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Publication Date

1989

Program on Advanced Technology for the Highway
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA AT BERKELEY

Opportunities and Constraints for Advanced Highway Technologies: A Speculative Analysis

Executive Summary

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UCB-ITS-PRR-89-8

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

October 1989

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PREFACE

This document is the executive summary of Volume I of a two-volume report, prepared for the Program on Advanced Technologies for the Highway (PATH) at the University of California at Berkeley. The work presented here was carried out under the PATH program element, "Opportunities and Constraints Research".

The two volumes of the report are:

Deakin, Elizabeth. "Opportunities and Constraints for Advanced Highway Technologies: A Speculative Analysis". University of California at Berkeley: Institute of Transportation Studies, Program on Advanced Technologies for the Highway. Oct. 1989. (Volume I)

Garrison, William, and Reginald Souleyrette II. "The Relations Between Transportation and Production". University of California at Berkeley: Institute of Transportation Studies, Program on Advanced Technologies for the Highway. Oct. 1989. (Volume II)

The authors thank the many reviewers who provided comments and suggestions on the reports.

PATH Goal Statement

"The research reported herein is a part of the Program on Advanced Technology for the Highway, PATH, within the Institute of Transportation Studies at the University of California, Berkeley. PATH aims to increase the capacity of the most used highways, to decrease traffic congestion, and to improve safety and air quality. It is a cooperative venture of automakers, electronic companies, local, state and federal governments, and universities."

Disclaimer

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Financial Disclosure

Funding was provided by PATH for this research in the amount of \$50,000 (Vol. I and Executive Summary: \$30,000; Vol. II: \$20,000.)

ADVANCED HIGHWAY TECHNOLOGIES: DEFINITION

The term 'advanced highway technologies' includes a variety of concepts which utilize computers, telecommunications equipment, and control systems to improve vehicle performance and/or guideway operation and control. Advanced highway technologies may contribute to the management of such problems as congestion in the highway and air transportation systems, infrastructure deterioration, petroleum dependence, air pollution, and safety concerns. Others are directed toward reducing transport costs and improving performance. Some, of course, may do both, or may transform transportation systems, permitting and propelling broad social and economic change of sorts now hard to envision.

TECHNOLOGY OPTIONS

'Advanced highway technologies' is actually something of a misnomer, since the technologies may be mounted in the vehicle as well as in or along the highway itself. Among the types of technologies being considered are the following.

Navigation Technologies:

Navigation technologies would direct drivers to efficient routes. Simple forms of navigation aids are already available. They include:

- o motorist information systems (radio announcements, dial-in phone messages, variable message signs along freeways), which recommend use of alternate routes or advise motorists of delays, weather conditions, lane closures, and so forth;
- o off-board computerized mapping and navigation aids, available at car rental and hotel desks, which print out step-by-step directions to the driver's destination;
- o on-board navigation aids, which provide on-board visual and/or auditory assistance to the motorist in finding and following the best route to his or her destination.

Advanced forms of navigation technologies would incorporate two-way communications, with real-time adjustments to street and highway operations as well as to routing advice. Navigation thus would be tied to network optimization and control. Vehicles might send traffic control systems data on speeds and delays being experienced; the information would be used to re-time traffic signals and ramp meters, and dispatch an accident clearance team if necessary; then both off-board motorist information systems and on-board navigation advice would be updated. Pre-trip planning also would be

possible, and could range from a dial-up information system, perhaps with predictive capabilities, to a reservations system which could save (or assign) a “space” on an on-ramp or guideway or in a parking lot for a specified period.

Vehicle Automation Technologies:

Vehicle automation technologies would assist the driver to operate with increased safety, both under ‘typical’ conditions and at higher speeds and/or shorter headways. Simple forms of on-board vehicle automation devices are already available: speed control (cruise control and governors), anti-lock braking, “breath analyzers” and other devices designed to prevent operation by impaired or unauthorized drivers. A few cars are being sold equipped with obstacle detection equipment that warns drivers when backing up, and experiments are underway with electronic vision systems (to overcome visibility limits due to fog or snow) and with automatic vehicle equipment diagnostic systems (to detect impending failures). In addition, industrial applications of technologies for proximity sensing, automatic obstacle avoidance, and automatic steering, acceleration and deceleration, and braking are in existence, albeit not necessarily in forms directly applicable to highways.

