The Challenge for Public Policy to Help Deploy IVHS in the U.S.

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IVHS Technical Report: 92-03

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Highway operations in the United States have been characterized by a broad set of problems that are more or less addressable through IVHS.[1,2,3,4,5,6] The IVHS vision appears to offer innovative countermeasures, new products and services, and significant changes in the way industries and government agencies serve the needs of the motoring public. Recognizing, however, that such initiatives may require a complex interleaving of public sector roles at federal, state, and local levels, together with new commercial activities, there are risks that helpful deployments would be delayed or misdirected such that benefit to the public is foiled. Some attractive systems currently face known barriers from legal, political, and public-cost factors. Private investment in new infrastructure is discouraged by uncertainties in needed public participation, the inability to defend one's investment against competitive forces, and worries over the eventual market, itself. Nevertheless, there exists opportunity for the development of public policies that would clear the way for public and private investments giving proportionately large benefit to the public while satisfying investors, as well. This paper addresses what appear to be key needs for public policy initiative. The discussion will address policy issues under each of two broad areas of IVHS application, namely, one whose focus is information technology and another whose focus is vehicular control.

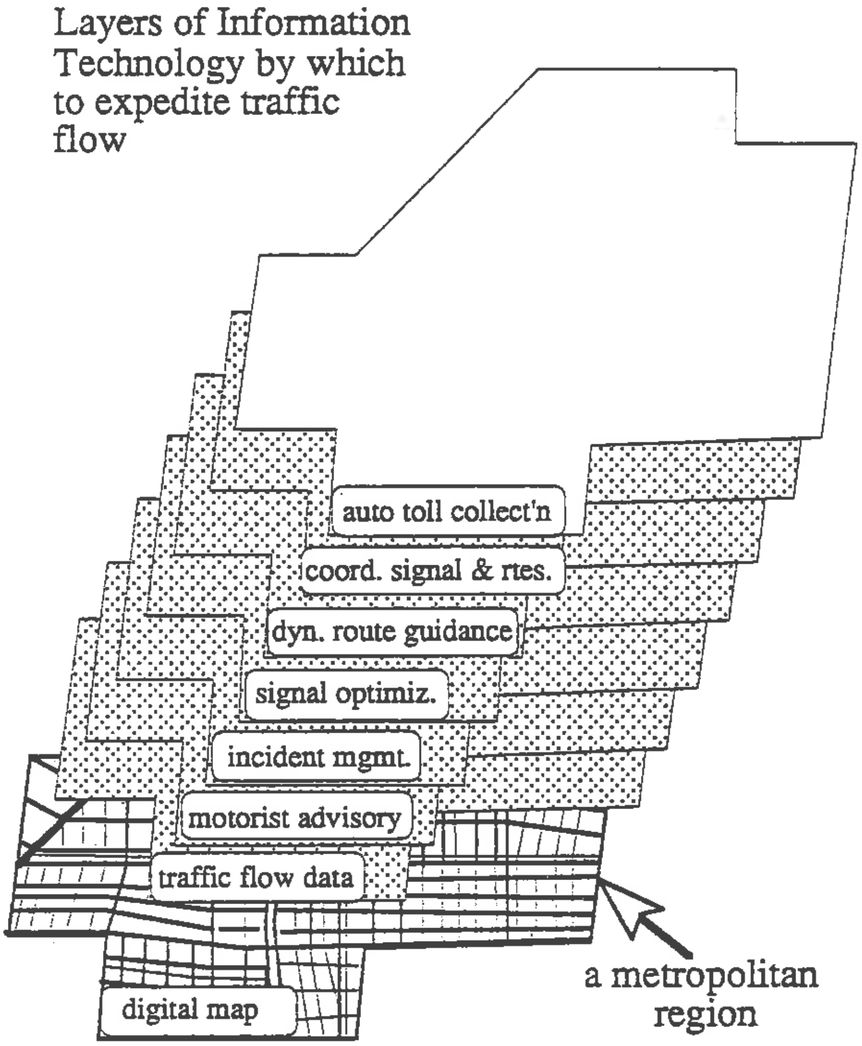
In the first, we are primarily interested in information technology by which to expedite traffic movement. Systems of this type are employed by highway agencies for optimizing traffic controls and by private services in assisting individual motorists to find optimum routes through congested road networks plus a host of related services. Because information systems are most near at hand, and highly complex from the viewpoint of public policy, this paper will dwell predominantly on this subject.

The second application involves technology to enhance the control of the motor vehicle. In this group, the driver is given warning and other alerts to avoid collision or is relieved as the controller, altogether, such that automated, hands-off, travel is effected. In every case, new information and new means of control are targeted at improving the performance of the overall system, more or less in the absence of new highway construction.

Section 2

Information Technology Expediting Traffic Movement

At the "information technology" level, various layers are defined, each of which contributes functionality to motor vehicle travel over a metropolitan road system. Shown in the next figure, eight layers serve to define the core of the technology which will expedite traffic movement. They are as follows:



- *digital road map*. The digital map reduces to numerical form the geographic layout of roads plus the physical and regulatory attributes of each road segment and intersection. It provides the spatial layer of data for making computations on network traffic flow and routing.

- *traffic flow characterization.* The continuous surveillance of traffic flow along all significant road links provides the temporal data characterizing the dynamic state of the road network. As may be obvious, this function is pivotal and will be addressed in considerable depth in this paper.
- *general motorist advisory.* Once traffic flow is defined across the network map, information on major traffic tie-ups can be communicated to all motorists as voice or text messages by means of commercial radio, roadside radio, and changeable message signs.
- *incident management.* When accidents are detected, emergency service vehicles can be dispatched quickly to the scene to effect a speedy clean-up.
- *signal network optimization.* Traffic flow data provides the basic information for computing the timing parameters that will optimize intersection control signals across the entire street system.
- *dynamic route guidance.* If all road links on the digital map have been described by a travel time, it is possible to compute a minimum-time route for any trip. Thus, individualized routing can be given to each motorist whose vehicle is equipped with (a) a continuous location system and (b) a means of digital mobile communications.
- *coordination of signalling and routing.* If the computations for optimum signalling and optimum routing are combined, an integrated strategy for guiding both functions may improve traffic efficiency well beyond that gained by either approach, alone.
- *automatic toll collection.* Vehicles equipped with automatic-debiting electronic tags can pay tolls at bridges, tunnels, and tollways without stopping to transfer cash.

The set of layers can also serve as building blocks for implementing other functions. Such functions can serve the driver, the highway community, public service organizations, emergency services, trucking operations, and so on. The question is, how can we build the needed infrastructure for enabling such functions? In order to answer this question, we must explore the current state of technology and institutions upon which the systems will be built. In the U.S., the discussion of such matters has been organized under two systems categories, namely, Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS). This terminology will be used in the discussion that follows so that the reader can bridge between the views presented here and those espoused in different thrusts of IVHS activity in this country.

ATMS installations are assumed to be built more or less exclusively with public money and are operated by state, county, and city departments of transportation. Such systems employ instrumentation in the roadway and central computing facilities to effect traffic surveillance, incident management, automated signal control, and the roadside display of traffic advisory messages to drivers in conventional motor vehicles.

ATIS pertains to information-based functions provided to motorists operating specially-equipped cars. In-vehicle equipment ranges from $20 for an automatic toll tag to perhaps $2000 for a full-option package that receives traffic data and provides optimum routing and various other services. These systems give direct benefit to the vehicle owner and synergistic benefit to the public by improving traffic. A digital radio communication infrastructure is essential for ATIS services.

The dollar-value of benefits to be gained from ATMS and ATIS functionalities will be presented later in the paper. Benefit estimates will be based upon a certain class of system configurations, to be introduced below.

