Control of Heavy Duty Vehicles for Automated Highway Systems", (Proceedings Vol. Q, pp. 37-42).
- R. Rajamani, A. Howell, C. Chen, J. K. Hedrick and M. Tomizuka, "A Complete Fault Diagnostic System for Automated Vehicles", (Proceedings, Vol. B, pp. 439-444).

1999 IEEE International Conference of Control Applications, Hawaii, August 1999.

- M. Tomizuka, Meihua Tai, J-Y. Wang and P. Hingwe, "Automated Lane Guidance of Commercial Vehicles," (Proceedings pp. 1359-1364).
- Pushkar Hingwe, Meihua Tai and M. Tomizuka, "Modeling and Robust Control of Power Steering System of Heavy Vehicles for AHS," (Proceedings, pp. 1365-1370).
- Ioannis Kanellakopoulos, "Longitudinal Control Experiments for Commercial Heavy Vehicles (CHVs)".

1999 American Control Conference, San Diego, June 1999

- K-T. Feng, Han-Shue Tan, M. Tomizuka and W-B. Zhang, "Look-Ahead Human-Machine Interface for Assistance of Manual Vehicle Steering," (Proceedings, pp. 1228-1232).
- J-Y. Wang and M. Tomizuka, "Robust H^∞ Lateral Control of Heavy-Duty Vehicles in Automated Highway System," (Proceedings, pp. 3671-3675).
- Arnab Bose, "Analysis of Traffic Flow with Mixed Manual and Semi-automated Vehicles".
- Ioannis Kanellakopoulos, "Autonomous Vehicle Systems: A New Paradigm for Control Research and Education" (Plenary Talk).
- C.-Y. Chan, H.-S. Tan, "Lane Tracking Control in Vehicle-Following Collision Situations", (Proceedings, pp. 3697-3701)
- C. Chen, H.-S. Tan, "Experimental Study of Dynamic Look Ahead Scheme for Vehicle Steering Control", (Proceedings, pp. 3163-3167).

Caltrans Operations-New Technology Meeting, Sacramento, California, August 25, 1999.

- James E. Moore II, Genevieve Giuliano, Jacqueline Golob, "Ventura Smartcard Demonstration Evaluation: Final Report".

Southern California ITS Priority Corridor Transit Working Group San Diego July 19, 1999.

- James E. Moore II, Genevieve Giuliano, Jacqueline Golob, "Ventura Smartcard Demonstration Evaluation: Final Report".

Caltrans Operations Statewide Traffic Engineering Meeting, Millbrae, California, September 28, 1999.

- Pat Conroy, "Overview of ITS".

1999 ASME Design Engineering Technical Conferences, Las Vegas, Nevada, September 12-15, 1999.

- Harry H. Cheng, Benjamin D. Shaw, Joe Palen, Jonathan E. Larson, Xudong Hu, Kirk Van Katwyk, "A Real-Time Laser-Based Detection System for Measurement of Delineations of Moving Vehicles".

Managing Car Use for Sustainable Urban Travel, (Sponsored and hosted by OECD/ECMT), Dublin, Ireland, December 1-2, 1999.

- Daniel Sperling and Susan Shaheen, "Carsharing: How It's Working and Where".

Human Factors, User Interaction, and the Creative Edge in Intelligent Transportation Systems TOPTEC: Designing Smart Products for Smart Vehicles, Society of Automotive Engineers, San Diego, California, June 21-22, 1999.

- Aaron Steinfeld, "Advanced Specialty and Transit Vehicle Systems".

Department of Electrical and Computer Engineering, National Technical University of Athens, Greece, May 20, 1999.

- Ioannis Kanellakopoulos, "Nonlinear Control Design for Autonomous Vehicle Systems" (Invited Seminar).

Department of Electrical Engineering, Swiss Federal Institute of Technology (ETH), Zürich, April 7, 1999.

- Ioannis Kanellakopoulos, "Nonlinear Control Design for Autonomous Vehicle Systems" (Invited Seminar).

ITS-Irvine Seminar Series, May 1999.

- Genevieve Giuliano, "Smart Cards in Public Transit: Lessons for Transit Planning".

Conference on Unmanned Ground Vehicle Technology, Orlando, Florida, April 1999.