Advanced forms of vehicle automation technologies would include:

- o sophisticated on-board vehicle equipment diagnostics;
- o on-vehicle methods for automated lane keeping (sensors for adjacent vehicles, automatic steering adjustments);
- o adaptive headway control (responding to the relative distance, velocity, and acceleration/deceleration of preceding vehicles, using on-vehicle sensors and/or inter-vehicle communications);
- o automated collision avoidance (sensing other vehicles, pedestrians, fixed objects, etc., with automated braking and *steering*);
- o adaptive environmental response (adjusting speed, etc. to respond to weather, road surface conditions, topography, etc.).

In combination, these technologies could permit vehicles to operate in narrow lanes and at close headways; special lanes might be reserved for suitably equipped vehicles. High-occupancy vehicle (HOV) lanes accessible only to vehicles with suitable control equipment are one possibility; or other specialized lanes, e.g., for trucks, might be developed.

Vehicle chauffeuring systems proposed in Europe would combine these features with route guidance systems to provide a monitoring and control system which could replace driver functions.

Vehicle Identification Technologies:

Vehicle identification technologies would allow the tracking of specific vehicles through a network without requiring any action on the part of the driver or observer. Automatic Vehicle Identification (AVI) technology is already developed and is being put into use as advances in both the technology itself and in data processing techniques have reduced costs and increased reliability and practicality. Current applications are predominantly industrial (control of rail cars, truck fleet management, etc.), although there have been several applications to monitor buses and vans at airports and, in Europe, to permit priority treatment of buses and ambulances.

Applications involving more widespread use of the technology would include:

For trucks:

- o weight-distance taxation;
- o weigh-in-motion;
- o tracking of hazardous waste movements;
- o high-value cargo tracking (to reduce thefts).

For general traffic:

- o traffic data collection;
- o parking control;
- o road pricing.

The information collected could be used to implement some of the vehicle navigation strategies discussed earlier.

Highway Automation Technologies:

Highway automation technologies would use specialized guideway designs or equipment or devices in, along, or over the roadway to improve highway operations (flows, speeds, safety). A variety of concepts have been proposed, ranging from moving roadways or pallet systems in which vehicles are transported, to “dual mode” systems in which the vehicle could operate either under automated control or on a conventional road. The latter generally would require at least some of the vehicle automation technologies described previously, and perhaps would require some of the vehicle navigation and vehicle identification technologies as well.

Early applications of (non-automated) in-highway technologies include the use of detectors and other monitoring devices in or along the roadway to perform traffic

surveillance and monitor for control system malfunctions. The data thus gathered are currently being tied into motorist information systems, and eventually may be linked to on-board navigation devices as well.

Advanced types of highway automation technologies have been proposed in the U.S. primarily to increase capacity of urban highway systems, although very-high-speed applications for intercity travel also have been discussed. Capacity increases are obtained by permitting narrow lane widths and close headways while reducing driver-induced flow breakdowns and related capacity reductions and accidents.

APPLICATION OPPORTUNITIES

Applications of advanced highway technologies could range from relatively minor amenities and “features” which motorists could find helpful and could purchase (or utilize) as they see fit, and which might be available before the end of the century, to more ambitious concepts which would require major government intervention to proceed. In the latter category are approaches which require major traffic operations control and/or installation of new technologies in or along the roadway and/or systems. Corridor management strategies, lane-centering systems, and automated roadways all fall into this category. However, the technologies also might offer opportunities to address pressing transportation problems, as discussed below.

Preserving Highway Infrastructure:

Advanced highway technologies may have a role to play in efforts to preserve investments in highway infrastructure, by facilitating traffic monitoring, weight monitoring, and perhaps road pricing. Roadway traffic monitoring and surveillance devices and AVI technologies would be of chief importance for these functions.

Congestion Relief:

New designs and technologies might enable roadways to carry more vehicles safely and at higher speed than they now do. Several substantially different options might help improve overall traffic conditions:

- o Control strategies might use accident detection and speed measurement devices along with route advisories or traffic diversions, and manage traffic signals along local arterials and at freeway entries as a system (“corridor management”). Corridor management would thus permit the use of available capacity in parallel routes to

handle traffic that today tries to use the freeway system, and thus could produce improvements from a system-wide perspective.

