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Author

Deakin, Elizabeth

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Opportunities and Constraints for Advanced Highway Technologies: A Speculative Analysis

Elizabeth A. Deakin

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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

This paper has been mechanically scanned. Some errors may have been inadvertently introduced.

Preface

This document is 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)

An Executive Summary for Volume I also is available under the same title.

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."

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1 PURPOSE OF THE STUDY

Might the performance of transportation systems be significantly improved through greater application of emerging technologies? Recent advances in computers, materials, communications, control systems, information systems, and many other areas raise intriguing possibilities. Scientists, engineers, planners, and other futurists are investigating ways in which these new technologies might be harnessed to address transport problems and needs:

- o to expand the capacity of current facilities;
- o to better match, and manage, demand;
- o to mitigate negative externalities of transportation such as air pollution, petroleum dependence, and accidents;
- o to reduce transportation costs and increase service quality;
- o to make effective transportation options available to those who cannot drive a conventional automobile;
- o to improve transportation systems' contributions to economic development.

A wide variety of technological changes in fuels, vehicles, and guideways are being considered. They include methanol and fuel cells, smart cars and advanced aircraft, high-speed rail and real-time, computer-controlled, traffic signalized local streets. For the short- to medium-term, technologies that could improve existing systems' productivity and effectiveness are being emphasized. But over the longer run possibilities are being explored that could literally transform transportation systems and open up mobility, access, and ways of living, working, and doing business that we can only begin to imagine now.

This study considers one aspect of these technological possibilities for transportation improvement -- possible markets for and impacts of advanced highway technologies. The study is not an assessment of the technologies per se; rather, it considers the possibilities raised by proposed highway technologies and applications, as a basis for the exploration of questions about the technologies' effects. Moreover, competing technologies are considered only insofar as they may enhance or detract from the possibilities for the highway technologies. The objective of the investigation is to provide a better understanding of the social, economic, and environmental context in which new highway technologies would be likely to operate, and to offer a preliminary assessment of opportunities and problems which the technologies might face.

The remainder of this report is organized as follows.

Chapter 2 reviews problems which are associated with today's transportation systems, as well as future prospects. Urban passenger transportation concerns receive the greatest attention, but freight transport and intercity travel issues are also considered.

Chapter 3 presents a brief overview of advanced highway technologies currently under investigation, and discusses possible applications and their potential for reducing or eliminating transportation problems.

Chapter 4 looks at competing ways in which transportation problems might be addressed and discusses their effects on market and deployment opportunities for new highway technologies. The chapter also considers characteristics of the technologies themselves and the issues they raise regarding market fit, liability considerations, social and economic issues, and state-local government relations.

Chapter 5 summarizes the major issues raised for the new technologies and identifies areas where further research is needed.

2 TRANSPORTATION PROBLEMS AND PROSPECTS

Transportation historically has been a major force promoting growth and change in the United States. The magnitude of expenditures on transportation illustrates its economic role: nationally, about 18 percent of the GNP is spent on transportation (with about half that amount accounted for by automobiles). Some 13 percent of total business expenditures for new plant and equipment are for transportation or transportation-related activities, and about one job in ten is in transportation (TPA, 1988).

For many years, American transportation systems were steadily expanded and improved. But over the past 15 years the situation has changed. In most states funds for transportation have declined in real terms, while costs have risen. Maintenance now claims a major share of highway expenditures. The railroads, faced with shifting markets and increasing competition from other modes, are abandoning some lines and consolidating others. Federal (and sometimes, state and local) deregulation has led to new entrants in trucking, but also appears to have contributed to financial instability in the industry. Air transport, also deregulated recently, has undergone corporate takeovers, route restructuring, and revisions in fares and services.

Over the same period in which transportation systems have been consolidating, reorganizing, and retrenching, demands for transportation have continued to grow, reflecting increases in population, in the number of households per capita, in real income, and in total and per capita employment. Shifts to a service economy, suburbanization of both housing and jobs, rapid growth in small towns beyond the suburban fringe, and increased trade with Pacific Rim nations have affected not only the magnitude but the pattern of demand for transportation.

Taken together, these broad demographic, economic and spatial changes are exerting heavy pressures on transport systems. One result has been a rapid increase in traffic congestion on freeways, arterials, and local streets. Mounting congestion increases the costs of commuting and doing business; it also takes a toll on urban and suburban dwellers in the form of increased human costs (lost time, stress). Congestion also troubles the air system, both airside and landside. Air traffic control delays, gate delays, and congestion in the terminals, roadways, and access routes have reached troublesome proportions in many urban areas.

Other concerns about transport systems also figure large in policy debates. Although energy prices are low and supplies unrestricted for the time being, analysts expect that petroleum importation will be back up to all-time high levels by the late 1990s. With 97 percent of transportation systems' fuel deriving from petroleum, transportation is the least flexible component of the U.S. economy from an energy perspective, and the most vulnerable in the event of a supply curtailment or price shock (CEC, 1983). Air pollution problems, in large part a function of auto use, persist in some 75-100 metropolitan areas (including every major California city), and over 100

million Americans live in areas that cannot meet health standards for air quality. Transport accidents account for some 45-50 thousand deaths each year; over 2 million more are seriously injured, and losses of property and productive time are in the billions of dollars. Hazardous materials spills are a particularly alarming form of the latter. Congestion at airports is leading to lengthening delays in flights, and airport-related noise and traffic are sources of community conflict. Concerns about rail and truck traffic to ports is a growing issue (Deakin & Garrison, 1986.)

2.1 Current Performance

The performance of the transportation systems is most easily considered by looking at three primary functions: urban passenger transportation, intercity passenger transportation, and freight transportation.

Urban Passenger Transportation

In urban areas passenger transportation is provided by auto (cars, vans, light trucks), transit, and paratransit modes, as well as bicycling and walking, but private vehicles account for 85-90 percent of all local person trips both nationwide and in most metropolitan areas. Transit use is concentrated in urban areas, particularly for trips destined for a central business district; taxis, shuttles, and other specialized public transport modes also are most common downtown. Carpools and vanpools are used on long trips both to the CBD and to suburban destinations that conventional transit cannot service sufficiently. Bicycling and walking are minor modes of travel, accounting for 5 percent or less of the trips in all but a few communities.

The private motor vehicle's dominance of urban passenger transportation is expected to continue for the foreseeable future. Even among people who earn less than \$10,000 annually, over 60 percent drive to work (and another 16 percent are auto passengers.) Auto use has remained high despite concerns about congestion, fluctuating energy prices, air pollution, and deteriorating street and highway pavements. Auto ownership also continues to grow, nearing one vehicle per licensed driver (FHWA, various years.)

Public transit presents a sharp contrast. While transit continues to play critical roles in dense downtowns and for those without other means of travel, its market share has been falling, from a national average of 7 percent of urban work trips in 1969 to 4-5 percent today. Most operators have not been able to attract a large ridership despite improvements to both capital equipment and services; difficulties in serving low density, scattered development patterns prevalent in the suburbs are one reason for this. Furthermore, heavy concentration of transit ridership in peak periods has exacerbated operators' management and financial problems, at a time when public subsidies are diminishing (TPA, 1988; APTA, various years.)

Travel demand management strategies ranging from car-pooling and vanpooling to parking management and flexible work hours also are being pressed into service. Most of these strategies have the advantage that they cost little. However, their benefits also are modest; it appears that they match consumer interests for only small segments of the travel market. Most efforts to increase the use of commute alternatives, for example, have reduced drive-alone mode share by 2-5 percent, although certain employers have achieved much more sizeable results.

Intercity Passenger Travel

Intercity passenger travel occurs by auto, air, bus, and passenger rail. About 62 percent of the intercity passenger trips over 100 miles in length are made by auto; air carriers serve another third of the trips. General aviation, while accounting for a tiny fraction of total trips or passenger-miles, grew rapidly until insurance rates soared; its growth rate has leveled off since. Intercity bus and passenger rail together account for 5 percent or less of the intercity trips and have had stagnant or declining patronage for several decades (although the rail numbers have stabilized as of late, and have increased in some markets.) (Caltrans, various years; Deakin & Garrison, 1986.)

The majority of trips by air are for pleasure or personal matters, although business travel is a growing segment of the air travel market. Long auto trips also are mostly made for personal reasons.