- A. Girard, J. Misener, J. Sousa and K. Hedrick. "Control and Evaluation of Mobile Offshore Base Operations", (Proceeding 3693) presented by Jim Misener.

ACSP Annual Conference, Chicago, Illinois, October 1999.

- Genevieve Giuliano, "Smart Cards in Public Transit; Lessons for Transit Planning".

CAATS Annual Meeting, Sacramento, California, September 13, 1999.

- Susan Shaheen, "CarLink: A Smart Carsharing System -Longitudinal Survey Results".

DEMO'99 Technical Session, Dublin, Ohio, July 28, 1999.

- H.-S. Tan, "Automatic Steering Control Based on Roadway Markers: From Highway to Precision Docking".

Bus Rapid Transit Demonstration Program Workshop, Orlando, Florida, October 14, 1999.

- Jim Misener, "BRT Visual Simulations", Moderator & first speaker.

ISOPE Conference, Brest, France, June 1999.

- K. Hedrick, A. Girard and B. Kaku, "A Coordinated DP Methodology for the MOB", (Proceedings, pp 70-75) presented by Anouck Girard.
- W.C. Webster and J. Sousa, "Optimum Allocation for Multiple Thrusters", (Proceedings pp 83-89) presented by Prof. Bill Webster.

VLF599 Conference, Honolulu, Hawaii, September 1999.

- J. Sousa, A. Girard and N. Kourjanskaia, "The MOB SHIFT Simulation Framework", presented by Joao Sousa.
- A. Girard, J. K. Hedrick, and J. Borges de Sousa. "Hierarchical Control Architecture for Mobile Offshore Bases", presented by Anouck Girard.
- S. Spry, D. Empey, and W.C. Webster, "Design and Characterization of a Small-Scale Azimuthing Thruster for a MOB Module", presented by Steve Spry.



PATH, AHMCT Win Award for Caltrans

PATH's automated vehicle demonstration at the 1999 California Alliance for Advanced Transportation Systems Annual Meeting, held 13-15 September in Sacramento, formed an integral part of a Caltrans exhibit that brought home one of the meeting's Awards of Excellence. Speeding forward and in reverse through cones on a half-mile track with very tight (39m radius) turns, a fully automated PATH Buick LeSabre demonstrated precision lateral control as well as precision automated docking. Passengers were impressed as the vehicle took the tightest turn at 0.5 g, no-hands, no-feet. "Fascinating," said Bernie Orozco, principal consultant to California Senate Majority Leader Richard Palanco, at the end of his ride.

Also on display at the Caltrans exhibit were automated highway maintenance vehicles from the Advanced Highway Maintenance and Construction Technology Center at UC Davis (AHMCT). Featured were the Advanced Snowplow, which uses the PATH Magnetic Guidance System, and a front loader, cone truck, and herbicide-spray vehicle.

From left to right: Caltrans staffers Jan Hoggatt, Pete Hansra, PATH liaison Greg Larson, Larry Baumeister, Hassan Aboukhadijeh, Bill Okwu, and Asfand Siddiqui with the award, inscribed:

*1999 Award of Excellence
CAATS Civic Entrepreneur
presented to the Caltrans Office of
Advanced Highway Systems.* ■



PATH on Paper

An Updated List of Recent PATH Sponsored Research Publications

PATH publications (which include research reports, working papers, technical memoranda, and technical notes) can be obtained from:

Institute of
Transportation Studies
Publications Office
University of California
109 McLaughlin Hall
Berkeley, CA 94720-1720

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

[http://www.its.berkeley.edu/
publications.html](http://www.its.berkeley.edu/publications.html)

A searchable database of
PATH publications is
available via the PATH World
Wide Web site at:
<http://www.path.berkeley.edu>

Assessing Opportunities for Intelligent Transportation Systems in California's Intermodal Operations and Services – Review of Literature, Mark Miller, Camille Tsao, August 1999, \$5, Tech Note 99-1*

Simulation of ITS on the Irvine FOT Area Using 'Paramics 1.5' Scalable Microscopic Traffic Simulator: Phase I: Model Calibration and Validation, Baher Abdulhai, Jiuhi-Biing Sheu, Will Recker, April 1999, \$15, UCB-ITS-PRR-99-12*

Collision Avoidance Analysis for Lane Changing and Merging, Hossein Jula, Elias B. Kosmatopoulos, Petros A. Ioannou, May 1999, \$10, UCB-ITS-PRR-99-13*