- o Devices to help vehicles stay centered in their lanes might allow vehicles to operate safely in a lane width of, say, 8-10 feet instead of twelve, and thus would permit additional lanes to be created within existing right of way. Additional devices which permit short headways to be safely maintained would further increase vehicle-carrying capacity.
- o Automated roadways would allow high-speed travel at close vehicle spacings, and thus would create the capability to substantially increase traffic-carrying capacity as well as reduce travel times and uncertainties. If they also assisted with braking, acceleration/deceleration, matching speeds to environmental conditions, and so on, the automated roadways might reduce driver error and thus reduce the accident/incident component of congestion (which now accounts for half or more of freeway congestion).

Some of these options could be implemented on the existing system, but others would probably be more appropriately incorporated into designs for new facilities.

Managing Truck Traffic:

Advanced highway technologies could help reduce the impacts of truck traffic through application of the techniques described for general congestion relief. For example, special truckways could have heavy pavements designed to withstand truck loadings, and thus might reduce overall costs of the highway system. They could be equipped with lane centering devices and headway controls. AVI equipment could keep track of hazardous wastes, or cargoes that the truck companies particularly want to monitor. Weigh-in-motion and weight-distance billing systems also could be installed. Such a system might simultaneously make it possible for trucks to operate at lower cost, pay their own way, and not disrupt traffic. Applications might include access routes to ports in dense urban areas, where growing truck traffic is increasingly leading to neighborhood conflicts and commuter concerns.

Improving Port Access:

High-tech truckways also might be developed to provide direct access to ports. Alternatively, they could be used to provide access from ports to remote warehouse and terminal facilities, allowing some waterfront land to be used for other high-value purposes (e.g., tourism, recreation). In either case, special lanes could be installed on existing highways, or in some locations the use of abandoned rail right of way might be an option.

Improving Airport Access:

Another application of highway automation might be in new corridors connecting the airports in a multiple-airport region, or connecting a new, outlying airport to the metro region's major activity centers. Airport access might be a high speed application of the technologies, and given air travelers' very high values of time, might be self-financing or close to it.

Fossil Fuel Conservation and Air Pollution Reduction:

New highway technologies could reduce both fossil fuel use and air pollution. Among the options are the following:

- o Vehicle diagnostics that signal the need for repairs and maintenance could both improve fuel efficiency and reduce emissions.
- o Route-finding technologies have the potential to reduce fossil fuel use and emissions by reducing VMT as well as improving operating conditions. VMT reduction would be accomplished by helping vehicles find more direct routes, while operations improvements would result from distributing traffic over the network in a way that reduces unnecessary delays and stop-and-go driving.
- o Vehicle automation technologies (headway control, acceleration/deceleration, etc.) also could help conserve fuel and reduce emissions by reducing sudden stops and starts and in general, keeping the vehicle operating at a steadier speed.
- o Some versions of the automated highway would include roadway electrification; vehicles would use roadway power when on an equipped highway section and would operate under their own power (from a small motor or perhaps batteries) off those sections. Depending on how the electricity were generated (nuclear or hydro power, coal, oil, or natural gas, other fuel stocks), and on how much power is lost in transmission and operations, etc., significant conservation of fossil fuels (or at least, petroleum) might be achieved. Emissions also might be reduced and/or exposure to emissions might drop, again depending on the specifics of electricity production.
- o New technologies that permit transit to operate at higher speeds (e.g., on a specially equipped HOV lane) might induce a mode shift favorable to fuel conservation and emissions reduction.
- o Technologies that support the use of very small cars would reduce fuel use and make it easier to reduce emissions (since it is

generally easier to control emissions from a small, fuel-efficient vehicle than from a large, less fuel-efficient one).

Better Highway Safety:

Highway safety could be substantially increased by a number of the advanced technologies. For example:

- 0 Vehicle diagnostic equipment could reduce accidents due to undetected, unsafe equipment or equipment failures.
- 0 On-board security and safety devices could help prevent operation by impaired drivers.
- 0 Accident detection technologies could make it possible to clear accidents faster; advanced motorist information systems and navigation technologies could help traffic avoid accident sites (with benefits both in clearance time and in avoidance of additional accidents).
- 0 AVI equipment could help track the movement of hazardous wastes and speed identification and clean-up in case of spills.
- 0 Vehicle automation technologies could help reduce accidents due to poor visibility, delayed braking, speeds in excess of posted limits or environmental conditions, speeds too low for flow conditions, and so on. These driver-assistance technologies might be particularly helpful to elderly drivers, who generally have poorer vision and slower reaction times than their younger counterparts.
- 0 Highway automation could reduce accidents due to flow breakdowns while permitting higher speeds. Controls also might make it possible to operate very small vehicles with improved safety.