Since federal deregulation of the air industry, a restructuring of fares, routes and services has been undertaken. Significant increases in hubbing have occurred, and thin markets have considerably less direct service than in earlier years. Hubbing, as well as general aviation growth, are in part responsible for airside traffic congestion at major airports. This congestion may soon necessitate airport expansion or even new airport development, as well as increasing use of reliever airports.

Intercity bus service, once common in big cities and rural towns alike, has declined severely in the past two decades. Since deregulation in 1982, most intercity bus carriers have pared back routes and schedules. Charter bus operations have been the only growth area, with new entrants since deregulation. Intercity passenger rail service also experienced sharp cuts following deregulation; today it is offered in only a few corridors.

Freight Transportation

Freight is moved by truck, rail, and water shipping, along with air cargo and pipeline transportation. Nationwide, about 40 percent of total transportation expenditures are for freight, a percentage that has declined somewhat over the postwar period. Trucking accounts for about 40 percent of the nation's intercity tonnage; rail, for about 26 percent; pipelines, 17 percent; and water shipping most the rest. On a ton-mile basis, rail carries 36 percent, truck 26 percent, pipelines 22 percent, and waterways 14 percent - the differences reflecting the longer distances of carriage by rail over truck. By either measure less than 1 percent of freight moves by air (TPA, 1988.)

Both trucking and rail have undergone dramatic changes in recent years, especially since federal deregulation. In trucking, although some firms have done well, overall economic performance has been weak. Increased competition from new entrants is one of the factors affecting performance. Shippers also have had concerns; confusion about rates, increased damage, and slow response to claims have been complaints.

For the rail industry changes since deregulation have been substantial. Mergers, line abandonments, and granting of trackage rights all have occurred, along with improvements in rail trackage, operations, and management. Changes in rates have been rapid and numerous. While these moves have helped to improve economic performance, the railroads continue to experience relatively poor rates of return, and thus the health of the industry is still shaky.

Notable changes in water ports have occurred in response to the increasing trade with Pacific Rim nations -- trade which exceeded trade across the Atlantic for the first time in 1982. The evolution of containerization technology, the development of mechanized intermodal transfer facilities, and the increasing location of industries at or in the vicinity of ports in order to add value to exports and imports, also have influenced the nature of ports' contributions to local and regional economies. Competition is particularly strong among West Coast ports, for both trans-Pacific and overland cargo. In addition, competition extends to broader questions about ports as economic development centers.

Air freight is a small component of overall freight movement, accounting for less than one percent of total tonnage. It nevertheless has been the fastest growing of the freight industries, and one of particular importance to producers of certain perishable and high value-to-weight goods. Growth in air freight has led to the emergence of a number of freight-only air services. In addition, air freight facilities are cited as important in the location decisions of high-tech industries (Deakin & Garrison, 1986.)

2.2 Prospects for Change

Change in the US transportation systems could come from several directions. Important considerations include changes in demand and changes in technology, at least some of which can be anticipated.

2.2.1 Changes in Demand

Changes in demand are likely to result from changes in population and population characteristics, household structure, employment rates, income levels, auto ownership and use, leisure time, and the like. In addition, suburbanization of both jobs and

housing, and changes in the structure of the economy and patterns of trade, will surely alter demand patterns.

Population

While the rate of population increase has slowed from historic levels, a population increase of 58 million is expected between 1985 and 2020, with additional growth through the middle of the next century. Over the next three decades 70 percent of the increase is will be in black, Hispanic, and Asian residents. Population growth will be concentrated in the South and West, where migration from other parts of the U.S. will further boost increases. Both passenger and freight demand will be increased by the sheer change in numbers (OTA, 1988.)

Demographics

The population under age 45 is expected to increase by less than 6 percent over the next 30 years, while those 45-64 will increase 71 percent and those over 65, by 80 percent. The number of households will increase faster than the population increases, with continued declines in household size. Single-parent families and nontraditional households are also expected to increase. Transportation will probably have to change to meet the needs of a greying, more diverse population, but the directions are not entirely clear (OTA, 1988.)

Labor Force Participation

A higher percentage of the adult population is now employed than in past decades; women now comprise some 45 percent of the work force; among women under 40, about 65 percent are working. Increased labor force participation probably will continue for another decade or two and then level off. The increases will result in more work travel per capita, and to the extent that they also result in more discretionary income, could stimulate increases in discretionary travel (for shopping, recreation, and social purposes) as well. Simultaneously, time constraints may lead to increased chaining of trips and higher values of travel time (OTA, 1988; Deakin & Garrison, 1986.)

Real Income Levels

Estimates of income changes vary substantially. Some analysts expect modest real increases on both a household and a per capita basis. Others have estimated that GNP growth will lag that needed to sustain the U.S. standard of living. The overall travel implications are unclear.

Auto Ownership and Use

Auto ownership in the U.S. is currently nearly 1 vehicle per licensed driver. There is some evidence, however, that the ratio will continue to climb, with households

owning more vehicles than they have drivers. Per capita use may saturate at about 10,000-15,000 miles/person/year, however, unless travel conditions and patterns of activity change substantially (FHWA, 1987; OTA, 1986.)

Leisure Time

Anticipated increases in vacation and holiday time over the next few decades could, along with growth in disposable income, lead to an increase in recreational travel (OTA, 1986.)

Shifts in Economic Activity

Nationwide, and particularly in the fast growing states of the Southwest, the service sector has grown faster than any other production sector over the past two decades. The service sector is somewhat more dependent on passenger transportation (for business travel) and considerably less dependent on freight transport than was the heavy manufacturing of earlier decades. Moreover, growth outside the service industries has been concentrated in sectors with relatively low freight input requirements (such as computers and electronics). This is the primary reason for slow overall growth in freight tonnage. In addition, the service sector, and the new light industries, are more “footloose” than earlier industries, allowing them a wider range of choices of location (Deakin & Garrison, 1986.)

Suburbanization of Population and Employment

Development of housing, industrial parks, and office complexes in outlying areas have shifted both commute patterns and the origins and destinations of other trips. Today, the majority of metropolitan work trips occur entirely in the suburbs. These shifts are putting a strain on street and freeway systems designed for much lower levels of activity, and creating demand for major infrastructure additions or expansions.

Changing Methods of Production and Management

Rapid growth in the output of high value commodities has led to the use of “just in time” production practices (which minimize inventory costs) and to increased concern about potential costs due to loss or damage during shipment. This, in turn, has placed increased emphasis on faster, more reliable forms of freight service. In addition, shippers have become more systems minded in their approach to freight transportation, treating it more explicitly as a cost that can be traded off against other input cost and quality considerations, and assessing its impact on quality of service to the customer. Both of these trends have tended to favor truck (or even air freight) over rail. At the same time, however, trends toward increasing product specialization (e.g., metal doors) and substitution of more distant resources for local ones (e.g., lumber) has resulted in longer lengths of hauls for many products. Long distance movements of bulk materials are particularly notable (Deakin & Garrison, 1986; OTA, 1987.)

Changing Trade Patterns

U.S.trans-Pacific trade exceeded trans-Atlantic trade for the first time in 1982. Access routes to ports on the West Coast already are feeling the strain. (Caltrans, 1984; Caltrans, various years.)

2.2.2 Technological Changes

Technological improvements to transportation also are anticipated. Some of them are as follows (Deakin & Garrison, 1986.).

Automobiles, Highways, and Fuels

For the automobile, advances in materials, design, and propulsion technology are likely to further lower fuel consumption through the 1990s. Currently mandated technological improvements in air pollution control equipment will achieve full effectiveness by the late 1990s. Thereafter, growth in auto use will probably cause emissions, and possibly total fuel consumption, to rise again, absent new regulations or significant fuel price increases. Alternate fuels (methanol, e.g.), advanced engine designs, and perhaps new vehicle designs (including very small personal vehicles) may be introduced if policy and economic conditions provide a favorable market.

Trucks

Pressures for the trucking industry to shoulder more guideway costs are leading to increased research on suspensions, axle loadings, and wheel and tire design which could reduce pavement damage, and some improvements seem likely over the next few years. Engines which use alternate fuels and/or reduce emissions also are expected by the mid-1990s. In the longer run, roadway and terminal redesign to may be considered, both to better accommodate the larger, heavier trucks already permitted and possibly to allow a transition to even larger trucks and truck trains.

