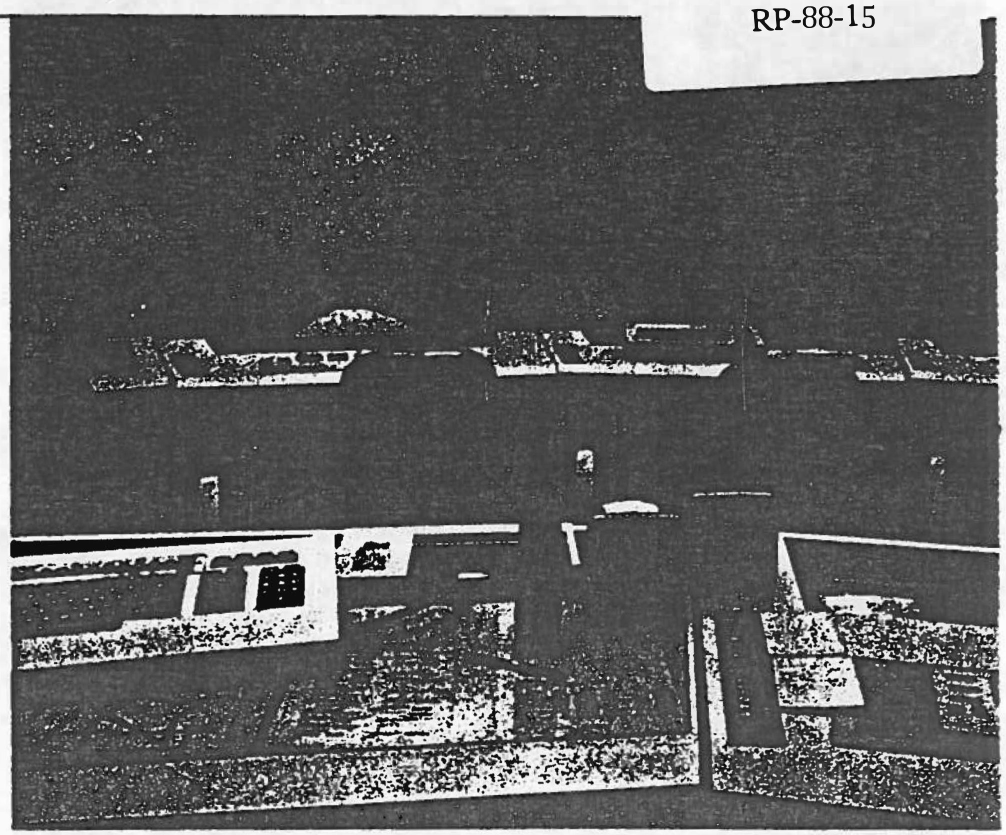
# AUTOMATING URBAN FREEWAYS

RP-88-15



*The authors, faculty members at the University of California at Davis, are research participants in ITS' Program on Advanced Technology for the Highway (PATH), which is sponsored principally by the California Department of Transportation (Caltrans). Robert A. Johnston is an associate professor of environmental studies, Daniel Sperling is an associate professor of civil engineering and environmental studies, Paul Craig is a professor of applied science engineering, and Jay Lund is an assistant professor of civil engineering. (The views presented in this article do not necessarily reflect the views or policies of the ITS PATH Program or Caltrans.)*

Urban residents are becoming frustrated and angry as traffic congestion continues to worsen. Indeed, surveys show that the public often perceives transportation as the number one urban problem—surpassing crime, housing, education, and drugs. Yet no compelling solution has emerged. For that reason, interest in the concept of automated control of motor vehicles on highways has gained renewed attention. Highway automation is an appealing concept because it promises increased capacity without having to build new highways. It is a technical fix that allows continued dependence on automobiles and avoids conflict with local communities opposed to new freeways. Automation promises reduced accidents, increased roadway capacity, and faster trips and reduced stress for the driver.

Automated technology would lessen dependence on the slow, imprecise, and erratic reactions of drivers (including those under the influence of alcohol and drugs), and would provide routing and traffic flow information to enable automatic selection of the fastest route. Drivers would experience less stress, shorter travel times, and eventually would be able to use their time in vehicles for purposes other than driving.