Depending on the mix of options and objectives, advanced highway technologies might be introduced as new transportation investments are made, or could be added to existing facilities as part of reconstruction projects. The technologies which would require a substantial amount of additional right-of-way, restrict the use of existing lanes, or require the sometime-use of parallel arterials might be more easily introduced in growth areas than retrofit into existing communities, although redevelopment may offer opportunities for major new facilities in built-up areas.

BARRIERS TO THE INTRODUCTION OF ADVANCED HIGHWAY TECHNOLOGIES

The degree to which opportunities for the introduction of advanced highway technologies can be captured will depend on competing public choices for development and investment, as well as on the characteristics of the technologies themselves and the institutional and financial framework in which they would operate. Understanding alternative policy directions and potential technological, legal and institutional barriers therefore can be as critical to the work on advanced technology concepts as the technology development itself.

Competing Policy Directions:

Policy directions which might dampen interest in new highway technologies are 1) a substantial new round of investments in conventional highways, 2) major investments in competing technologies such as high speed rail, and 3) greater emphasis on demand management and alternatives to the auto. A fourth option, road pricing, could reduce demand, and hence interest in the new technologies, but (depending on the implementation approach) also might provide the funds needed to implement the new technologies.

If conventional highway construction were to resume on a large scale in the next 10-15 years, interest in new highway technologies might be dampened. A successful program of investments -- one that reduced congestion, improved safety, etc. -- would reduce the need for and interest in technological change (especially change that comes with a big price tag.) A program of investments that did not produce results, on the other hand, also could reduce interest in further investments in highways, both by reducing confidence in proposals' efficacy, and probably by creating a situation wherein other ways of adjusting to traffic will have been undertaken.

Competing technologies may vie with highways for investment dollars in some markets. High-speed rail and tilt-rotor aircraft, if successful, could reduce demand for conventional highways and new highway technologies as well.

A reorientation toward demand management and alternatives to the auto could reduce pressures for urban and suburban highway improvements. Transportation systems management (TSM) plans, parking controls, employer-based commute alternatives programs, and land use - transportation coordination could be components of a demand management program. Increased investment in transit could further support mode shifts away from the auto, while telecommuting and increased use of flextime respectively could reduce travel and remove it from congested periods of the day. Such measures could be part of a package to reduce air pollution, fuel consumption, and greenhouse gas emissions, as well.

Road pricing presents mixed signals for advanced highway technologies. On the one hand, marginal cost pricing could moderate demand for highways, removing much of the motivation for advanced highway technologies such as corridor management or high-capacity automated facilities. On the other hand, road pricing might reveal a demand for such facilities, and provide the revenues to proceed with them.

Markets:

Questions also need to be asked about certain aspects of the advanced highway technologies themselves. Of critical importance is the size and distribution of the potential market (consumer interest and use) for the various technologies being considered. How big would the market be, and what would be its geographic, social, and economic characteristics?

As noted earlier, some technologies may be suitable for implementation during reconstruction or as “retrofits”, while others may be better applied in new highway designs. In the latter case, the technologies would initially have a small market, and if their costs are high, equity questions about differential levels of benefit and expenditure may arise unless there is some surcharge on users of the advanced-technology facilities. Technologies that can be applied to existing facilities, or at least within existing rights of way, would seem to have a distinct advantage.

One of the main arguments for advanced highway technologies over conventional highway construction is that the advanced technologies could substantially increase capacity without requiring new rights-of-way (or double-decked structures, whose questionable aesthetics would probably result in protracted battles over their acceptability.) In initial years, for example, automation probably would be offered as modifications to a lane on a freeway otherwise operating conventionally -- perhaps a high-occupancy vehicle lane, or perhaps a lane into which any properly equipped vehicle could enter. If, however, additional lanes are needed to handle merging, new rights of way might be needed after all (assuming that taking more than a lane of an existing freeway would be hard to do in early years, when only some of the vehicle fleet would be equipped to use the new technologies.)

Other problems might result if in early years gasoline and diesel powered vehicles are concentrated in an automated lane. Air pollution emissions could be excessive, possibly resulting in violations of air standards and unhealthy, high levels of pollutant exposure for freeway users. Of course, this problem might be avoided if the vehicles or roadways were electric-powered; but that would mean automation might be farther off.