Rail

Near-term technological improvements in the rail industry are most likely to be applications of known concepts such as welded rail and more energy-efficient locomotives. In the longer term, rail mergers may create the networks and profitability needed to introduce such freight service innovations as the integral train, designed specifically for bulk transportation point to point without interchange of cars, as well as Roadrainers and other multimodal equipment. For passenger service, prospects are less certain. While high speed rail has been suggested as an option for interregional travel and is attracting much attention, it currently looks inferior in most markets to both auto and air options.

Air

New passenger aircraft are expected to be more fuel efficient and quieter than current models, and noise levels should drop as older aircraft are finally retired. If airline profitability continues to be healthy, new market-differentiated aircraft may be introduced. Vertical/short takeoff and landing (V/STOL) or tilt-rotor aircraft could serve for short hauls, and very large aircraft (perhaps accommodating 1000 passengers) could be used for long haul, high density markets. These types of vehicles are technologically feasible, but face other problems. The V/STOL, which proponents claim could operate at costs under 40 cents a seat-mile by the end of the century, may not be economically viable if military support for its development is cut off; moreover, finding acceptable sites from which it could operate could be problematic. Large aircraft may face opposition because they could worsen congestion problems at terminals and along airport access roads.

Telecommunications

Telecommunications developments may change patterns of travel, although the nature and direction of change is debated. In some cases telecommunications may serve as a major substitute for travel; in others it, like the telephone, may expand networks of business and personal contacts, further weaken the importance of location-based relationships, and result in more travel overall. Already facsimile transmissions are substituting for some hard copy shipments, for example, but the net impact on travel is unclear. Options that seem likely to receive attention over the next ten years or so include teleconferencing, satellite work centers connected to the supervising office electronically, and work-at-home incentives.

2.3 A Preliminary Statement of Problems

As the preceding discussion illustrates, both a scaling up of transport activity and shifts among modes and locations of trips have occurred over the last 20-30 years, continuing even longer-term trends. Car, truck, and air transportation have been growth modes; rail, bus, and urban transit use have declined. Absent major change in policy or unforeseen trauma, these trends are anticipated to continue, although other issues (an older population, slower growth, and perhaps even labor shortages as the baby boomers are followed by the baby bust generation) may grow in importance.

Such a future would also be likely to mean, however, that auto, truck, and air traffic congestion will increase, demands for transportation infrastructure rehabilitation and expansion will grow, and the negative environmental consequences of transportation will be magnified. Concerns about such problems already are high, and could indeed lead to major redirection of policy. Thus it is worthwhile to consider the problems in some detail, to assess what options for addressing them might exist.

The discussion which follows considers the transportation issues that are most directly relevant to the concerns of this report -- those relating to, or affecting, highway transportation. The examples are taken from national data in some cases and from California in others.

Deteriorating Infrastructure

The poor state of many of the nation's roadways and bridges has been extensively reported, and although recent investments are improving the situation, problems still persist. In California, one estimate is that we need to spend some \$914 million a year to repair, rehabilitate, or replace deficient roads and bridges; current annual expenditures are about three-quarters of that amount. The same source estimates that California motorists spend an extra \$1.69 billion a year in driving costs (wasted fuel, excessive tire wear, and added vehicle repairs) as a result of poorly maintained roads. While other, less dramatic estimates of the costs also have been made, there is little disagreement that current maintenance practices are costly (Caltrans, various years.)

The issue of deteriorating infrastructure is intertwined with those of worsening traffic congestion and unaddressed new needs, because funds for streets and highways remain tight and choices must be made about where to invest first. In California, matching federal dollars, maintaining geographic equity within the state, preserving existing facilities, and responding to emerging demand are competing objectives; the priority that should be given to maintenance is by no means agreed upon. In addition, the choices are complicated by questions of how to pay for the maintenance of streets and highways--and who should pay. Arguments persist about the allocation of responsibility for highway and bridge deterioration (and hence, for repair costs) among users (trucks and cars). Also, the actual magnitude of maintenance needs is an issue; estimates of deficiencies vary considerably, as do opinions on the dollars required to bring deficient roads up to acceptable standards, and about how much deterioration is acceptable (i.e., how a particular level of pavement quality translates into user costs now and repair costs in the future). This is especially an issue concerning the portion of the shortfall that is at the local level, where needs estimates are the least reliable, where many local governments have made the explicit decision to give road repairs relatively low priority, and where local sources of funds (e.g., assessment districts, property tax increases, etc.) could be used and might arguably be fairer ways to raise the needed monies (especially for roads whose primary function is access) than via state-level taxes and fees. And some note, as well, that local needs account for the lion's share of the total, but are concentrated on streets and roads that carry relatively little traffic.

Moreover, roads are not the only problem area. For transit operators, the average age of their vehicle fleets is creeping up again after a decade or more of improvements. Sharp reductions in federal subsidies along with major losses in market share have made vehicle replacement difficult to afford. Yet aging vehicles impose higher operating and maintenance costs, are less reliable, and produce dirtier emissions than do newer vehicles. Finding the funds to maintain older vehicles and to replace a portion of them will be a challenge.

Traffic Congestion

Traffic levels are steadily increasing throughout the U.S., especially in metropolitan areas. In California, total annual traffic climbed from 160 billion vehicle-miles in 1981 to 208 billion vehicle-miles in 1985, an increase of nearly 30 percent; the total had climbed to 215 billion a year later (Caltrans, various years). Highway building has not kept up with such increases: in California, traffic growth outstripped increases in capacity by a factor of nearly 5 to 1 over the past twenty years.

Congestion is one result. Caltrans reports that over one-third of its urban Interstate and freeway miles are severely congested for some period of the day, nearly every day of the year, and the percentage of freeway miles that are congested is growing fast. While highway building has increased recently, additions to the system are nevertheless expected to fall short of the rate of increase in demand. The result is likely to be a reduced level of service to highway users, with increased travel times and higher out-of-pocket costs.

Local streets and roads also are increasingly congested. In some communities, concerns about traffic are leading to a backlash against development--building moratoria are being imposed until such time as traffic problems can be brought under control. Other communities are forcing developers and employers to shoulder costs of needed street and highway improvements. Still others are experimenting with transportation systems management requirements: developers and employers are being required to reduce auto use to their sites and businesses, usually by providing financial support and management encouragement for employee commutes via ridesharing, transit, and even bicycling and walking.

Changes in location patterns exacerbate these problems. Many newly developing areas have roads designed for rural traffic levels, or for suburban residential traffic. With the growth of office and industrial parks in these areas, severe traffic problems are occurring. Spot widenings and interchange improvements are being made and offer partial relief, but little attention is being given to advance planning of transportation systems to serve these growth areas, in view of the backlog of other, already needed projects elsewhere.

There are three basic approaches for addressing the congestion problem. One is to significantly expand the state's street and highway network: to add lanes to existing facilities, and build new facilities. A second approach is to improve the operation of the existing system, by making spot improvements at bottlenecks, installing control systems to even out flows, and so on. A third is to manage demand, discouraging excessive auto use by pricing parking and roadways, providing incentives and subsidies to users of transit and ridesharing, developing land use patterns that reduce auto dependence, restricting development to levels that can be accommodated by available transportation capacities, and encouraging the substitution of telecommunications for travel. The first two options are severely restricted by funding shortfalls, and unless substantial new funds are approved it will be difficult to prevent further degradation of operations let alone improve conditions.

Truck Traffic

Growth in truck traffic, reflecting changes in the U.S. economy and land use patterns discussed earlier, is a factor in the debates over congestion, safety, pollution, and energy use, as well as an important issue in economic development. Major questions for California state government include: whether changes in the rail network will strongly affect the highway system, e.g., increase demand for truck service in some parts of the state; and the broader question of the effects of truck and rail changes on the economic performance of California industry. With regard to the trucking industry, questions of PUC regulation of rates, safety matters, and insurance, as well as taxation for highway use and truck traffic issues. In addition, the state role in the development of intermodal freight terminals and transfer facilities is a topic of some concern. The location of such facilities, competition among them, and their impact on freight flow and traffic levels are matters at issue.