But will all these wonderful benefits ever be realized? As a preliminary exploration of the concept and promise of highway automation, we sketch a likely implementation path for the advanced technologies and explore some of the important policy issues associated with this implementation path. We focus on urban areas because they experience the worst problems, and on freeways because they carry a disproportionately large share of the traffic.

First, as background, note that highway automation encompasses three sets of technologies: navigational information and controls so that vehicles follow optimal routes from origin to destination; lateral control of vehicles within lanes; and longitudinal control between sequential vehicles. Increased capacity would result from shortened headway distances between vehicles, smoother and more efficiently routed traffic flows and possibly reduced lane widths.

## A Developmental Path for Automated Highways

**Stage 1—Voluntary use of navigational aids.** Navigational systems would provide route guidance and real-time traffic information to drivers. On-board electronic maps that track a vehicle's location (already commercially available) could be upgraded into sophisticated route guidance devices that would inform drivers of optimal routes to their destinations. Real-time information on traffic conditions would be provided by a system of sensors, computers, and communication devices operated by the state department of transportation or other highway manager. Such systems are already being tested in England, West Germany, Japan, and the United States (Los Angeles).

**Stage 2—Longitudinal and lateral controls on-board the vehicle.** New technologies, added to vehicles either during manufacture or after-market, automatically keep the vehicle within freeway lanes laterally and at specified longitudinal distances behind the preceding vehicle. Optical or radio signals, transmitted or bounced back by barriers and vehicles, are fed continuously to the steering, acceleration, and braking controls of the vehicle. Since these "smart" vehicles would be operating independently of each other, they would continue to require relatively large spacing between vehicles to assure safety.

It is possible, though not certain, that vehicles equipped with stage 2 technology could operate in mixed traffic without operator intervention as long as the

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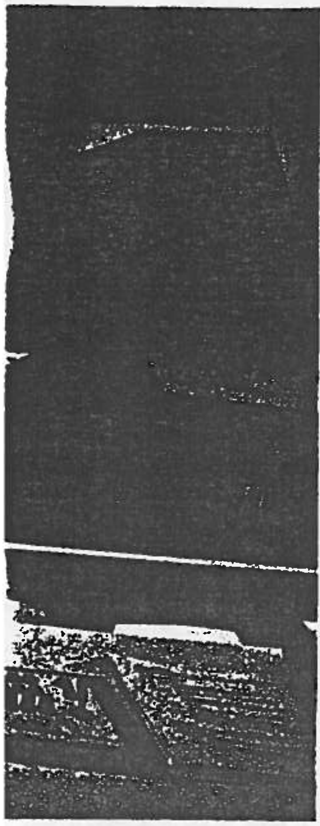

Photo courtesy of Caltrans

*Products such as computerized maps . . . are the building blocks for highway automation.*

vehicle stays in one lane. Clearly, there are many legal issues associated with "hands-off" technology, which would have to be resolved. While such a system would not increase traffic volumes much, it would appeal to many drivers since it would free their attention for other tasks and perhaps improve safety as well.

**Stage 3—Dedicated (left-hand) lanes and communication among clusters of vehicles.** Dedicated lanes and inter-vehicle communication would reduce headways, minimize the "shock wave" effects that occur when vehicles operate independently, and thereby increase traffic flow. By allowing only vehicles with automated controls to access one or more specified lanes, speeds may be increased, but because of safety problems and vehicle acceleration limits in moving in and out of the automated lanes, speeds probably could be only about 20 mph more than traffic in the adjoining nonautomated lanes.

**Stage 4—Full automation of all freeway lanes.** Only automated vehicles would be allowed on the freeway. Vehicles would be able to change lanes and exit to other freeways under automatic control. Small vehicle spacings would be used both laterally and longitudinally, allowing more lanes than today. A special lane for trucks and buses would be needed for wide vehicles. High flows could be obtained since most lanes would operate at high speeds and short headways. Drivers would be completely released from vehicle responsibilities while on the freeway. All entering vehicles would need to pass a diagnostic scan to make sure their equipment was in good working order.