Although ATMS is relatively mature and has been extensively deployed in Europe and Japan, the U.S. has preferred to meet its traffic demands by building more roads rather than "managing" their operation. Thus, ATMS has seen minimal deployment in U.S. cities to date. For example, only 7% of urban freeway miles are instrumented for surveillance and only about 0.1% of intersection traffic lights have adaptive signal timing.[3,7] With the great era of road construction now drawing to a close, the need for traffic management is rising rapidly in states and cities whose highways are increasingly overloaded.

In the ATMS model, the key need for traffic characterization is met by means of hard-wired surveillance equipment—normally using magnetic loop detectors installed in the pavement, although techniques for processing video traffic images have also been developed. Such in-situ types of traffic surveillance account for a large share of the cost of conventional ATMS implementation, running around one-half million dollars per mile of expressway.

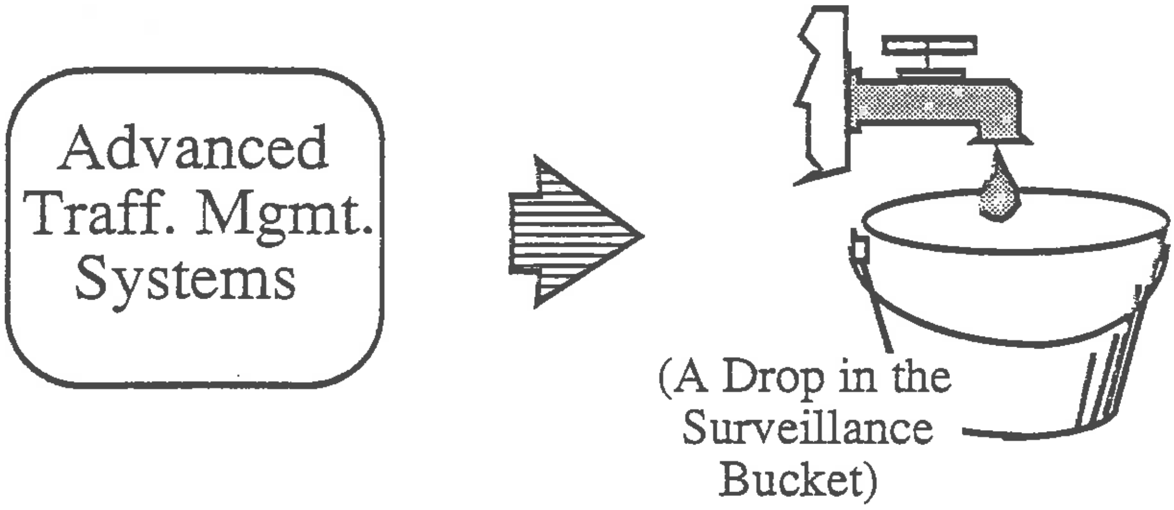
The overall cost for installing ATMS capability in America's largest cities is estimated at $22 billion.[8] And yet, in 1990 the total national expenditure for deployment of ATMS installations amounted to approximately $250 million.[7] Clearly, America's current expenditure on conventional ATMS is a drop in the bucket relative to the need. If we were to get serious about achieving complete ATMS installation and maintaining it over a fifteen-year service life we would need a per-annum investment that is twenty times the current rate, or $5 billion per year.

Although the recent Surface Transportation Assistance Act offers federal cost-sharing for ATMS projects, such activities may have trouble competing with other conventional road improvements that are broadly underfunded in most state and local jurisdictions. Individual cities and towns may also face an interesting form of disincentive for deploying traffic surveillance, upon noting that the data may be used to guide dynamic routing of individual vehicles. An insular-minded municipality might consider its options thus: "If dynamic routing of vehicles in this metropolis is done without any data from our specific town, then the router must presume that our streets are all clogged up—otherwise it may be routing its clients into an undetected traffic jam, and the system will lose credibility. So, in order to minimize traffic on our turf, our best bet is to become a little 'island of darkness' in the metropolitan landscape, with surveillance-less streets. That way, all dynamic-routing will be confined to other people's street systems. The principle is, no data—less traffic.".

This startling problem implies that dynamic routing based upon anything other than inherently wide-area surveillance may be basically unsound.

Beyond the logical disincentive for installing ATMS-style surveillance equipment, state and local governments in this country are also entering a period of great financial stress. The financial reality alone tends to argue that no more than a skeleton ATMS infrastructure will be available in virtually all major cities by the year 2005. In the words of former DOT Secretary, Sam Skinner, "the states are broke."[9] And many cities are virtually bankrupt, as well.[10] Thus it is sobering to note that 20,000 more or less financially-troubled units of government stand between the ATMS concept and its effective implementation in urban America. It is also true that most of these jurisdictions are short on professional expertise and tradition for supporting ATMS installations.

The author concludes that conventional ATMS will fail to provide comprehensive surveillance of expressways and arterial streets in any American metropolis within this decade, and perhaps the next decade, as well. Thus, if the U.S. is to realize the multi-layered "information technology" vision for IVHS, it must employ system architectures that do not depend upon state and local government to deploy a traffic surveillance infrastructure, one street at a time. To assume that the crucial surveillance function will be covered by the weak link of state and local agencies is to jeopardize the entire IVHS process and render much of the ATIS investment shaky and unassured.



State and Local Deployment of ATMS

Recognizing both the disincentive and incapacity of these jurisdictions, we seek another model for generating the high-fidelity, real-time traffic description that is required. Such traffic data are needed to support all forms of motorist advisory and dynamic route guidance in the near term while later enabling the local jurisdictions to optimize their signal networks as the political imperative for managing the traffic control system grows.

(Interestingly, the U.S. situation is in sharp contrast to that of Japan where the highly-centralized public agencies have already deployed a rather complete hard-wired surveillance infrastructure covering surface streets and expressways.[11] In the Japanese case, traffic data are on hand, today, to support the creation of ATIS services. Thus, a suitable architecture for the mobile communications system supporting ATIS in Japan can be substantially simpler than is necessary in the U.S. This distinction will be expanded below.)

Surveillance by means of "Vehicles-as-Probes"

We take the view, then, that the key requirement for optimized traffic controls and the core ATIS function is real-time traffic characterization—and in the United States, the publicly-financed ATMS approach is not about to deliver it. Thus, a first order of business is to identify one or more means for accomplishing traffic surveillance without the large public investment and multi-jurisdiction vulnerability that conventional ATMS presupposes. All candidate approaches meeting this requirement fall in the so-called "vehicle-as-probe" category. By such schemes, the instantaneous location of an individual vehicle is determined and then communicated by some type of digital radio link to central computers. The compilation of such data from thousands of vehicles operating continuously through the city yields a characterization of flow across the network.