In urban areas, such matters as truck safety and urban truck traffic impacts are increasingly volatile issues. Local governments, responding to concerns about truck noise, pavement damage, and congestion, are adopting truck restrictions, controlling access to downtown areas or restricting routes to protect residential neighborhoods. Proposals to relieve traffic congestion by restriping major roads for narrower (hence more) lanes are beginning to surface, with little discussion of the potential impact on truck operations and safety. Access to ports is sometimes constrained by the combination of congestion and local restrictions, and as port activities grow, truck traffic -- hence concerns about it -- are bound to increase.

Access to Ports

Ground access problems plague a number of California ports, raising costs and reducing port capacity. Resolution of the problems may require innovative approaches, especially in view of increasing concerns about traffic impacts on local roadways. Routing and scheduling improvements offer one approach; a farther reaching strategy would be to locate some port facilities at a distance from the port, where congestion is not an issue, and connect them to the port with limited access facilities designed especially for freight movement.

Congestion in the Air Transport System

A number of California's major airports are beginning to experience either airside or landside congestion, or both. For example, Los Angeles International is fast reaching capacity, and further expansion is constrained. The Los Angeles Department of Airports owns land for a new airport, however. Other airport authorities, e.g., San Diego and Orange Co./John Wayne, are less well endowed, raising questions about what steps might be taken to assure safe and convenient air travel.

Among the policy options being considered are the development of new airports (or, at least, site identification and procurement); better management of existing airports, e.g., encouraging the reassignment of general aviation activities from commercial airports

to general aviation airports, emphasizing use of reliever airports by some commercial services, or using pricing policies to divert some flights to lesser-used airports or times of day; management of multiple airports in a region as a system (for both flights and ground access); and substitution of ground transport alternatives, particularly in short-haul corridors (high speed rail, e.g.) New tilt-rotor aircraft developments offer another possibility: development of “vertiports” connecting major work centers, and substituting not only for conventional air travel but possibly, for executives’ within-region commuting and business trips as well.

Airport ground access also is an increasing problem for the major Los Angeles and Bay Area airports as congestion on local freeways has worsened. Air travellers’ extremely high values of time suggest that improved access be considered and suggest that full cost pricing might be possible. Proposed solutions to ground access congestion at airports range from building new infrastructure improvements serving the airports (e.g., express highway lanes, transit extensions), to building high-speed rail as a substitute for air travel in selected corridors, to managing airport entry and parking, so as to encourage access via transit and paratransit rather than auto use. Reservation of right of way for airport access facilities and easements permitting control of development over a broad area in the airport environs are other ways that airport landside congestion might be managed.

Fossil Fuel Consumption

The U.S. transportation sector is almost entirely dependent on oil for its energy. In California, transportation consumes three-quarters of the state’s oil supply and about half the total energy used. Heavy transportation energy consumption is largely responsible for California using twice as much energy per capita as industrial nations with similar standards of living--and results in transportation being the least flexible sector of the economy from an energy perspective, and the most at risk should another price shock or supply constraint occur.

Current strategies for reducing energy consumption emphasize vehicle efficiency standards (which, along with the market effects of price shocks in the 1970s, have doubled the fleet-average miles per gallon to about 25 mpg currently.) Fuel- efficient traffic signal timing also has been pursued in California, along with a variety of other minor operations improvements. Increased use of alternate modes (transit, ridesharing, etc.) has been advocated although not rigorously pursued.

Particularly in California, the use of alternative fuels and new vehicle types has been advocated as a way to reduce petroleum dependence. However, questions of costs, availability, and effects on vehicle performance have limited the use of alternatives to experimental fleets and specialized market niches. Recently, methanol has been promoted as a clean air strategy for the heavily polluted Los Angeles basin; but there is not enough methanol available to fuel more than a small percentage of the state’s autos, and new supplies would probably be too expensive to compete with petroleum products (except, possibly, for methanol made from Saudi natural gas). Furthermore,

concerns about global warming due to CO₂ emissions have led some to question the advisability of substituting one fossil fuel for another.

Electric vehicles also have been proposed, but the poor performance of current battery technology limits interest, and unless fuel cell technology improves significantly EVs are unlikely to be acceptable substitutes for conventional autos. Electrifying major highways might reduce the effects of battery limitations, but roadway electrification raises technology and power supply questions which are yet to be resolved.

California has been carrying out small scale demonstrations of methanol vehicles (urban transit buses, and cars in the state fleet); has been monitoring Electric Power Research Institute- and utility-sponsored electric vehicle demonstrations; and has been working with the U.S. DOT on the development of inductive power transfer technology for buses. Whether these efforts result in sufficient technological gains to support broader deployment remains to be seen.

Air Pollution

The impacts of air pollution include health costs, lowered property values (because of the adverse effect on quality of life), crop damage, and potentially, federal and state restrictions on industrial growth. While the U.S. has substantially reduced emissions of each of the six air pollutants for which health-based ambient air quality standards exist -- lead, sulfur dioxide, ozone, carbon monoxide, nitrogen dioxide, and particulate -- problems remain; some 100 million Americans live in the 75 or more urban areas that still violate the air quality standards for ozone or carbon monoxide (CO). Recent evidence that the health effects of ozone may be worse than previously thought, that children are several times more vulnerable than adults, and that crop damage also is considerably worse than formerly recognized have raised the stakes involved. Estimates of the costs of air pollution vary by region and area within region, and most studies quantify only some of the known costs (e.g., costs to a small sample of crops). Most studies suggest average costs of half a cent to two cents per mile, although in heavily polluted areas the cost may be as high as nine or ten cents a mile, according to air pollution experts (Deakin, 1989.)

Transportation emissions, while a small fraction of earlier levels on a per-vehicle basis, are nonetheless largely responsible for continued violations of the air standards. EPA reports that mobile sources make up one-half or more of the ozone-precursor volatile organic compounds (VOC) and nitrogen oxide (NOX) emissions in many cities, and that the CO nonattainment problem is almost entirely the result of mobile sources. In many metropolitan areas, including California's many severely polluted cities, the role played by transportation is even larger.

Growth effects will begin to erode the transportation sector's air quality gains of the last two decades unless additional control measures are implemented. In particular, increases in both the number of vehicles in use and the total vehicle-miles of travel will more than offset the reductions expected from vehicle emissions controls and inspec-

tion/maintenance programs, if emission controls remain at current levels. In especially fast growing areas this may already be occurring.

Recently additional emissions-related issues have emerged. Acid rain is increasingly recognized as a national and international problem, and while industrial emissions are the main culprit, transportation emissions of VOC and NOX also have been implicated. In addition, concerns about global warming have raised questions about emissions of CO₂, for which transportation accounts for about 31 percent of total U.S. emissions. (CO₂, it should be noted, is not technically an air pollutant.)

Given this situation, additional efforts to reduce emissions are again being proposed, as they were under earlier air quality planning efforts. While additional emissions reductions are technically feasible from tighter controls on industries and new vehicles, as well as more stringent regulation of fuel composition and handling, the costs of such reductions will most likely be high and business and vehicle manufacturer opposition can be expected.

Other options include more frequent (e.g., annual) vehicle inspection and maintenance, which also could be used to help keep cars operating in a fuel-efficient manner; experimentation with and demonstration of new vehicle types and alternate fuels; and the use of price incentives and/or regulation to encourage scrapping of high-emissions vehicles and induce purchasers to choose the least polluting vehicles. Measures to reduce vehicle use (through transportation demand management) also are being put forward, though support for these measures is mixed and available evidence indicates that aggressive programs can obtain best.

Highway Safety

Roadway accidents claimed an estimated 48,800 lives in the U.S. in 1987. This compares to about 3,000 deaths in all other modes of transport (of which a third were in recreational boating and nearly as many more, general aviation.) Motor vehicle deaths have increased substantially since the early 1980s, probably because of higher speeds. On the other hand, the 1987 death rate per million vehicle miles was the lowest ever recorded (TPA, 1988; MVMA, various years.)

Government intervention in accident prevention includes regulation of equipment, setting of facility design standards, and investment in safety-enhancing facilities and operations. For example, at the federal level the National Highway Traffic Safety Administration sets standards for the motor vehicle industry on crash avoidance, occupant protection, post-crash protection, and other matters; the Federal Highway Administration sets design standards and provides funding to both capital and operational projects to improve roadway safety. Other administrations have similar programs for their respective modes.