**Stage 5—Full "door-to-door" automation of all roads.** With ubiquitous automation of roadways, all vehicles would be automatically controlled. A driver's selection of route and time of day for trips would be influenced by some roadway allocation scheme. Full automation would result in complete reorganization of the transportation system, generating large time and convenience benefits. With this technology, one can imagine major changes in the ownership, storage, and use of vehicles. Examples are automatic parking of vehicles outside of congested core areas, goods delivery without human involvement, and driverless taxis. Stage 5 is highly futuristic and unlikely to be attained for a very long time, if ever.

## Capacity

From a systems manager's perspective, the most important benefit of automation is increased throughput. Today's freeways attain their peak capacity of roughly 2000 to 2200 vehicles per hour per lane when traffic moves at about 35 mph. An automated lane could potentially carry several times as many vehicles. For instance, the capacity of a lane when vehicles are operating at 60 mph at a vehicle headway of 0.5 seconds (compared to about two seconds under manual control) would be 7200 vehicles per hour. With lateral guidance controls on vehicles, lanes could be narrowed, further increasing the capacity of a given width of freeway. Thus, highway capacity could be increased over threefold without widening existing highways or building new ones.

These capacity increases will not be realized during the initial implementation stages, however. Even with automated lanes, one can easily imagine many problems. For instance, it will be difficult for vehicles entering a freeway to move through two or three lanes of bumper-to-bumper traffic, quickly accelerate into fast-moving automated traffic, and then reverse the procedure to exit. Merging may prove not to be worth the trouble for drivers traveling only a few miles on the freeway. Also, limited vehicle performance and safety considerations associated with merging may require that automated traffic move only 20 mph or so faster than traffic in nonautomated lanes. This problem of merging through congested lanes could be eliminated by building exclusive entry and exit ramps for the automated lanes, but the cost in land and money would be very high.

In addition, as automated lanes become more tightly packed, drivers wishing to enter the automated lane(s) may have difficulty doing so—a situation analogous to that in transit systems where late-arriving passengers must wait for later buses or trains.

## Equity and Efficiency: The Need to Allocate Space

Advanced stages of automation will provide maximum benefit only if access to automated lanes is restricted. A number of techniques for allocating roadway capacity are possible: waiting or delay, pricing, selection based on purpose of trip, random or statistical selection, and ration tickets. These allocation systems for automated highways could, of course, also be used on nonautomated freeways.

Currently, the waiting and delay method, whereby drivers shun already crowded routes, is the only method used to allocate freeway access. Freeway automation can increase throughput, and perhaps provide temporary respite, but if demand continues to grow and roadway space is not managed, the system—especially the exits—will again become clogged. If we continue to use delay allocation, delay must be moved off the freeway. If off-ramps are not kept free, traffic will back onto the freeway. Ramp metering is one strategy, but has a heavy cost in consumer driving time.

Any allocation system must deal with this problem of clogged exits, possibly by not permitting entrance to a roadway without an exit ticket. Computer analysis could anticipate off-ramp demand, and allocate entrance permission based on anticipated off-ramp load. A less satisfactory system would ban exiting at overburdened off-ramps, causing commuters to occasionally pass through the entire downtown area of a city.

Pricing allocation schemes could be implemented by placing heavy taxes on vehicles or by charging for access to downtown (based on time of day or current traffic conditions). Computer models from the energy allocation field (peak-load and marginal cost pricing) should be applicable to this decision-making process. For example, the cost of a particular trip could be continuously computed, and the rates made available to each commuter. One could even envisage a market for roadway use which would provide known prices to the commuter in the same way that the farm product futures market protects the farmer.

Alternatively, access to roadways could be provided on the basis of trip purpose—for example, unrestricted access might be given to ambulances, police and fire services, or even local politicians. Like economic allocation, allocation schemes based on trip purpose are subject to attack on equity grounds. Statistical allocation based on random selection or with statistical weighting (for example, on the basis of vehicle occupancy) would overcome this objection, though the uncertainty might be costly for those who need to arrive at work at well-defined times. Allocation by rationing would give each consumer a certain number of allowable vehicle miles for each peak and off-peak period throughout the year. Perhaps these vehicle-mile ration tickets could be traded.