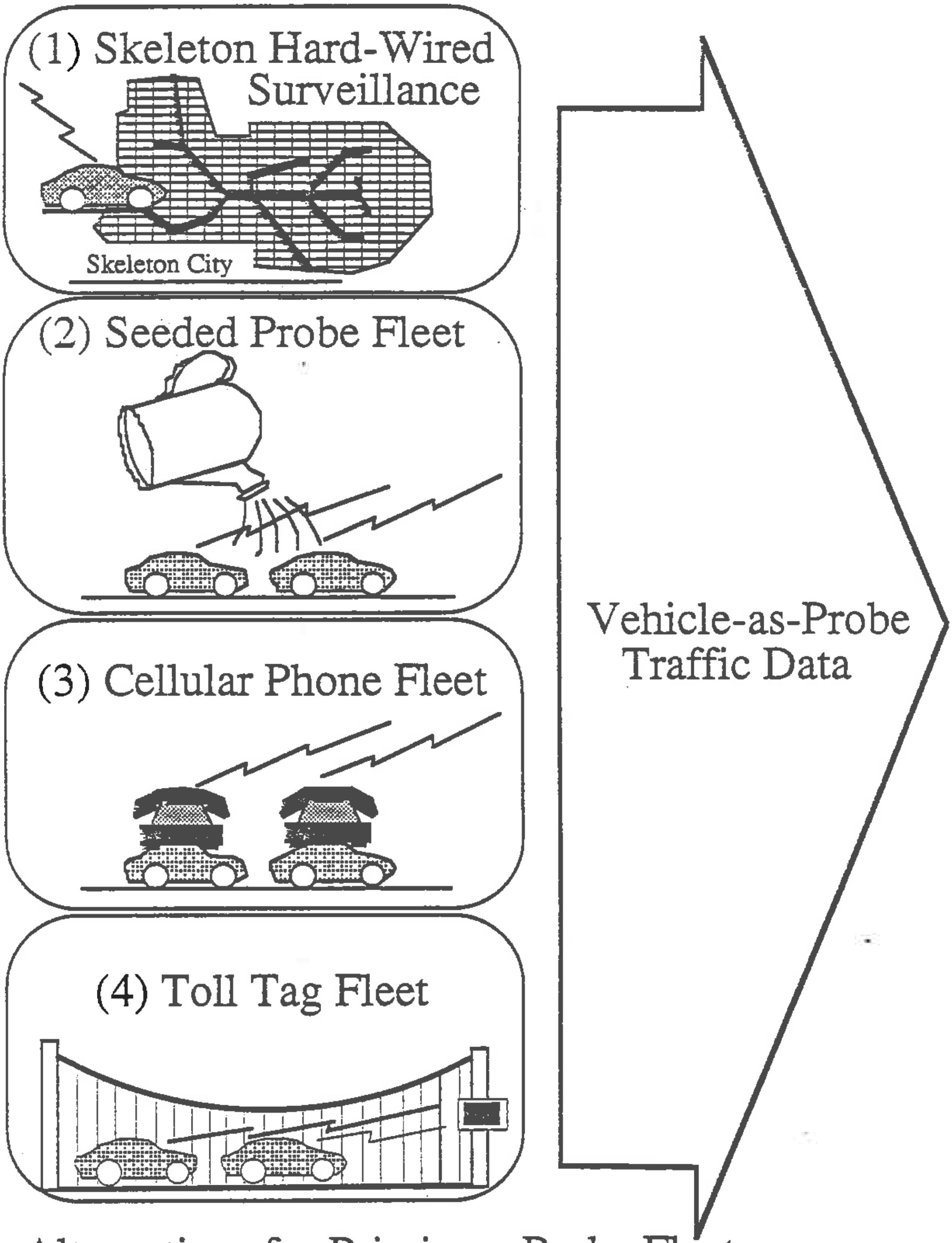
Since a vehicle-location technology must be provided in order to attain the "dynamic route guidance" (DRG) layer of functionality, we find that one way the vehicle-as-probe method of surveillance can be achieved is through certain systems that also give route guidance to the motorist. Motorola's "Advance" architecture and Siemen's "Ali-Scout" system both incorporate this feature. In all such systems, the driver enters a destination address and then proceeds along a route advised by the system. The recommended route is based upon a weighting of all candidate highway links, according to current and perhaps predicted travel time on each link, thus requiring that the state of traffic be characterized through continuous data collected at a central location. In order to access DRG services, drivers must purchase a special in-vehicle module. They will then pay a monthly fee for the data communication service while implicitly allowing their own vehicular travel to be tracked for the sake of its probe data (although the explicit identity of the vehicle may be sanitized from the centrally-processed data to protect privacy.) If the DRG vehicle does serve as a probe, the data link must involve two-way digital communications.

There is an obvious "chicken and egg" problem, however, in first deploying a DRG service for which the traffic characterization requires data from a large fleet of probes. In particular, we must figure out how to "jump-start" the mobile information service by generating a sufficient level of traffic characterization to lure in at least a first wave of customers. As the usage fleet grows, the quality of the traffic data will improve and costs for in-vehicle units will decline such that broad popular usage may materialize. Four mechanisms for building a probe-based traffic characterization are as follows:

1) *"Priming" the system by means of a hard-wired surveillance skeleton.* For those cities in which a substantial skeleton of the road network has been instrumented for hard-wired traffic surveillance, there may be sufficient traffic characterization to begin operation of a user-pay DRG services. Typically, the skeleton would cover a major portion of the expressway network. User fees would start out low in reflection of the minimal coverage. The early customers would include travelling salesmen, truckers, and upscale motorists who place special value on even a modest level of serviceability, or who simply dismiss cost as an impediment. Data from the hard-wired traffic detectors would be fused with other soft sources of information such as police reporting, cellular call-in, and commercial reporting services in order to crudely extend coverage to the off-skeleton roadways. When a sufficiently large probe fleet materializes, the hard-wired system may become superfluous, not requiring continued operation.

2) *Priming by means of a seeded probe fleet.* It may be attractive to equip certain classes of high-use vehicles with location and communication equipment so as to field at least a minimum fleet of probes throughout the network from day-one. The fleet could be drawn from local delivery vehicles, city buses, taxis, etc. that agree to operate with the equipment installed. DRG services and the simple navigation utility of the equipment may be suitable incentives for enlisting the seed fleet. As the fleet of subscribers grows, the seeded fleet of probes could be phased out.

3) *Vehicles with Cellular phones as location probes.* It has been demonstrated recently that cellular phone signals can be processed to closely locate vehicles whose mobile phone is turned on (i.e., activated, but not necessarily engaged with a call.) Since this approach could enable the existing fleet of 6 million cellular phone users to be used as probes, the concept might offer a relatively inexpensive means for traffic surveillance in most big cities in this country. Cellular subscribers stand to benefit in a special way from such an adaptation since it would be relatively straightforward to set up a computerized calling service advising users of traffic tie-ups that have been detected ahead, on their current roadway. If cellular-equipped cars simply became the permanent national probe fleet, then DRG services could be offered via a one-way radio link (since it would only be necessary to downlink the highway travel time data to on-board routing algorithms, thus avoiding the much more sophisticated 2-way



Alternatives for Priming a Probe Fleet

communications equipment through which DRG vehicles, themselves, serve as probes.)

4) *Vehicles with automatic toll tags as location probes*. The rapid rise in electronic tags for automated toll collection at bridges, tunnels, and toll roads could also provide a path toward traffic characterization via a fleet of probe vehicles. Namely, in those cities having relatively dense populations of vehicles equipped with the toll tag, non-debiting tag readers can be installed throughout the road system for tracking the movement of tag-equipped vehicles. This concept is currently being studied through the so-called Transcom experiment in the metropolitan New York City area. Since the tags are short-range communication devices, the detection of a certain tag serial number at two successive reader sites provides one sample of the travel time along the intervening road link. But, installation and maintenance of individual reader equipment throughout a metropolitan area may be relatively expensive. Thus, the tag-equipped probe scheme is probably best viewed as an alternative "skeleton" strategy for initiating traffic surveillance.

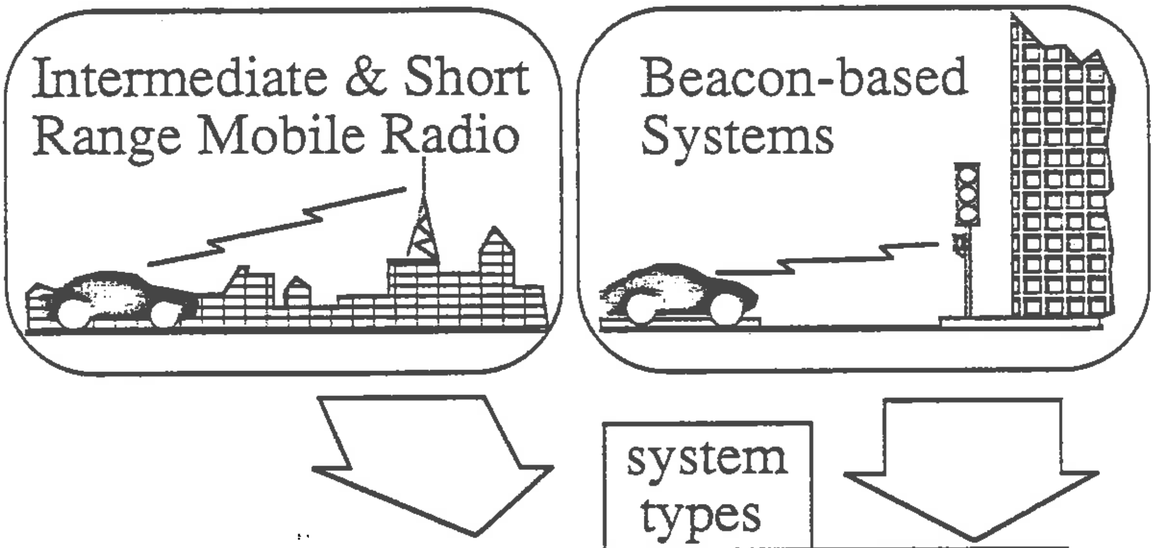
(Another intriguing aspect of vehicle I.D. tags is that a community could begin to exact tolls simply for using the public roadway, perhaps with the fees weighted to discourage travel during peak-traffic hours. The mere existence of automatically-debitable tags on many vehicles may constitute a setting which tempts the community leaders to establish these so-called "road pricing" statutes—especially if most of the fee-payers are residents travelling from other jurisdictions.)