Operational characteristics of the advanced highway technologies could affect the nature and size of their markets, as well. A basic issue may turn out to be the length of trips for which the technologies are truly helpful. Many of the technologies being proposed seem to be aimed at improving conditions for what are popularly perceived as

ever-lengthening commute trips made during the peak periods on the freeways. But the popular perception is a series of misconceptions (e.g., the average auto trip is about 10 miles, with the median lower yet, and some 40-50 percent of work trips do not use a freeway at all.) These figures suggest that technologies whose benefits fall mainly to peak period freeway users would be valued by half or fewer of all commuters -- by considerably fewer if the technologies were applied only along selected freeway links. Furthermore, if the benefits are principally to those who make long trips, only some freeway users would be helped, further reducing the potential market (and number of supporters) for the advanced technologies. This might be the case, for example, for automated lanes, if because of merging and weaving considerations access is permitted only every few miles. Even cars equipped to use such lanes might choose not to do so if their stay on the freeway is short and the merge procedure is complicated and time-consuming.

Market issues are raised by several other of the prominently considered advanced highway technologies. For example, it has been suggested that lane-centering and lateral guidance systems might be applied first to improve the operation of HOV lanes and vehicles. While these lanes and vehicles may be a useful testing grounds for the new technologies, in most cases it is not clear that there is enough transit demand to justify much investment in capacity or speed enhancements for HOV lanes. If, on the other hand, the market turns out to be auto drivers making long trips to the CBD, one might ask: since these are also the trips most easily served by transit, car-pools and vanpools, why create a new service? The possibility that many of the users of the automated highway might formerly have commuted by transit or ridesharing should be evaluated.

Another consideration is how ons and offs would be handled if automation increases flows. Ramp capacity might prove to be the limiting factor -- or local street capacity to handle traffic going to and from the automated roadway, or local parking capacity to handle a higher number of vehicles being brought to a particular destination. Off-system problems, if not carefully dealt with in advance, could prove to be the limiting factors in consumer acceptance of new highway technologies.

Costs, and the direct consumer benefits they produce, are another important consideration. Consider navigation technologies. While route guidance equipment could save drivers time in finding destinations for the first time, and might be a valued feature on rental vehicles, it is not at all obvious that the market for adding such equipment onto privately owned vehicles would be large, unless the cost were very low. The additional equipment necessary to permit a car to operate on an automated guideway could up the price considerably. While consumers might be willing to pay for automation technologies that would save them a lot of time, applications which emphasize social benefits such as capacity increases or safety instead of personal benefits such as speed improvements are not likely to induce car buyers to add optional equipment to their new vehicles.

Institutional Issues:

New highway technologies raise a number of issues concerning costs, benefits, and their distribution, some of which could be critical to implementation. For example:

- o What tort liability issues might the advanced highway technologies raise, and how might those issues be dealt with? What effects might they have on interest in producing, deploying, or using the advanced technologies?
- o What social and economic issues might the new technologies raise? Would access to the benefits of new technologies be limited, or could the benefits be widely available?
- o What issues would the new highway technologies raise concerning state/local relations?

Liability:

Tort liability is an issue which goes well beyond questions of advanced highway technologies. Liability claims plague the medical profession, manufacturers of a wide variety of products, state and local governments, even lawyers. While there are growing arguments being made that litigation has gotten out of hand and awards have become excessive, others argue forcefully that the injured have legitimate reason to seek compensation. Resolution of these different views of tort liability does not seem likely to occur in the near future.

Tort liability is a serious issue for several of the proposed highway technologies. Already, liability claims consume substantial portions of many state and local transportation agencies' budgets; vehicle manufacturers also are subject to vast liability claims. So-called "deep pockets" decisions, in which awards exceed apparent fair-share damages caused, add to the concern. No one is anxious to take on additional risks, yet that is exactly what some of the new technologies would seem to entail.