Cost studies of accidents are more detailed and more widely available than was the case for noise or air pollution. Kanafani reports that for the U.S., accident costs (including fatalities, injuries, and property damage) are in the range of \$.024 - \$.027 per

mile , in 1975 dollars (Kanafani, 1983). It should be noted that, to a far greater extent than for air pollution and noise, accident costs are internalized by road users. Insurance coverage and allocation of responsibility helps internalize some (perhaps half?) of these costs, while others not covered by insurance fall, at least in part, to the involved parties directly.

2.4 Summary

This chapter has reviewed the status and performance of the U.S. transportation systems, focusing particularly on those of California, and has identified changes in demand and supply that are likely to occur over the next 20-30 years. Overall, the transportation systems are showing the effects of age as well as stress from heavy demand, and future growth and change could exacerbate these effects. A number of problems are apparent, and a variety of policy options are being debated to address them. It is in this context that the advanced highway technologies discussed in the following chapter may be developed.

3 **ADVANCED HIGHWAY TECHNOLOGIES**

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. Some of these technologies may be able to contribute to the management of the problems discussed in Chapter 2 - - congestion in the highway and air transportation systems, infrastructure deterioration, petroleum dependence, air pollution, safety concerns. Others are directed toward reducing costs and improving performance of various transport modes. 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.

This chapter presents an overview of some of the advanced highway technologies, then discusses possible applications which have been proposed (or speculated about) and the opportunities they might present.

3.1 Technology Options

Although the term ‘advanced highway technologies’ is widely used, the technologies included under this heading 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 (FHWA, 1988.)

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 not only identify the best route but provide on-board visual and/or auditory assistance to the motorist in finding and following it.

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. For example, vehicles might send traffic control systems data on speeds and delays being experienced; the information would be used to retime traffic signals and ramp meters, and dispatch 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 (Kanafani, 1987.)

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 have been demonstrated 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 checking systems (to detect impeding 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 (FHWA, 1988.)

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.

Potential applications involving more widespread use of the technology would include the following:

-- 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. Urban highway capacity is increased, in the dual mode case preferred in the U.S., by permitting narrow lane widths and close headways while reducing driver-induced flow breakdowns and related capacity reductions and accidents.

3.2 Applications

As the preceding discussion indicates, 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, to major new 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 in this category.

Because substantial public investments might be necessary for these government intervention options, it is worthwhile considering how the technologies might offer opportunities to reduce or avoid some of the problems identified in Chapter 2.

Preserving the 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 California’s roadways to carry more vehicles safely and at higher speed than they now do (Workshop Notes, 1988.) Several

substantially different options might help improve overall traffic conditions (Castle Rock Consultants, 1988):

- 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).

All of these options would require considerable development, and testing probably would be expensive. In addition, while some could be implemented on the existing system, 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, suppose special truckways were developed (possibly on freeways, possibly along rail rights of way). These 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.

Improving Port Access

High-tech truckways of the sort discussed in the preceding paragraphs 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 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, given air travelers' very high values of time.

Fossil Fuel Conservation and Air Pollution Reduction

New highway technologies could reduce both fossil fuel use and air pollution, and while the two are not entirely congruent the overlap is substantial enough that they will be treated together here. Among the options are the following (Sobey, 1988):

- 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 (Sullivan, 1987; Koltnow, 1988; Sobey, 1988):

- o Vehicle diagnostic equipment could reduce accidents due to undetected, unsafe equipment or equipment failures. Cost savings also might accrue to the extent that early detection permits lower cost preventive actions.
- o On-board security and safety devices could help prevent operation by impaired drivers as well as by unauthorized persons.
- o Accident detection technologies could make it possible to clear accidents faster; advanced motorist information systems and navigation technologies could help drivers avoid accident sites (with benefits both in clearance time and in avoidance of additional accidents).
- o AVI equipment could help track the movement of hazardous wastes and speed substance identification and clean-up in case of spills.
- o Vehicle automation technologies could help reduce accidents due to poor visibility, delayed braking, vehicle speeds in excess of posted limits or environmental conditions, speeds too low for flow conditions, wandering out of lane, and so on. These driver-assistance technologies might be particularly helpful to the elderly, who generally have poorer vision and slower reaction times than their younger counterparts, and also might be of benefit to disabled drivers.

- o Highway automation could reduce accidents due to flow break-downs while permitting higher speeds. Controls also might make it possible to operate very small vehicles with improved safety.

3.3 Commentary

The advanced highway technologies described in this chapter are only some of the many possibilities for technological innovation and evolution. Similarly, the possible applications outlined here are but examples. Technology's potential often lies not in addressing the problems of the moment, but in opening up new ways of doing things that are not now foreseen or understood.

Nevertheless, the opportunities for technological innovation often depend on the extent to which the new technologies offer help with pressing problems -- thus more detailed consideration of how various technologies might reduce congestion, lower emissions and fuel use, improve safety, and improve the handling of a variety of other problems seems in order.

At the same time, the technologies described here are not the only ways in which these problems could be addressed, and they raise certain issues of their own. The next chapter thus looks at competing policy directions, as well as potential barriers to advanced highway technologies raised by the technologies themselves.

4 BARRIERS TO THE INTRODUCTION OF ADVANCED HIGHWAY TECHNOLOGIES

The vigor with which advanced highway technologies are developed and introduced 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. In this chapter, alternative policy directions are considered, and concerns about new highway technologies and their potential consequences are reviewed.

4.1 Competing Policy Directions

Two major policy directions which might dampen interest in new highway technologies are 1) a new round of investments in conventional highways, and 2) greater emphasis on demand management and alternatives to the auto. A third policy 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 (Deakin, 1987; Deakin, Spring 1987.) The three options are discussed below.

A New Round of Highway Investment

Building new highway facilities (or substantially improving and expanding existing ones) has been the traditional way to respond to urban/metropolitan congestion problems. Thus, the decline in highway construction in recent years has been seen by some as a problem to be addressed by undertaking a major, renewed construction program. In this view, an injection of new funds for highway building, coupled with the adoption of procedures to accelerate project delivery, would go far to alleviate congestion.

Advocates of new construction recognize a significant barrier: funding shortages. A variety of ways to increase funds for highways have been under consideration at both the national level and among the states. The approaches include fuel gallonage tax increases; changing the fuel tax to an ad valorem tax (in the expectation that prices will rise); fuel tax indexing; local sales tax increments earmarked for road construction; sale of bonds for highway building; weight-distance taxes on trucks; increases in registration and licensing fees; and greater private sector participation in highway development.

The barriers to these options are sizeable. They include, foremost, a deep reluctance at both the federal level and in most states to introduce new taxes. At the federal level, concerns about the budget have led to suggestions that a gas tax increase might be used for deficit reduction rather than new investment; some also worry that new expenditure programs could refuel inflation and therefore are reluctant to support in-

creased spending for highways. At the state level, fuel tax increases have had a mixed reception, with most states enacting some increases over the past decade but generally to levels still below those felt by transportation agencies to be needed to reverse declining levels of service.

Current proposals from national study groups seem to accept that federal taxes for highways will not be raised substantially, and suggest instead focusing the available resources on a subset of the roads currently eligible for funds. This redefined "system of national significance" would absorb current federal funds for maintenance and a limited amount of new construction. Whether new technologies might have a place in this concept is unclear, although in a number of the proposals federal funding for research and technology development would increase.

Among the states, California has done particularly poorly in raising fuel taxes or other transportation revenues and now ranks 49th or 50th by most indicators (Caltrans, 1986.) Barriers to raising more money for transportation include proposition-mandated restrictions on taxation and spending (especially the Gann limit on appropriations); political leaders' reluctance to take a strong stand in favor of higher fuel taxes (most proposals would, at most, put a tax before the voters, with a list of projects on which it would be expended); and citizen resistance to increased government spending, as well as likely local opposition to specific highway projects and lobbies favoring a redirection of transport investment toward rail.

To avoid or minimize tax increases, a variety of narrower fund-raising strategies are being considered. Toll roads are an option getting closer scrutiny, and proposals to build private highways are being considered. Requirements that new development contribute to the cost of needed road improvements (including freeway lanes) are widely used in prosperous areas undergoing rapid growth, though their utility in built-out areas (through which some of the most congested highway sections may pass) or those which are less favored for development is less promising. Joint development and value capture techniques and benefit assessment districts are other ways that transportation improvements can sometimes be funded.