Assuming that some mechanism will develop for generating traffic characterization data, it is useful next to consider the appropriate model for deployment of a mobile information utility that supports DRG and other ATIS-type services based upon digital communications between a relatively intelligent vehicle and an intelligent infrastructure. Because there is public sector authority over use of the airwaves as well as the highway right-of-way, opportunities exist for negotiation, regulation, and authorization of IVHS business in order to cover the concern for public benefit. The problem is that mismatches exist between regimes of public authority and domains of system configuration. On the one hand, for example, any use of a regulated frequency band will require authorization by the Federal Communications Commission (FCC,) but not all communications bands of interest for IVHS are regulated. On the other hand, any installation of equipment along the public right-of-way must be authorized by the state or local agency having jurisdiction over the roadway in question, but only certain ATIS architectures require the physical installation of equipment at the roadside.

The ability of the public sector to beneficially influence the nature and extent of ATIS deployment will depend upon the authorization that is needed, given the system design. While the FCC can assure through the allocation of regulated frequencies that national-level interests are secured, systems whose designs require local authorization, or maybe none at all, could emerge as "wildcats" employing in-vehicle equipment that is incompatible from one community to the next, perhaps also upsetting the competitive balance that is needed to assure wide deployment across all metropolitan areas, nationally. By way of example to illustrate the competitive issue, consider the chaos that would prevail in the cellular telephone industry if the two FCC-authorized franchise-holders in each region had to contend with wildcat mobile phone service which opened for business with an unregulated mobile phone technology. Imagine also that, being unregulated, the newcomer was able to mount a national network that could selectively undercut franchise-holders in a given community in order to cripple their competitive position. The unregulated provider could methodically "dump" services at below-cost rate into one city at a time to strangle the regulated, local, competitors one after another. If such rodeo-style risks had been anticipated in advance, cellular investors would have balked at the high uncertainty of return.

Examining alternative ATIS technologies, at least two or three incompatible versions of communication and computing infrastructures could appear in large-scale service. One of these might be FCC-authorized and could represent the desired national standard. Others may appear to satisfy some local expedient and yet not be compatible with the standard. Noting the preceding figure, imagine that the standard involves FCC-authorized, 2-way cellular data communications occupying a band in the range of 900 MHz. Such a service could blanket an entire metropolitan area without requiring the installation of equipment along the highway right-of-way. An alternative but incompatible system might use a network of infra-red beacons installed along the highway right-of-way and communicating at very short range with individual vehicles as they pass through the transmission window of the beacon. Because infrared is an unregulated portion of the electromagnetic spectrum, the only public authorization that is needed involves local highway agencies responsible for the right-of-way. A third possible system might involve the unlicensed spread-spectrum

Domains of Public Control vs.Types of Communication System

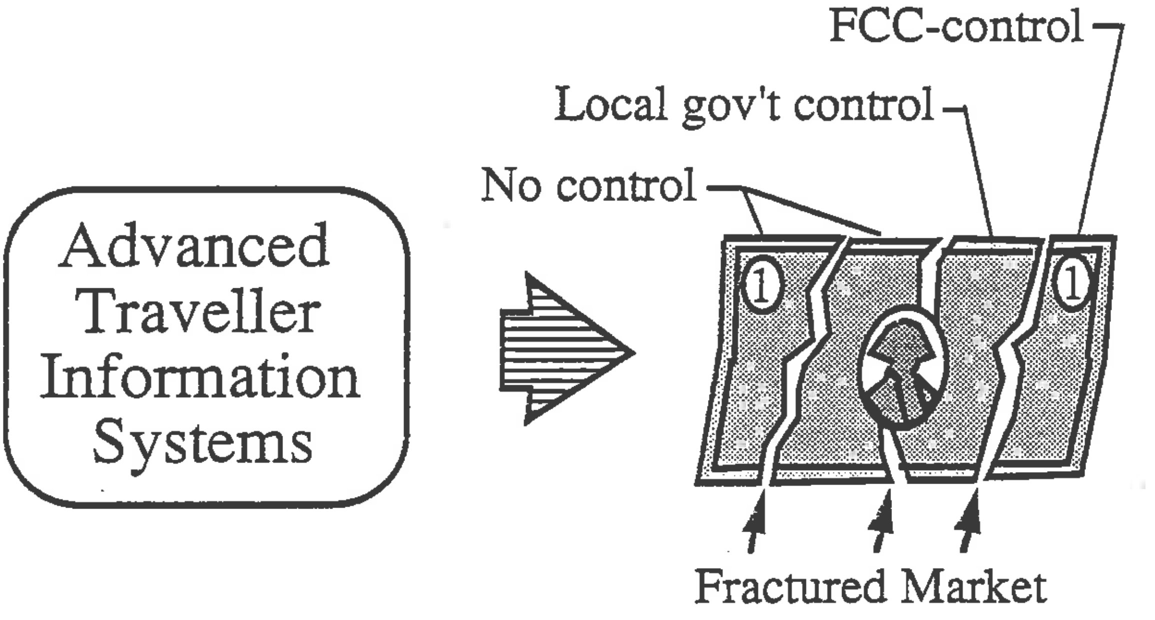


Requires FCC Allocation of Spectrum	No	Yes
Yes	Digital Cellular (900 Mhz)	Microwave Beacon Network
No	Unlicensed Spread Spectrum	Infrared Beacon Network

Requires Authorized Access to Highway Right-of-Way band of radio communications. In this case, with intermediate range capability, transmitters could be placed on leased property that is not on the right-of-way. Thus, no public authorization of any kind would be required. Yet a fourth alternative, microwave beacons, would lie in the combined domains of both the FCC and the state and local highway jurisdictions.

If multiple, incompatible, and non-uniformly regulated systems materialize, the market is likely to be fractured such that costs stay high, some buyers get stuck with obsolete systems, and no in-vehicle module works in every town. Or, in anticipation of chaotic competition, the serious investments may not occur in the first place. In either case, the public loses.

There is even a reasonable likelihood that state and local highway agencies will facilitate the proliferation of systems, especially those that do not require FCC authorization. The probable scenario would involve a highly congested metropolis that comes under heavy political pressure to "do something" in the local interest. Consider that an unregulated ATIS proposal is brought to the community's doorstep by an eager and credible service



ATIS based on Incompletely-Regulated Infrastructure provider, offering low cost and perhaps quicker installation than is likely from regulated options whose standard is still being developed. The city or regional government may be attracted to leverage its local funds in order to launch a more-or-less user-pay service that plausibly addresses congestion. Lacking a traffic surveillance infrastructure, anyway, the typical community would recognize that vehicle-as-probe data streaming back downtown have great value for highway planning, management, and eventually for central control of signals—and this approach circumvents the "islands of darkness" behavior that otherwise faces any hard-wired surveillance plans. Thus, it may be straightforward to show public value for the local matching money that is required. If the process of developing a national standard appears to be delayed and uncertain, local interests would readily transcend the national interest. Because congestion problems are inherently local, local priorities should be expected to govern the action unless other mechanisms prevail.