Probably the most serious (and apparent) liability issues arise in the case of automated highways. It is one thing for drivers to follow too closely on their own; accident responsibility falls on their shoulders. It is another thing for a public agency to encourage, or require, close following. In the case of an accident, whether due to roadway equipment failure or foreseeable vehicle failure, a public agency which has encouraged close spacing between vehicles probably would be held liable for at least a share of the costs of the foreseeable harm due to a multiple-car collision. If vehicle manufacturers' equipment also is involved (e.g., environmental sensors fail to detect an icy pavement), they too might share responsibility for the tort. Because of concerns about liability, some analysts have suggested that automated facilities (at least, in their

early forms) might carry fewer cars than do freeways today -- because drivers follow more closely than control equipment would permit.

Route guidance and corridor management also could raise critical liability issues. If, based on an incorrect route description, an accident occurs, liability might well fall upon those providing the guidance. If corridor management diverts traffic and a severe accident occurs on the street to which traffic is diverted, is there shared liability? Here, too, the answer may well be yes.

How severe the liability problem might be is hard to say this far in advance. Some fear that liability concerns could totally block the introduction of the more ambitious, centrally managed highway technologies; others argue that liability concerns mean that use of the highway and vehicle technologies would have to be optional (an approach which may or may not really protect the technology providers, depending on the specifics). If demonstration projects can be undertaken and the technologies demonstrated and refined in a somewhat sheltered operating environment, it may be possible to reduce liability concerns (and insurance requirements). Alternatively, legislative limits on liability could be established -- but the chances of obtaining such legislation do not seem very good at this time, considering the reluctance to address pressing concerns of hospitals, doctors, and other active interest groups.

Social and Economic Issues:

New highway technologies raise several questions about social and economic issues. One of the main issues may be that the affluent would be far better served by advanced technologies than the average citizen or the less fortunate one. For example, if advanced highway technologies require higher car purchase prices and higher maintenance costs -- some estimate that added purchase costs might reach \$2000 per new vehicle, and that maintenance costs would be several times higher than current levels -- the effect would be felt most severely among low- and moderate-income people. They might be priced out of auto ownership, priced off high-tech roads, or pushed into holding onto older vehicles for a longer period than they'd like. The method used to pay for the new technologies could moderate these effects (if users of the new technologies were charged the costs) or perhaps could exacerbate them (if, for instance, the costs of the innovations were shared by all, whether or not they could make use of the new technologies.) Alternatively, only certain lanes of a facility, or certain facilities where parallel routes exist, might be fitted for the new highway technologies, allowing drivers to choose whether to utilize them or not.

Another concern is whether advanced highway technologies might reduce personal freedoms. If road pricing is implemented using AVI technologies, privacy concerns may be raised. The fear would be that a government data bank on where personal vehicles were, when, could be seriously abused. (Such fears might be allayed by development of a toll-deducting technology, with charges stored in or on the vehicle rather than in a

central data bank.) More generally, if highways in the future are rigorously controlled by government -- some visions of the future might even require a reservation to use the automated highway, or might restrict where a driver could exit -- one of the celebrated features of the auto, its ability to take the driver anywhere, any time, would be lost.

A final issue concerns the potential of advanced highway technologies to further disperse development. By making it possible to travel at high speeds through areas that now are congested, the technologies would allow longer distances to be travelled within a given time budget. Whether this would be a positive thing (allowing people access to cheaper land for housing, country living with urban jobs, etc.) or a negative one (adding to the pressures on farmlands and other open space, further detracting from the possibilities for an urbane community) would likely be a matter of considerable debate.

State/Local Relations:

Finally, some of the advanced highway technologies raise questions about state-local relations. Corridor management may be the most obvious. In a number of cases the alternate routes to which traffic is to be diverted are owned not by the state but by local government. Whether the locals will be willing to accept the additional traffic is an important issue. Local acceptance is likely to depend on 1) how much traffic would have to be dealt with; 2) whether the diverted traffic could be handled without severe impact on local traffic flows; 3) whether the local community had other plans for the use of the extra capacity (e.g., to support local development), and 4) whether impacts on businesses and residents along the diversion route would be positive (as might occur if traffic increases brought more potential customers in contact with local businesses) or negative (due to disruptions of pedestrian flows, loss of on-street parking, increased traffic noise and air pollution, etc.) Responsibility for the maintenance of pavements, traffic signals, etc. along the corridors and liability for accidents during diversion periods are other questions that may need to be resolved.

Of course, improvements in freeway operations also could reduce traffic on local streets if, because of their favorable travel times, etc., the improved freeways divert unwanted traffic from the local streets. Once again, this could be considered a benefit or a loss, depending on the nature of the streets affected and the traffic diverted.

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