Improvements to the management and operations of existing facilities also are being given increased attention as ways to avoid or reduce costs of capital investments. Improvements of this type currently finding widespread application include spot widenings; flow metering; coordinated signal timing; installation of turning lanes and traffic channels; correction of weaving, sight distance, gradient and curvature deficiencies; and similar, relatively small-scale, actions to eliminate bottlenecks and flow restrictions, thus maximizing the carrying capacity of available roadway space. More advanced operational improvements might incorporate some new technologies in relatively low cost forms, e.g., motorist information signs and signals, automatic data collection, and perhaps AVI and lane-keeping technologies in special applications (toll facilities, HOV lanes, etc.)

While accelerated implementation of conventional operational improvements is emphasized in the current highway program, some nevertheless question their cost-effec-

tiveness and degree of improvement. Some operational improvements seem to shift problems from one location to another (as when the removal of a bottleneck reveals another one upstream); others require repeated attention to maintain benefits (traffic signal timing); still others are cost-effective, but the resulting improvements are small. There seems to be an emerging consensus that operational improvements are useful but insufficient to resolve problems of any real severity.

Whether new construction or operations are under consideration, an important issue is where new investments should be made. If the criterion for investment is where the problems are most severe, construction and operations programs would generally emphasize congestion relief in built-up areas (in downtowns, routes leading to the central core, and perhaps in a few of the more recently built-up suburbs, where congestion has become severe and densities and land use patterns make the auto the only practical alternative.) If feasibility of providing significant improvement is the criterion, new construction might be focused instead in areas where rapid growth is anticipated, as well as areas where economic development is to be encouraged via government investments. Advance planning also might make it feasible to identify needed improvements and at the same time to guide development so that the transportation and land use plans fit together better. For example, new highway construction could be coupled with circulation and land use plans (and zoning) that are geared to the planned highway capacity. Realistically, fair-share politics would probably necessitate that some investments be made in all different kinds of communities, and probably a mix of operational improvements, construction within existing rights of way, and construction on new rights of way would be proposed.

In either the built-up areas or the newly-developing ones, advanced highway technologies might be introduced as the new investments are made. But those which would require a substantial amount of 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 areas.

Whether a new round of investment in conventional highway facilities and operations comes to pass is an open question. While some believe it to be a necessity, others are not convinced that new construction is the answer to congestion. They point to the fact that many of the congested lane-miles of highways are in built-up areas, where the cost of right of way would be very high, and where takings (of land for right of way, or even of a lane for specialized use) could arouse massive and organized protest. They note the almost certain opposition of environmental groups to a renewed emphasis on highway building. They point out that congestion is the consequence of intense activity coupled with improper pricing, and argue that less expensive, less disruptive operations and management alternatives would be as effective as, or more effective than, new construction. These views are certain to arise if a new round of highway building is seriously under consideration.

If a new round of highway construction were to be undertaken in the next 10-15 years, concerns about social and environmental impacts, economic and fiscal effects, and political responsibility seem likely to mean that funding would have to be targeted to

specific projects. Whether there would be the flexibility to introduce new technologies is unclear; perhaps the best way to do so would be to have earmarked supplementary funds especially for the purpose. If new technologies are **not** part of the highway investment package (because the timing is wrong, the project design is unsuitable, or the funding is not available), it seems possible that the opportunities for later investments in new technology might be diminished. 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.

It also is worth noting that competing technologies may vie with highways for investment dollars in some markets. High-speed rail continues to attract attention, and projects underway in Europe, Asia, and the U.S. may increase interest in this option, both as an intercity mode and as a suburbs-to-downtown mode, if these early applications are successful. Vertiports (tilt-rotor aircraft) may become a serious contender if costs of 35-40 cents a seat-mile can be delivered; not only could such a technology serve short-haul air markets (and thus take pressure off airports), but it also might become the executive's commute mode of choice, offering premium service at minimum travel times for a somewhat higher cost (probably to the company) than a car. If either high-speed rail or tilt-rotor air transportation were to take off, it not only would reduce demand for conventional highways, but might reduce demand for new highway technologies as well.

To summarize, then, increased investment in conventional highways and operations may retard interest in new technologies -- either by moderating the problem, or by failing to do so and undermining transportation agencies' credibility. Timing may be critical; opportunities may be lost, or may open up, depending on when various options are available, considered, and applied. In addition, other technologies that compete with conventional highways -- high-speed rail and tilt rotor air -- could also compete effectively with advanced highway technologies in several applications (congestion avoidance, intercity travel.)

Emphasis on Demand Management and Alternatives to the Auto

A major alternative to construction and operations investments involves the use of regulation and/or incentives and subsidies to manage demand for highway travel. Rather than support and encourage auto use, programs to encourage the use of alternative modes (carpools, vanpools, transit, bike, walking) might be emphasized. Development could be guided to occur in ways that can be served by transit and that make walking and bicycling feasible; TSM plans could institutionalize private sector parking management, transit and ridesharing programs. Development approvals might be restricted to levels consistent with available transportation capacity to assure acceptable levels of service.

Pricing to reflect the externality costs of congestion also could be used to deter trips that users find not to be worth their true social costs (or transfer trips to other modes or times of day). However, because pricing raises somewhat different set of issues than do other demand management approaches, it will be treated separately here, in a later section.

A reorientation toward demand management and alternatives to the auto could take several forms. Increased investment in transit is one possibility. Although transit use has declined in most areas of the country, public interest in new rail starts seems strong as ever, and local funding and private sector investment in transit appear to be growing. In California, proposals have surfaced for a rail bond initiative which, if passed, could support both intercity and urban rail investments. County sales taxes also have been committed to transit. Land use planning concepts to increase the use of rail systems also are receiving increased attention.

Another approach would emphasize demand management at the local government level and in particular, at all major employment centers. Currently a growing number of cities are adopting transportation systems management (TSM) plans, and some have proposed that TSM should be a mandatory part of all local general plans. TSM plans could help local governments to reduce traffic and/or allow more development for a given level of traffic. A requirement for a TSM plan as part of the circulation element of the general plan could help institutionalize ridesharing, transit promotion, flexible work hours, urban design that facilitates walking and bicycling, etc. A TSM plan also might assure that traffic levels resulting from the land use element are consistent with maintenance of an adequate level of service on local streets and roads (or not lead to a significant worsening of conditions); might strongly encourage employer-provided transit pass subsidies, preferential parking for high occupancy vehicles, etc.; and might limit parking and/or ban free parking for solo drivers.

Still another approach would be to tighten requirements for consistency between land use and circulation plans, and between the plans and zoning. Many local governments have never explicitly evaluated the traffic implications of their land use plans and zoning; many that do such an analysis find that the level of development permitted under their local plans and ordinances produces traffic volumes that swamp available transportation infrastructure, both local and state. Because of this it has been proposed that state legislation should require an analysis of the consistency of the land use and circulation elements, and zoning, at buildout (or, say, 20 years into the future), as a way of inducing local governments to examine the potential for traffic problems so that they can be planned for or avoided.

How effective any of these actions would be is an important consideration:

- o More people seem willing to vote funds for transit than to use it themselves, and the favored rail systems do not fit well with the low density, sprawl development patterns of most metropolitan growth areas. Whether increased densities in areas near stations and similar transit supportive strategies could reverse this pattern is not well understood.
- o A TSM requirement, widely implemented, would probably help reduce traffic, but not enough to make a noticeable degree of improvement in areas with heavy traffic. In fact, some cities with aggressive TSM programs already in place nevertheless have severe congestion problems. The best available estimates are that TSM plans offer a 5-10 percent reduction in peak period travel; to go beyond that level of achievement usually would require stringent auto disincentives, whose political acceptability is doubtful (attempts to impose unwanted changes in travel behavior and unnecessary expenses on the public.)
- o Whether a stronger state requirement for plan consistency would encourage California local governments to be more responsible about traffic planning is uncertain. Traffic estimates depend on assumptions about trip generation rates, travel modes, and time of day travel, and on a project level (where state-mandated environmental reviews usually require traffic analysis), these assumptions are regularly “adjusted” to avoid findings that problems will arise. There is no reason to think similar adjustments would not be made if a desired land use plan appeared to have negative transportation impacts.

Overall, then, transit, TSM, and land use - transportation coordination seem likely to be effective only if there also are changes in public attitudes and in the incentives and disincentives associated with travel mode and land use and location choices.