On the private side, the key players may be national providers of communication services who target the ATIS arena as a vast new business segment, with many and varied opportunities for growth and expanded functionality. When access to one or two large communities is achieved, long-range strategy might call for partnerships which tend to add functionality quickly by expanding the map and commercial databases and adding services which are inherently linked to the proprietary system design. A party which is most successful in achieving rapid expansion across the country while giving good service may indeed dominate the others before long. Or, perhaps the market distributions would migrate into regional zones of dominance by differing systems. Such scenarios lead to early obsolescence of some products and maybe a stalemate of multiple incompatible systems over the long run. In any case, a multi-player market is to be expected as long as a fast-rising business opportunity appears simultaneously in many parts of the country. Since no single company or set of partners would have the resources for immediately mounting new infrastructure and service operations in every city, one would expect multiple players in at least the near term.

The Benefits to be Accrued from Information Technology that Expedites Traffic Movement

Considering the many issues that reveal the complexity of ATMS and ATIS implementation, there is an obvious question as to the magnitude of the benefits that are at stake. In general, there is compelling evidence that the benefits are large relative to the investment. Benefits can be expected in five categories, as follows:

1) *The benefits of conventional ATMS.* Benefits amounting to an additional 10% in expressway capacity have been gained through the metering of traffic at the on-ramps.[12] Similarly, capacity improvements in the range of 20% may result from adaptive optimization of intersection traffic signals.[13,14] Both types of systems have also shown substantial reduction in traffic accidents due to the regularization of flow.

2) *The benefits of DRG.* The routing of traffic to better utilize the overall traffic network has been shown to improve effective system capacity by 10% to 20%, depending upon the street system and base traffic demand.[15,16,17]

3) *The reduction in demand deriving from "systems knowledge".* When quantitative information is available every day (i.e., from probe data) showing the ebb and flow of congestion patterns, it is expected that government, individual employers, public interest groups and others will examine the information to derive logistical and policy strategies for avoiding congestion. There is an expectation that authoritative information would lead to new state and local regulations, traffic management plans, industrial and truck scheduling, and so on, plus stronger warrants for telecommuting trends among varied work groups. One obvious public policy outcome could be a carefully strategized plan to introduce road pricing into a community. Since it would be possible to show the spatial and time character of the congestion problem in black and white, the pricing scheme could be placed on an objective, and less politically-burdensome, basis and the expected results could be more readily modelled. Moreover, the general result of publicly-available system performance data should be a net reduction in the rate of growth in congested operations plus a more intelligent basis for managing existing facilities and urban development, in the whole.

4) *Combined capacity improvements.* Although no one has yet been able to show the synergistic influence of combined ramp metering, signal optimization, route guidance, and the community-wide influence of "systems knowledge," considered estimates show that the equivalent capacity of the urban road system could improve at least 35%, overall.[8]

5) *Reduction in environmental pollutants.* A major benefit of systems that expedite traffic movement comes from the reduction in automotive pollution which otherwise rises dramatically in congested traffic. Because of exaggerated emission output when accelerating and when stopped at idle, the better distribution of vehicles across the street network and the regularized travel through computer-controlled intersections has substantial

benefit. It can be shown that reductions of 10% to 20% in automotive emission levels can accrue from the combined traffic control and efficient routing improvements outlined here.

One can compute the dollar value of a 35% improvement in capacity by reference to two differing measures. In one, we can illustrate the cost of an equivalent 35% expansion in the expressway network in large metropolitan areas such as, for example, Detroit. Based upon Detroit's most recent experiences with expressway construction, a per-mile cost of $50 million is representative.[1] Thus, extending the Detroit area's current 200 miles of expressway by another 35% would cost on the order of $3.5 billion. The bill for a 35% expansion in the expressway capacity of the fifty largest cities in the U.S. is roughly on the order of $70 billion and would carry a maintenance requirement of approximately $7 billion per year for its upkeep and eventual refurbishment. (Again it must be noted that this hypothetical construction program would be unachievable, in practice, due to the strength of community resistance to new roads.)

Another dollar-value illustration can be obtained upon noting that a 35% improvement in capacity will yield on the order of a 39% reduction in the annual vehicle-hours of delay predicted to occur by the year, 2005.[3] The reduction in delay is estimated to be worth $13 billion per year (which, interestingly, is very close to a $14 billion/yr sum one gets by adding the $7 billion maintenance cost plus $7 billion for a 10% cost-of-capital associated with the $70 billion construction program mentioned above.)[8]

Estimates of System Cost

Corresponding to benefits illustrated above, it is possible to make order-of-magnitude estimates on the cost to deploy information-based systems which expedite traffic flow. It was noted earlier that some $22 billion has been estimated as the cost of conventional ATMS in America's larger cities. Since we can forego approximately $9 billion of this amount if vehicle-as-probe surveillance is substituted for a "hard-wired" road system, then we might say that some $13 billion in public capital is still needed for effecting the traffic control portion of ATMS. A fifteen-year amortization of this investment imposes a $1.7 billion annual cost. Another $1.3 billion per year will be needed to maintain and refurbish these systems, for a total of $3 billion per year.

The additional costs for an ATIS infrastructure may be very roughly estimated by way of comparison to the investment already put into the cellular phone system. Namely, we note that some $5 billion has been invested in the cellular phone infrastructure to serve 5 million customers (in 1990.) Private users have spent a total of $2.5 billion for in-vehicle equipment, (at an average cost of $500 per unit.) The annual revenues for usage amounted to $3.8 billion in 1990 ($760 in annual billing for the average customer!)[18]

For purposes of discussion, we might speculate that the infrastructure for two-way digital communications will equal that of the cellular system, costing perhaps $5 billion in capital outlay. We shall assume that the relative risk of this private investment calls for a stiff discount rate—say, 30%—and that costs of 10% for maintenance and 5% for system refurbishment and upgrading apply. The $2.25 billion annual cost for capital, maintenance, and refurbishment plus an assumed equal amount to cover operations and corporate profit must come through total user fees, requiring a total annual revenue of $4.5 billion.

The cost of high-volume, in-vehicle, units capable of route guidance are expected to be in the vicinity of the $500-per-unit that was paid on average through 1990 for cellular phones. This is a private cost borne by the up-scale motorist, trucker, or other high-mileage user that desires the DRG service. As for the ATIS user fee, figures in the range of $400 per year have been frequently cited as a target. If we assume that a user population of 10 million vehicles materializes, yielding $4 billion per year in user revenues (@ the $400/yr user fee) we have an illustration requiring another $0.5 billion per year to be supplemented from public funds to satisfy the $4.5 billion revenue target and to make the business viable. A substantial public payment is warranted, of course, since the state and local agencies can use privately-generated probe data for optimizing their signal networks, giving traffic advisories to the general public, and for highway planning and policymaking. The public "buy-in" is also very desirable as an incentive for priming the business at its outset and as a "hook" for assuring that the system gives good public benefit.

The bottom line of this discussion is that a minimum of $13 billion in *annual* public cost due to congestion, predicted by the year 2005, is avoided through the following:

- a $13 billion public capitalization of ATMS, imposing an equivalent annual cost of $3 billion per year for capital financing and maintenance,
- a $5 billion privately-capitalized ATIS infrastructure, whose capital recovery and operations costs are covered by user fees,
- a $5 billion private purchase of in-vehicle equipment by individual motorists—who get the most benefit,

- $4 billion per year in private user fees paid to the ATIS service providers, (of course giving many features that benefit the individual subscriber,)
- $0.5 billion per year in public-sector user fees paid to the ATIS providers in exchange for probe data.