Note that all of these allocation systems could be used to encourage ride-sharing, by making price, probability of access, or delay dependent upon vehicle occupancy.

## Privacy

Systems capable of routing vehicles and allocating access will generate an enormous data base of information on vehicle and road use—creating threats to privacy. Similar privacy issues are occurring throughout the nation as computers become ubiquitous. One example in transportation is the data associated with automated vehicle identification technology in which sensors automatically record passing vehicles so that computers can bill vehicle owners. Such systems are being tested today for collection of bridge tolls and may soon be used for the apprehension of speeders. Even if encryption and security techniques can be developed that would meet toll collection needs while maintaining confidentiality, public acceptance is still not guaranteed.

## Safety and Liability

For two reasons, automated freeways will have to be much safer than today's roadways to be acceptable. First, people tend to be more willing to accept higher risks in situations where they believe they have control than in situations where control is given to others. Also, our society is less comfortable with large accidents than with a multiplicity of smaller ones—as evidenced by the greater attention given to aircraft accidents than to automotive accidents.

Second, motor vehicle manufacturers and other suppliers will be reluctant to market new technologies if by doing so liability for accidents passes from the driver to the supplier. Congress and the state legislatures may need to change liability laws, for example, by reducing or restricting the liability of auto manufacturers and the makers and vendors of automotive devices. Congress did exactly this for nuclear power plants, limiting the liability of owners to a specified dollar value.

How safe must automated technologies be to be acceptable? Can we know in advance how well they will work? Could a few early accidents demolish the credibility of the entire concept? We do not know the answers to these questions, but it is clear that the system must be designed to reduce the number of accidents and to allay fears about possible accidents.

## Environmental Issues

The design and implementation of automated highways may be influenced by air quality regulations and future concern for a global "greenhouse" warming. Most metropolitan areas, especially in California, are in severe violation of air quality standards. The main culprits are motor vehicles. Because the use of automation technologies would increase highway capacity and therefore

*See page 8*

# ITS Extension Calendar

**Preparation of Contract Special Provisions***
Santa Rosa September 7
Redding September 14
Sacramento September 21
Modesto October 5
Santa Maria October 12
Bakersfield October 19
San Bernardino November 21
Hayward November 9
San Diego November 16
Ventura November 30

**Writing Contract Change Orders***
Santa Rosa September 8
Redding September 15
Sacramento September 22
Modesto October 6
Santa Maria October 13
Bakersfield October 20
San Bernardino November 3
Hayward November 10
San Diego November 17
Ventura December 1

**Field Supervision and Project Management of Public Work Projects***
Sacramento September 15-16
Los Angeles September 29-30

**Managing Traffic Growth on Urban Streets***
Riverside October 6-7
Sacramento October 20-21

**Traffic Congestion: Causes, Symptoms, and Mitigation***
Richmond October 12-13
Anaheim October 26-27

**Roadside Safety Features for Rural Roads and Highways***
Fresno October 17
Redding October 19
Sacramento October 21

**Fundamentals and Traffic Engineering***
Los Angeles October 17-21

**Administration of Public Works Construction Contracts***
Eureka October 26-27
Long Beach November 9-10

**Microcomputer Data Management to Support Safety and Traffic Operations***
Location to be announced November 1-2

**Traffic Signal Maintenance Mangement***
Richmond November 2-3
Anaheim November 16-17

**Fourth Airport Noise Symposium***
Los Angeles November 2-3

**Special Assessment Proceedings for Public Works Administration and Engineers***
Fresno November 4-5
San Bernardino December 2-3

**Risk Management and Traffic Safety***
Pleasanton January 10
Anaheim January 24

**Fundamentals of Traffic Signal Design***
Pleasanton January 11-12
Anaheim January 25-26

**29th Airport Management Short Course***
Monterey January 11-13

For information, write or call ITS Extension Programs, Richmond Field Station, 1301 South 46th St., Bldg. 452, Richmond, CA 94804; (415) 231-9590.