Other considerations may create pressures for such changes, however. Continued difficulties in attaining air quality standards are one such consideration (EPA, 1987). Most drafts of Clean Air Act renewal legislation currently under consideration would assign an important role to transportation control measures; in one proposal, eight categories of TCMs would be defined for use in offsetting the emissions associated with VMT growth, while in another proposal, the use of TCMs would be encouraged through a fee on gasoline and diesel fuel (up to five cents per gallon in severe nonattainment areas, to be used to cover up to fifty percent of the cost of TCM implementation.) EPA itself has proposed a policy, still in draft form, for areas that had not attained the ozone or carbon monoxide standard by December 1987. Designated non-attainment areas would be required to demonstrate a minimum average annual emissions reduction of three percent from a baseline emissions inventory, after accounting for growth. Most non-attainment areas would have to utilize transportation control measures in order to

achieve such an annual reduction target. Finally, several state laws require transportation controls, including the California Clean Air Act (Sher Bill) and several bills applying to specific metropolitan areas. In many ways the California legislation is much more rigorous than anything being considered by the federal government.

Strategies for transportation control include 'technological fixes' such as additional on-vehicle emissions controls, fuel substitution, and new engines, as well as traffic operations improvements and travel demand oriented measures aimed at altering behavior. The strategies requiring improved technologies have many proponents, but raise concerns about declining benefits per dollar expended; most entail technological uncertainties as well. For example, substitution of methanol for diesel in heavy trucks and buses raises questions about whether adequate engines can be developed, as well as questions about toxicity and price. The uncertainty concerning technological strategies is one of the reasons transportation controls aimed at changing travel behavior (and perhaps land use decisions and location choices as well) are again being proposed.

Concern about fossil fuel use is yet another reason for greater emphasis on transit, TSM, and transportation-land use coordination. While in the past, the major issue has been the possibility of a petroleum price shock or supply restriction, it also has been proposed to substitute methanol, natural gas, or other carbon-based fuels. Recent evidence about global warming, while fraught with uncertainty, raises the possibility that use of all carbon fuels (except perhaps biomass fuels) should be sharply curtailed. This would mean, for transportation, that substantially increased fuel efficiency would become imperative. Vehicle efficiency improvements to 40-50 miles a gallon in the short term, more -- perhaps through substitution of electricity or hydrogen fuels made from non-fossil fuels, or by introducing very small cars such as GM's "Lean Machine" -- over a 15-20 year period, might be necessary. Substantially greater use of transit, ridesharing, and walking for passenger transport, rail for freight transport, and telecommunications rather than any sort of transport might be mandated in the interim.

It important to note that TSM strategies designed to reduce congestion do not always reduce energy consumption or emissions. The latter changes are more effectively attained via trip-reducing strategies; TSM options that shift travel route or time of day of travel, or that increase travel speeds, may or may not reduce air pollution and fuel consumption.

For the most part, emphasis on alternatives to the automobile would likely be at odds with policies emphasizing advanced highway technologies. Advocates of alternatives believe that the automobile is unduly subsidized, imposes severe externalities, and over the long run is an unsustainable technology, at least in its current form. Advocates of advanced highway technologies believe that the auto is the mode of choice and will continue to be so, and that government actions should be directed to making that choice possible (and more efficient.) Perhaps a middle ground can be found in which new highway technologies support transit and ridesharing, and environmentally superior vehicle designs are supported by advanced highway technologies; perhaps conflict between those holding the two views will be unavoidable.

Road Pricing

Road pricing is a third policy direction, and one whose signals for advanced highway technologies are even more mixed than for the previous two. 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.

Economists advocate the use of pricing as a means of managing demand, as well as more efficiently allocating resources to transportation and other uses. On freeways and other roads, tolls or more sophisticated mechanisms that help users understand the costs of their consumption might accomplish this end. Road pricing, however, would involve a host of technical and political problems. For example, cost varies by time of day, vehicle weight, number of other users, and so on, but a toll that reflected all of these factors would be highly complex and would require complicated equipment. Political questions are likely to be even more thorny than the technical ones, and include: Is such pricing elitist? Is it regressive? Will it harm some areas or groups?

Automatic billing for road use, issued on the basis of transponder readings, would probably be the most efficient way to collect tolls. But in many areas, the acceptability of tolls on facilities that were built as "free"ways is doubtful, and tolls high enough to reduce congestion -- \$2 to 5 or more per commute trip in some areas -- would be likely to face strong resistance.

It also is likely that if sharp tolls were imposed on limited access highways, traffic would be diverted to parallel facilities -- usually local roads -- which are ill-equipped to handle it, and where the traffic would disrupt shopping districts and neighborhoods. Implementing tolls on local roads would be a much more difficult proposition than pricing only freeways. If local roads were not priced, however, while freeways were, not only might the traffic problem simply be transferred from one area to another, but it might have much worse social, economic, and environmental effects on local streets than on the freeways.

Tolls also might shift a substantial number of travelers to transit. If that were to happen, it would be critical that toll revenues be spent on transit improvements; otherwise these systems might be thrust into crisis (since in most areas, transit lacks the capacity to accommodate substantial peak period increases in ridership, and adding transit capacity that is in demand during the peaks only is extremely costly.)

Tolls are not the only way pricing might be implemented for peak period users - parking charges are another option. Charging for parking is hardly any more popular than tolls would be, however. Free parking is widely viewed as an important tenant amenity and employee benefit; parking costs are embedded in lease terms and absorbed as a (tax-deductible) operating expense rather than charged to users. It is estimated that nationwide, about eighty percent of all employees receive free parking, and another ten percent pay only a portion of the cost.

Free parking is not, however, free in any real sense of the word. A 320 sq. ft. space in a surface lot, financed over a 30 year period at a 10 percent interest rate, (or alternatively, assessed an annual land rent), would cost \$20-25/mo. (including costs of pavement, striping, maintenance, etc.) if \$5/ sq. ft. A space in a garage would cost much more: in most markets, \$10,000-15,000 if the structure is above-ground, and \$20,000 or even more if below-grade spaces are considered. Such spaces, considering amortization and operating expenses, would rent at \$120-250 per month (Deakin, 1989).

Analyses and a few experiences indicate the size of the effect that charging for parking would have. Modeling results suggest price cross-elasticities (how many would shift modes) are low, in the .1 - .3 range for most commuters, meaning that a doubling of (the perceived) costs of drive alone travel would reduce traffic by 10-30 percent. But even a moderate parking charge could double drive alone commute costs. Commuters behave as though their trips cost them 6-9 cents a mile excluding parking (fuel at 3-5 cents plus a little for oil, maintenance, etc.). At the median US commute trip length of 10 miles one way, operating costs are some \$1.20 -1.80 a day. Thus, parking at \$30 -35 per twenty day working month would more than double the cost of the drive-alone commute -- which should in turn cut drive-alone commuting by 10- 30 percent (Deakin, 1989.) (It should be noted that extrapolation of observed elasticities to the higher ranges of parking charges might not be warranted. Also note that lower response would be expected among higher income workers and vice versa, and less response than predicted might occur if people see themselves as having no reasonable alternatives, need the car at work or to pick a child up on the way home, etc.)

Studies in Los Angeles have reported that a 30 percent decline in driving alone did, indeed, occur under fairly similar conditions to those reported above. Some analysts have suggested that parking pricing may be a second-best approach to rationalizing transport costs. (Direct road pricing reflecting miles driven, amount of congestion and air pollution caused, etc. is clearly preferable from an economist's point of view.) However, there are several barriers to change, and caution is in order.

First, the federal tax code is not supportive of a change in policy. Free parking is classified as a working-condition fringe benefit to employees, much as would be a sofa in the office. As such, parking is a tax-deductible expense for employers. Furthermore, the value of these tax benefits has no ceiling, and as indicated earlier, can exceed \$200/mo. per employee in some areas.

On the other hand, vanpool and carpool subsidies are taxable benefits, and transit pass subsidies are deductible only up to \$15.00; any subsidy above that amount results in the **entire** subsidy being treated as taxable income. Attempts to redress this disparate treatment have so far failed. Given the federal budget deficit, any change would probably have to be tax-neutral. Thus, proposals simply to raise the permissible subsidy to commute alternatives have so far failed. UMTA has suggested that an alternative revenue-neutral approach would be to exempt all commute subsidies up to \$60 and to tax all over that amount; but they note that the taxes would fall principally on core areas of major cities and hardly at all on suburbs. Moreover, observers argue that the vanpool/carpool taxable benefit is unenforceable in any practical sense because of the

trail of audits that would be needed, as well as difficulties in determining “market value” of the vanpool trips under many common circumstances. At the same time, market value of parking spaces also could be hard to establish given current cost accounting and leasing practices. Some conclude, then, that the only serious problem with the current situation might be that some employers are dissuaded from providing rideshare financial assistance because of the law.