Capitalization and maintenance of the ATMS infrastructure plus payment for the privately-generated information services can be expressed as a total annual cost to the taxpayer of $3.5 billion/yr. This figure is 30% less than the $5 billion/year estimated earlier for full ATMS, alone, and offers approximately twice the level of real public benefit. The $3.5 billion figure compares favorably against the benefit of $13 billion/yr in reduced congestion delay plus the associated public benefit of reduced pollution, energy waste, and accidents that attend a 39% higher level of traffic congestion.

The individual citizen that does not subscribe to the ATIS service accrues benefit primarily through time savings while travelling by personal vehicle. His community is better served by emergency response services and is less polluted; he has better access to employment; his truck-borne goods cost less; and his personal travel is better advised and more predictable. Moreover, the public benefit of this combined public/private development is (a) substantial in absolute terms, (b) worth it, given the benefit/cost relationship and (c) probably underrated given the potential long-term value of "systems knowledge."

Conclusions and Suggested Action Steps to deploy an Information-based Technology for Expediting Traffic Flow

Conclusions from this discussion, plus certain suggested policy actions are as follows:

1) A means of producing traffic surveillance data covering the full network of metropolitan streets and expressways is the key ingredient of a powerful information-based IVHS technology.

2) Conventional ATMS technology, deployed by state and local highway agencies, is not likely to deliver traffic surveillance data to meet the needs posed by the congestion crisis that is developing in large U.S. cities. A service providing dynamic route guidance to individuals, based upon real-time traffic data, will not materialize unless an alternative for hard-wired surveillance is created.

3) The primary opportunity for attaining an accurate characterization of traffic flow across large metropolitan areas, absent hard-wired surveillance equipment in the roadway, is by means of vehicle-as-probe technology. Four different scenarios for "growing" a fleet of probe vehicles have been identified. The pursuit of one or more means of gaining probe data constitutes the greatest single need for attaining information-based systems to expedite traffic flow in the U.S. The possible use of cellular phones as the probe-link is especially attractive, if proven feasible.

4) Implementing an infrastructure and the operations for privately-generated probe surveillance and DRG services can require authorization by the FCC, by state and local jurisdictions, or no one depending upon the configuration of the system to be deployed. Since some regulation of system configuration is seen as necessary if private investment is to be encouraged, and incompatible proliferation of equipment avoided, some overarching form of public control of the commercialization process must be sought.

5) Probe data generated by private providers of ATIS services, or others, are extremely valuable to metropolitan communities that fail to mount their own traffic surveillance infrastructure. Anticipating that most American cities fall into this category, a consolidation of the interests of urban America is in order. In particular, an *a priori* guarantee of the public purchase of probe data would constitute a powerful means of underwriting the private risk of investment in an infrastructure that collects probe data while delivering ATIS services. It appears to be persuasively in the public interest to forward such a guarantee.

6) The public guarantee also offers a mechanism for gaining some public control over the deployed architectures. New federal legislation is needed to gain authority over a domain which is incompletely covered by existing FCC and state and local highway authority. The leveraging power of the legislation is that public purchase of probe data will go only to one or more providers that meet the full requirements which protect the public interest. The guaranteed purchase price must be high enough that no commercial venture lacking the public revenue would be competitive against those that comply. The actual amount paid in a given year would be based upon the extent of system implementation in each urban area.

7) A level of congestion relief at least comparable to that estimated from dynamic route guidance can derive from optimized control of ramp metering and intersection signals. Although state and local governments will not significantly optimize their traffic control

systems over the next ten years at their current rate of installation, the availability of probe data from private sources will simplify and reduce the cost of such installations, perhaps helping to accelerate their deployment.

Section 3
Technology to Enhance the Control of the Motor Vehicle

Enhancement of the process of motor vehicle control can impact upon the safety of operation and can effect a wide range of improvement in traffic flow. Technology to bring about such enhancements will be discussed at two levels, namely, Active Safety Technologies (AST) and Automated Highway Systems (AHS). It is generally expected that an evolutionary trend will begin with AST's "smart car" products that provide control warning and assistance, but otherwise leave the driver in primary control. Success at this level would presumably lead toward interactive AHS installations in which vehicle control is turned over to automatic equipment on special roadways. Both phases of control enhancement will be discussed, here, in terms of the functionalities, the cost/benefit situation, and the actions that may overcome major barriers.

Implementing Active Safety Technology

AST packages assist the driver in avoiding accidents, thus accomplishing a more efficient and humane transportation system. Such technologies primarily involve autonomous systems which are purchased as OEM or aftermarket enhancements to individual vehicles. In various embodiments, they assist the driver by supplementing perceptual cues, warning of impending collision, monitoring for drowsiness or other impairments of the driver, and perhaps providing backup control in emergencies where the time available for driver response is too short. In all such applications, some degree of responsibility that was traditionally borne by the driver becomes adopted by "the system." Because these technologies are delivered primarily by automakers and automotive system suppliers, the liability for such innovation will transfer to that segment of industry.

Movement toward AST products in the OEM vehicle is accelerating rapidly in Europe and Japan, but more slowly in the U.S.[11,19] The contrasting rates of progress appear to reflect differences in both the perceptions of market readiness and the respective legal mileu regarding tort liability. And yet, the potential public benefit of AST implementation in the U.S. is enormous.

Benefit estimates can be derived from a careful examination of the accident experience occuring today. As implied above, AST systems are intended to make up for shortcomings in the driver's attentiveness, visual perception, alertness and quickness in discerning a pending collision, selection of speed given road surface conditions, perception of right-of-way at intersections, etc. Because extensive, (albeit incomplete) accident data are available, the benefit of individual AST countermeasures can be roughly assessed by matching each with its corresponding accident modes. Nighttime vision-enhancement devices, for example, may minimize run-off-road and pedestrian-strike accidents that claim some 40% of the highway death toll each year. Early attempts at quantifying AST benefits show that some $4 billion to $22 billion per year in reduced accident costs could accrue by the year 2010 if products currently under development enjoy the market penetrations that have been estimated through wide-industry surveys.[6]

Because accidents account for the largest portion of all traffic delay, AST implementation also promises to markedly reduce the congestion problem. Headway-control devices, for example, would work to reduce the rear-end type of collisions that account for the majority of accidents in congested traffic. It is estimated that 6% of total delay could be avoided by the year 2010 if 25% of the vehicle fleet were equipped with relatively effective devices to avoid rear-end collisions.[6] The corresponding public benefit from congestion relief is on the order of $2 billion per year, for total AST benefits amounting to $6 billion to $22 billion per year.