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# PAYING THE TOLL

Photo by S. Liebscher

Orange County, California—where 60 miles of high-tech tollways may soon spand the landscape— will be the site of a national conference sponsored by ITS-Irvine. "Paying the Toll: National Perspectives on Toll Road Development," will be held at the Irvine Hilton and Towers, November 13–15, 1988. The two-and-a-half day meeting will convene national experts on toll road planning, financing, and operations, who will join forces to explore ways in which toll roads can ease mounting congestion in rapidly developing areas, and help pave the way for highway construction in an era of constricted budgets and limited public funds.

General and workshop session topics will include: land use and related impacts, public attitudes and perceptions, automatic vehicle identification and toll collection, toll facility design and operation, assembling a revenue package, project success through planning and analysis, financial and institutional issues, and the view from the financial community. Case study presentations will highlight toll road innovations in California, Colorado, Florida, Pennsylvania, Texas, Virginia, and other sites throughout the nation. Participants will also tour the Coronado Bridge automatic toll collection system in San Diego, and view a 15-foot scale model depicting Orange County's proposed transportation network.

The fee for the conference is $295 and includes continental breakfast, luncheon, receptions, and tours. For further information, contact: Lyn Long, Manager of Information and Extension Programs, ITS-Irvine, University of California, Irvine, CA 92717; (714) 856-6294.

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## Automating Urban Freeways

emissions, environmental protection laws could be used to oppose their introduction. However, smoother traffic flows would provide some emissions benefits.

One way to mitigate the air quality and greenhouse effects of increased traffic is to electrify the vehicles and highways. Because electrified vehicles are more reliable and easier to control, highway electrification could increase the viability of highway automation technologies.

### The Potential of Automation

Rapid growth in freeway congestion is occurring at the same time as advances are being made in automation technology, computer control, and data processing. The technical capability to automate roadways is near. How we proceed is unclear.

Highway users are ready and willing to pay for products that provide them with additional travel information, convenience, and time savings. Products such as computerized maps and collision avoidance devices are the building blocks for highway automation; they should be encouraged.

More broadly, though, the promise of automation must be viewed in the historic context of many major failures to apply new technology to transportation problems. While technology offers enormous promise, limited societal resources make it imperative that careful thought be given to how it meshes with society. Highway automation has great potential, but considerable effort is still needed not only to develop the hardware technology, but also to consider where, when, and in what form it will be most effective and accepted.

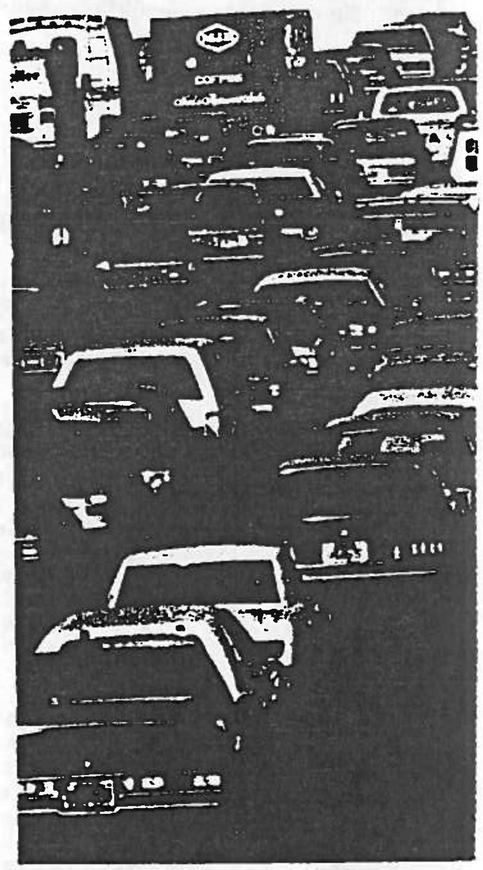

Photo by Frank Smith

# ITS Librarian Receives Award

The Transportation Division of the Special Libraries Association has awarded Michael C. Kleiber the Transportation Division Professional Achievement Award for outstanding service to the library profession and the association. Head librarian at ITS-Berkeley, Kleiber has led major cataloging projects and co-edited several transportation reference works.