Another reason for caution about using parking charges as a “second-best” alternative to road pricing is that commuters may find any of several ways to circumvent a parking surcharge. Many will make use of off-site free parking if it’s within walking distance--and sometimes if it’s not. For example, in the central areas of Berkeley, where free employer-provided parking is rare and off-street spaces cost \$35-\$65/mo., a severe problem with spillover into residential neighborhoods has developed. Resident permit parking programs are being instituted to cope with the problem. In a number of other cities, commuters reportedly park in residential districts near transit stops and take the bus or train the last few blocks to avoid paying for parking; in suburban areas, shopping center parking lots reputedly are used as rendezvous for formation of “car-pools” to take advantage of preferential parking.

What are the prospects for road or parking pricing? Currently, political interest in either strategy is limited. A few toll roads will probably be built, though even they are unlikely to implement true road pricing; rather they will use tolls as a supplementary source of funds (in addition to fuel taxes, etc.) The toll roads may nevertheless offer opportunities to test AVI equipment on a large-scale basis. Some parking price increases also can be expected (many of them, as part of TSM plans or transportation-land use restudies), and while here too, few are likely to approach marginal cost pricing, there again may be some opportunities to test out certain AVI equipment, automatic billing systems, and the like. One possibility is that road and parking pricing will take hold as an air pollution reduction strategy, one that is more efficient than TSM, auto use restrictions, and the like. Currently, such possibilities are beginning to be discussed in each of the major metropolitan regions of California; but there is a long way to go before acceptance and implementation could proceed.

Over the longer run, road pricing probably will have to be given more serious consideration. Use of a variety of fuels would raise questions about appropriate taxes; significant increases in vehicle fuel economy would necessitate a rethinking of road finance as well.

4.2 Concerns About Advanced Highway Technologies Themselves

The previous section discussed policy directions that might conflict with, or reduce interest in, advanced highway technologies. But questions also need to be asked about certain aspects of the advanced highway technologies themselves. In particular, the following questions deserve attention:

- o Is there likely to be a 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?
- 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?

Each of these issues is addressed in the following sections.

Markets for Advanced Highway Technologies

Previous sections pointed out that markets for advanced highway technologies might depend, in part, on developments in competing transportation options. Significant new investments in conventional highways, a reorientation of public policy toward transit, TSM, and coordinated land use-transportation planning, acceptance and deployment of road pricing and parking charges, high speed rail and tilt-rotor aircraft are some of the options that could reduce interest in, and markets for, advanced highway technologies. While each of these options could open up certain opportunities for the new technologies, a larger effect might be to reduce pressures for further change.

Certain aspects of the technologies themselves also could affect their acceptability. 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 might mean automation would 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, and this suggests that a closer look is warranted.

First, the average work trip in the U.S. is not long -- in 1983, for example, 54 percent of all workers commuted five miles or less, and 75 percent commuted less than ten miles. While these figures include trips by all modes, the average auto trip also was quite short (9.9 miles), and that average was skewed upward by the long "tail" of the trip length distribution. Indeed, the longest trips are ones made to the central business district in transit vehicles and vanpools, and those made in rural areas -- on uncongested rural local roads. (U.S. Bureau of the Census, 1984).

Data on which trips use freeways and other major arterials are sparse, but those that are available suggest that perhaps 40-50 percent of all work trips do not use a freeway at all. Of those trips that do use the freeways, average trip lengths are in the vicinity of 12 miles, but (according to interviews with regional highway planners) half or so of all freeway users travel less than five miles before returning to local streets.

Taken together, these figures raise important questions for advanced highway technologies. Most notably, they 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. Therefore, these access issues must be addressed as part of the process of designing an automated system.

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 capacity increases (or safety) instead of speed improvements are not likely to induce car buyers to add optional equipment to their new vehicles.

In summary, markets for advanced highway technologies are likely to depend on producing, **from the consumer's point of view**, benefits that would justify additional costs of the equipment that probably would be needed on new cars. It is critical that planners recognize that increasing carrying capacity on the freeways may be a laudable public objective, but it is not likely to motivate consumers to pay more unless they personally see sufficient improvements (reduced travel times, higher speeds, greater predictability in trip times.)

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. Legislative action could resolve these matters, but agreement on a course of action does not seem likely to occur in the near future. In addition, there is some argument to be made that early protection from tort liability has a negative effect on technology development, by reducing the strong incentive to make a product safe and to test it thoroughly before deploying it.

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 possibility of 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.)

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.

4.3 Summary

This chapter has reviewed some of the competing policy directions for transportation, as well as some of the characteristics of proposed highway technologies themselves, that may limit interest in the technologies. It has been argued that either significant new investments in conventional highways or a redirection toward TSM and transit, rail and land use planning, could reduce interest in and markets for new technologies for the highway. Pricing strategies also could have this effect, or they could confirm consumers' demand for highways and provide the funds for responding to that demand. Concerns about air quality and energy may work against a highway emphasis in the short run, although over time electrification or other alternative fuels may reduce the potential for conflict.

The technologies themselves also raise a number of questions: fit with trip patterns, benefits to consumers vs. highway operators, price, equity, and personal freedom concerns; development dispersal potential. Liability issues and possible state-local coordination and conflict issues also arise.

5 IMPLICATIONS

This study has reviewed current transportation problems and prospects for change, and the opportunities and barriers they present for new highway technologies. The purpose of the study has been to speculate about advanced technologies' potential for improving transportation systems' performance, as well as to identify potential limitations the technologies may have to face up to.

Transportation systems today are heavily oriented toward the automobile, truck, and air transportation modes, and are plagued by a number of problems: deteriorating infrastructure, highway, airway, and airport congestion, constrained access to ports, heavy dependence on petroleum fuels, safety problems, and excessive air pollution. Advanced technologies ranging from navigation aids to vehicle automation, vehicle identification, and highway automation have been proposed and might, in various ways, help manage or reduce these problems. Incremental introduction of helpful, if not dramatic, technologies could eventually be organized into an ambitious technology-changing strategy involving route guidance, corridor management, lateral and longitudinal vehicle control systems, and eventually highway automation.

Competing policy directions for transportation may limit interest in the advanced highway technologies. Significant new investments in conventional highways or a redirection toward TSM and transit, rail and land use planning, could reduce interest in and markets for new technologies for the highway. Pricing strategies also could have this effect, or they could confirm consumers' demand for highways and provide the funds for responding to that demand. Concerns about air quality and energy may work against a highway emphasis in the short run, although over time electrification or other alternative fuels may reduce the potential for conflict.

The technologies themselves also raise a number of questions: fit with trip patterns, benefits to consumers vs. highway operators, price, equity, and personal freedom concerns; development dispersal potential. Liability issues and possible state-local coordination and conflict issues also arise.

Taken together, these measures suggest several areas for further research:

- o Who would benefit from the kinds of technology applications now being considered -- particularly route guidance and roadway automation? What steps might be taken to broaden the range of potential beneficiaries?
- o Could special applications of advanced highway technologies improve freight movements -- in general, or to ports? Could they help solve airport access and inter-airport connection problems?

- o What is the potential for corridor management, considering both the availability of alternate routes capable of carrying additional traffic, and local governments' interest in participating in such an undertaking? What kinds of intergovernmental agreements, assignments of responsibility, and quid pro quos might be needed to make corridor management an option satisfactory to all parties?
- o What effects would highway automation have on city form? How might it interface with local street systems, parking, land use opportunities?
- o How would highway automation fit in with air quality plans and energy conservation strategies? What implications would recent policy initiatives on these matters have for the implementation feasibility and timing of new highway technologies?
- o How might liability concerns be managed? Are there examples from the introduction of other consumer products that might offer lessons for advance highway technologies?

As technological developments proceed, a parallel look at such questions as these should help researchers direct their efforts to options that seem most likely to produce significant payoffs.

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