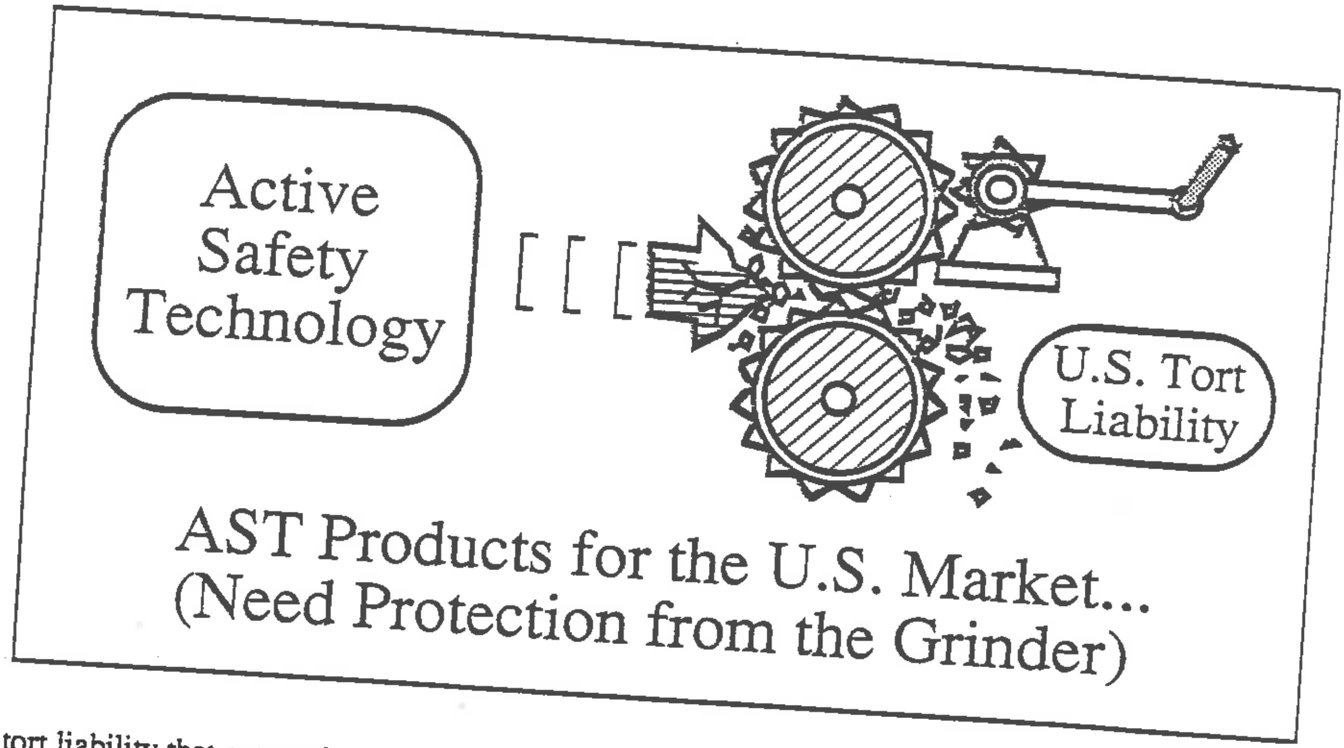
Taking an intermediate $13 billion figure for an example illustration, the dollar benefit alone would fully justify an investment that outfitted 50 million vehicles with $1000 worth of AST equipment that gives even 5 years of effective service. The private benefit, which ultimately prompts the private purchase, is of course immediately realized by the buyers who pay for their own safety advantages. The non-buying public benefit through reduction in their risk of collision with all AST-equipped vehicles, through a decline in their own insurance costs as the national loss experience improves, and through reduced traffic delay.

Because the public benefit is potentially large, it makes sense to explore policies that may expedite the implementation of AST products. More directly, we must now address certain barriers which otherwise discourage the quick advancement of the AST era. The primary impediment to an aggressive product strategy by U.S. domestic manufacturers is the problem of tort liability. One illustration highlights the manufacturer's concern for future liability with AST products. Namely, court records show that only one in ten present-day auto accident suits targets a manufacturer as the defendant. The rest charge other drivers. This statistic reveals the obvious premise that conventional vehicles leave the responsibility for vehicle control primarily in the hands of each driver. American juries generally adopt this view. However, if AST systems tend to dilute the driver's responsibility by assisting in the alert-and-control process, the deep pockets of the automotive industry may become the target in a large portion of the remaining 9 out of 10 tort litigations.[20]

Accordingly, corporate aversion to the risk of large and unpredictable levels of liability constitutes the biggest barrier to accruing public benefit from AST innovation in the U.S. Conversely, because European and Japanese markets are virtually litigation-free, overseas manufacturers can refine products quickly based upon the most valuable of all types of product iteration—those based upon field experience. Since American manufacturers will not have the benefit of a domestic market in which to develop and refine an active safety technology, one should expect that foreign-based corporations will develop full-fledged product capability before American corporations, thus posturing to play strongly in a U.S. market that may emerge later on the strength of highly litigation-proof products. The author argues that benefits to the American public warrant steps to facilitate the marketing of AST products. And it should be done in a way that aids U.S. manufacturers to compete in what promises to be a new era of increased value-added for the motor vehicle.

One path of action on the legal front is to seek new legislation which bounds the liability level that AST manufacturers will otherwise bear. In fact, the high level of public benefit may justify public indemnification of manufacturers beyond a certain manageable level of liability exposure, or we may simply decree a liability cap. Precedents for such action by the U.S. Congress exist in the cases of commercial air travel and nuclear power utilities.[20]

A second avenue of action that deals with both the liability issue and the ultimate effectiveness of the systems, themselves, involves the role to be played by the federal agency that has responsibility for automotive safety, the National Highway Traffic Safety Administration (NHTSA.) In a nutshell, the agency's ability to promulgate national standards for automotive safety equipment poses an opportunity for deflecting much of the



tort liability that automakers might bear in selling AST products. Standards would also serve to establish uniform requirements for safety-effectiveness.

It is apparent that the U.S. auto industry may already have a favorable view toward federal AST standards.[21] This attitude, if widespread, would represent an ironic turnabout from the vigorous opposition during the 70's and 80's that was mounted against safety standards dealing with crashworthiness, lighting systems, etc.—i.e., safety features that still left the driver overwhelmingly responsible for crash avoidance. The premise for embracing federal rules on AST products is that American juries would tend to forgive any perceived inadequacy in products that comply with federal performance specifications. Thus, systems that attempt to augment human capability in crash avoidance may become viable products for sale in the U.S. if they become reasonably insulated from liability through compliance with federal rules.

The development of such rules requires a new mandate for NHTSA and relief from certain court orders that prevent the agency from collaborating with industry to expedite a technical foundation for rulemaking. The agency and the industry must work together over an extended period to assure that AST delivers solutions to real safety problems. Since the early eighties, however, NHTSA's rulemaking activity has been effectively shut down by administrative fiat. This action was begun early in the Reagan administration on the belief that further safety standards were simply too onerous for industry and were opposed to

U.S. economic interests. Now the same economic interests pose a legitimate need for government involvement. In fact, serious consideration might be given for federal stimulation of AST technology in a manner mirroring the vigorous PROMETHEUS program in Europe.[19] In the PROMETHEUS case, public monies are put up to advance the competitiveness of manufacturers in E.C. countries by expediting development primarily in AST product areas. Changes in federal policy could give a corresponding boost to domestic manufacturers in the U.S. while also dealing with the liability issue that is peculiar to this country.

Implementing Automated Highway Systems

Automated highway concepts promise to achieve large increases in traffic throughput by continuously controlling vehicles on specially-converted portions of conventional expressways. Automation generally implies "hands-off" driving, although the vehicle is switched to manual control on all other streets that are not automated facilities. Throughput on the automated highway is increased because vehicles are grouped more tightly than occurs with human operation and because vehicles move very uniformly, thus avoiding inadvertent disturbances in overall traffic flow. This very high level of functionality is to be achieved through sophisticated command and control systems that distribute their sensing, communications, and processing functions among the vehicle, roadside, and central facilities.[22] It is assumed that some or all of this infrastructure is capitalized and operated by the public sector. Clearly, "the system" envisioned in this case assumes complete responsibility for the vehicle occupants while undertaking fully automatic control.