Analysis of Traffic Flow with Mixed Manual and Semi-Automated Vehicles, Arnab Bose, Petros Ioannou, May 1999, \$10, UCB-ITS-PRR-99-14*

A General Framework for Verification, Simulation and Implementation of Real Time Control Algorithms, Farokh H. Eskafi, May 1999, \$5, UCB-ITS-PRR-99-15*

Diagnosis and Communication in Distributed Systems, Raja Sengupta, May 1999, \$5, UCB-ITS-PRR-99-16

The Market for Traffic Information - A Study of Industry Structure and Prospects, Shirley Chan, Matthew Malchow, Adib Kanafani, June 1999, \$10, UCB-ITS-PRR-99-17

Evaluation of the Anaheim Advanced Traffic Control System Field Operational Test: Executive Summary, M.G. McNally, James E. Moore II, C. Arthur MacCarley, R. Jayakrishnan, July 1999, \$5, UCB-ITS-PRR-99-18*

Assessing the Benefits and Costs of Intelligent Transportation Systems: Ramp Meters, Seungmin Kang, David Gillen, July 1999, \$15, UCB-ITS-PRR-99-19*

Assessing the Benefits and Costs of Intelligent Transportation Systems: The Value of Advanced Traveler Information Systems, David Levinson, David Gillen, Elva Chang, July 1999, \$15, UCB-ITS-PRR-99-20*

Position Location in AHS by Magnetic Pseudo-Noise Signals, Soheila Bana, Pravin Varaiya, July 1999, \$5, UCB-ITS-PRR-99-21*

Address Resolution in One Lane Automated Highway Systems, Soheila Bana, Pravin Varaiya, July 1999, \$10, UCB-ITS-PRR-99-22*

Simple Results on Communication With Neighbors, Anuj Puri and Pravin Varaiya, July 1999, \$5, UCB-ITS-PRR-99-23*

Fault Diagnosis for Intra-platoon Communications, Hidayet Tunc Simsek, Raja Sengupta, Sergio Yovine, Farokh Eskafi, July 1999, \$10, UCB-ITS-PRR-99-24*

Bus Operations in Santa Clara County, Potential Uses of AVL, and Framework for Evaluating Control Strategies, T. Chira-Chavala, David Gillen, Lee Klieman, Amy Marshall, July 1999, \$20, UCB-ITS-PRR-99-25*

Evaluation of the Anaheim Advanced Traffic Control System Field Operational Test: Introduction and Task A: Evaluation of SCOOT Performance, James E. Moore, II, M.G. McNally, C. Arthur MacCarley, R. Jayakrishnan, July 1999, \$20, UCB-ITS-PRR-99-26*

Evaluation of the Anaheim Advanced Traffic Control System Field Operational Test: Final Report Task B; Assessment of Institutional Issues, M.G. McNally, James E. Moore, II, C. Arthur MacCarley, R. Jayakrishnan, July 1999, \$20, UCB-ITS-PRR-99-27*

Evaluation of Caltrans District 10 Automated Warning System: Year Two Progress Report, C. Arthur MacCarley, August 1999, \$15, UCB-ITS-PRR-99-28*

Transient Aerodynamic Effects on a Four-Car Platoon During Passing Maneuvers: Data Summary, L. Tsuei, J.K. Hedrick, Ö. Savas, August 1999, \$20, UCB-ITS-PRR-99-29

Ventura/Lompoc Smart Card Demonstration Evaluation: Final Report Volume 1 Technical Performance, User Response, and Institutional Analysis, Genevieve Giuliano, James E. Moore II, Jacqueline Golob, August 1999, \$35, UCB-ITS-PRR-99-30*

Safety Analysis of Concept Systems for Guidance and Control of Transit Buses, James Bret Michael, August 1999, \$5, UCB-ITS-PRR-99-31*

Models of Vehicular Collision: Development and Simulation with Emphasis on Safety V: MEDUSA: Theory, Examples, User's Manual, Programmer Guide and Code, Oliver M. O'Reilly, Panayiotis Papadopoulos, Gwo-Jeng Lo, Peter C. Varadi, August 1999, \$20, UCB-ITS-PRR-99-32*

*Available online at: [http://www.path.berkeley.edu/
Publications/PATH/index.html](http://www.path.berkeley.edu/Publications/PATH/index.html)

Patrick Conroy New ATMIS Program Manager

Patrick Conroy has joined PATH as Advanced Transportation Management Information Systems (ATMIS) Program Manager. He comes to PATH from Caltrans' New Technology and Research Program, where he served as Office Chief.

In welcoming Conroy to PATH, Director Karl Hedrick said: "Pat is known around the world as an innovative proponent of Intelligent Transportation Systems. His experience in the area of advanced traffic management and information systems will help him to establish PATH as the premier ATMIS research organization in the country."



For some twenty years, Pat Conroy has been exploring system management approaches to transportation, energy and environment issues, frequently working with the Institute of Transportation Studies and other academic institutions. Starting at the California Energy Commission in 1978, and moving to Caltrans in 1983, Pat's professional history includes principal roles in a number of milestone programs in California:

- Initiated the California Fuel Efficient Traffic Signal Management Program which provided technical and financial assistance to some 160 local jurisdictions to improve arterial street network operations through computerized signal timing optimization. This program, first of its kind in the nation, and involving UC Berkeley Professors Dolf May and Alex Skabardonis and Professor Will Recker from UC Irvine, received a national award from the Institute of Transportation Engineers.

- Acted as transportation policy and impacts evaluation manager for the pioneering California State Employee Telecommute Pilot Project. In this role, Mr. Conroy worked closely with UC Davis Professors Ryuichi Kitamura and Patricia Mokhtarian. Positive findings resulted in the execution of a Governor's Executive Order establishing tele-commuting as a formal State employee work option.

- Served as principal author and editor of the 1991 report to the California Legislature entitled "Transportation Technology Development for California: Program and Policy Review" which helped launch California's broad-based Intelligent Transportation System (ITS) program; also a principal author of Caltrans' first Advanced Transportation Systems Program Plan.

- As Chief of the Office of Advanced Transportation Systems Management and Planning in Caltrans, Pat worked with PATH and other partners to develop the Transportation Management and Information Systems element of the Advanced Transportation Systems Program. One significant milestone was the establishment of a real-world testbed for system management applications, linking research labs at the University of California, Irvine and Cal Poly San Luis Obispo to Transportation Management Centers at Caltrans District 12 and the cities of Anaheim and Irvine.

Pat Conroy has also been intimately involved in the national research arena, first in exploring transportation energy efficiency strategies and more recently in helping broaden the national ITS agenda from highway-only to multimodal transportation system management. In 1998, Pat served part-time as an Instructor at the University of California, Davis, developing and teaching a post-graduate course on Intelligent Transportation Systems. He is a long-time member of the Transportation Research Board, the Institute of Transportation Engineers and ITS America.

Pat Conroy had this to say about his new job at the California PATH Program:

"I am delighted to join PATH and be part of a team of such bright, innovative people. Throughout my career I have been associated with extremely competent and enthusiastic transportation professionals in government, industry and academia. My good fortune continues. I look forward to working

I hope to be able to expand cooperative ATMIS research and development with other governmental agencies and private industry, including transportation entities in other states and nations.

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Pat Conroy New ATMIS Program Manager

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with Caltrans and the academic partners that make up PATH in continuing to advance the state-of-the-knowledge in transportation. With the development of strategic deployment plans by many of our ITS partners, I see new opportunities for PATH to support the collective ITS/system management agenda through research specifically linked to these plans. To this end, I hope to be able to expand cooperative ATMIS research and development with other governmental agencies and private industry, including transportation entities in other states and nations." ■

Intellimotion

Intellimotion is a quarterly newsletter edited and designed by the California PATH Publications Department.

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PATH Database

The PATH Database, the world's largest on Intelligent Transportation Systems, is now accessible at:

<http://www.nas.edu/trb/about/path1.html>

It currently lists over 18,000 bibliographic records with abstracts.

Also available is the monthly PATH Recent Additions list, a collection of 150-200 recent citations to the Database, at:

<http://www.lib.berkeley.edu/ITSL/newbooks.html>

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PATH

Partners for Advanced Transit and Highways

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Deputy Director, AVCSS Program Manager	Steve Shladover
ATMIS Program Manager	Pat Conroy
Caltrans Management Liaison	Greg Larson

Primary funding provided by:



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ISSN-1061-4311

Printed on recycled paper