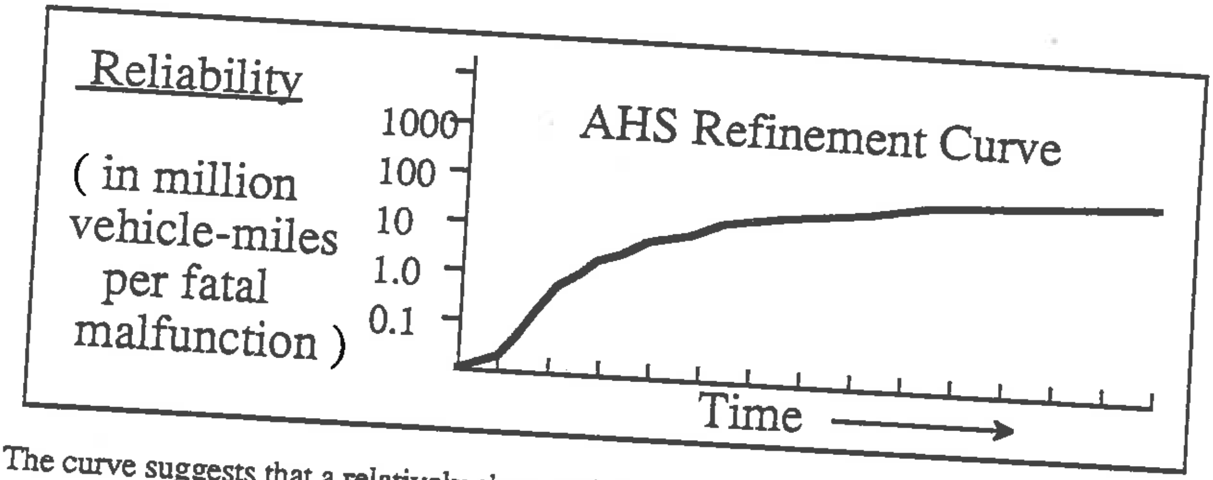
The principle embedded in highway automation is that vehicles will be operated at longitudinal and lateral spacings which are much less than those actually adopted by people in conventional driving. By means of close spacing the overall throughput of the highway can be dramatically increased, achieving from 100% to 400% higher capacity.[22] From the viewpoint of potential benefit, automation obviously registers far higher in possible payoff than any other congestion-relief concept. Its radical character suggests that automation will be targeted primarily at the communities that suffer most acutely from congestion.

It is not surprising, therefore, that the key agent promoting automated highways is the State of California. Since the L.A. and Bay-area regions are experiencing such crushing congestion, the California perspective is that radical improvements in highway capacity, via highway automation, will be required. The risk is that superheated political stresses for congestion relief may call for automation to "deliver a solution" before its time.

Various barriers oppose the attainment of highway automation, some of which are at the systems level. There is a challenge, for example, posed by the high flow rates emerging from automated expressways onto surface streets—presumably requiring the construction of extensive buffer capacity at the surface level. There is also the concern that orderly merging of vehicles in and out of automated lanes requires that additional lanes be allocated for these transitions as well as for safety escape, thus reducing the payoff in net capacity.

Many take the view, however, that the central challenge involves the safety implications of close spacings and hands-off control. Conventional spacings under peak flow conditions are generally recognized as defining not only the safe bounds of operation under human control but also the clearances that just barely allow for panic braking and steering when a sudden hazard appears. Thus, spacings achieved through highway automation inherently pose the "closer than (manually) safe" scenario—putting a heavy burden on the technology to assure public safety, not to mention psychological comfort.

In particular, there is the conviction that relinquishing total control of the personal motor car while operating at inherently threatening spacings will require a fantastically high level of reliability. The process of refining a reliable technology for "public-use" automated highways seems likely to follow a development curve such as that shown below.

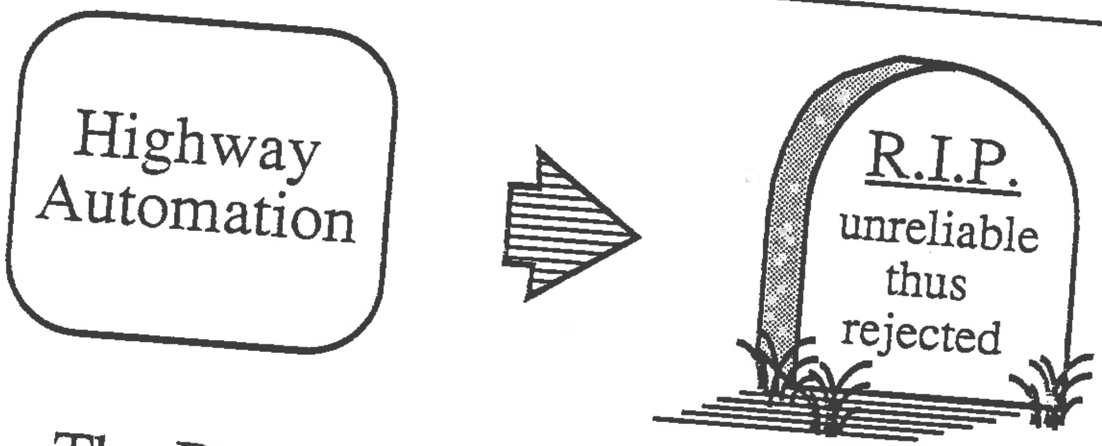


The curve suggests that a relatively short period of time will be needed to develop a system having "basic reliability", so to speak, giving the right functions and a high level of dynamic performance. Then we'll see a long period of time during which the reliability is raised from a hazard coefficient that is the equivalent of 0.1 million vehicle-miles per fatal malfunction to, say, 10 million. Note that the motor vehicle fleet currently averages 50 million miles per fatal accident— and some individuals drive at least 10 times more safely than the average. The author suggests that a safety level at least matching that of the "safe driver" will be required as the price for people to turn over control to a fully automated system.

This rough logic results in a requirement that automated equipment be able to achieve on the order of 500 million vehicle-miles of operation between fatal malfunctions. It is sobering to note that such performance would push up against the remarkable safety record achieved by large airlines, currently averaging around 1 billion miles per fatal accident.[23] And if vehicle reliability is more determined by hours of exposure than by distance travelled, it is startling that the time-reliability of automated vehicle operation would need to be around five times as good as that of the airlines. Yet, this level of safety must be obtained on "the family car" that also has a manual mode of operation, is driven over dirt roads, is bumped-out and repainted following minor fender-benders, is parked with the kids' bikes and the lawn mower in the garage overnight, and is maintained in a local dealership on the monthly budget of the individual wage-earner. Clearly, highway automation is extremely ambitious, as currently conceived .

An anecdote may illustrate one individual's "reality-check" on highway automation. The Chairman of a German automaking firm recently rode in an automated platoon of that company's vehicles on a specialized track at their central proving ground. After riding at highway speeds for a short period in an automatically-controlled van at a headway of 1-2 meters behind the preceding vehicle, the executive stepped out blanched and very shaken, declaring that this product will never be sold to the public! The project was terminated on the spot even though, from a technical point of view, the prototypes showed a higher level of dynamic performance than was known to have been achieved by any other organization.

The critical juncture in California's pursuit of automated highways will come when the full magnitude of the system reliability requirement is seriously compared with that which can be realistically derived with the privately-owned automobile. If, up to that point, the public had been told that other tough measures for controlling congestion could be deferred because automation promises a way out, a political firestorm may erupt when the program is shown to have another twenty or thirty years to go. (Major extension in transit services, enforced carpooling, and road pricing, for example, represent strong measures requiring a good deal of community preparation before being implemented. If such steps are, in fact, necessary in some communities where highway capacity has been simply overwhelmed, it would be inappropriate to hold out the elixir of highway automation when determined preparation of other measures is warranted.) There is, indeed, a bottom line in any acutely-congested community, and it is congestion relief. If, as Yogi Berra said, "the ballgame's not over 'til it's over" then, correspondingly, "a congestion fix has'nt begun until it begins." Automation will not begin to relieve, for example, California's great road crisis until it is actually able to carry very high volumes of traffic at very high levels of safety.



The Demise of Hwy. Automation if Touted as an Early Congestion Fix

The national stake in this subject is that some form of highway automation may be feasible and attractive for its benefit to the public in the long run. If the concept, itself, gets a black eye through its peculiar political exposure in California, the prospect for developing feasible approaches would be jeopardized. Thus, it seems important that a substantial effort in highway automation research proceed outside of the "congestion-fix" mileu. Ideally, the entire California research effort could be shaped within a national effort, with clear statement of the kind of long-range timetables that reflect the sober reality on safety and reliability. The first order of work must focus upon the definition of overall system concepts which are inherently robust in securing the reliability needed for public safety, meeting the logistical needs, and fitting the socioeconomic reality in which we live. After such concepts have been evaluated for face validity on paper, more detailed work to develop and demonstrate specific systems would be warranted.

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