Pretty melodramatic...

901505

Social and Institutional Considerations in Intelligent Vehicle-Highway Systems

Steven E. Underwood
The University of Michigan
Ann Arbor, MI

ABSTRACT

Recent advances in communications and electronics technologies promise to allow significant improvements in the overall efficiency. These advances promise to enable real-time adjustments of traffic to current and predicted travel conditions, more effective trip planning and real-time route selection and improvement in overall road safety. In developing and planning for these systems we need to make assessments about how each of these promises are actually going to pay off. Are there markets for these systems? What are the likely barriers to adoption? What policies can be adopted to overcome these barriers? What are the likely impacts of these developments? How will social and institutional considerations impinge on these developments? This paper presents the results of a Delphi survey of experts' opinions on these questions regarding the future development of intelligent vehicle-highway systems (IVHS) in North America.

The development of technology is always uncertain. The course of technology development is determined in part by undefined societal needs, uncertain institutional support, and unexpected technical breakthroughs. However, technology development is also determined in part by things that are known or things that can be influenced. For example, the future of a particular technology can be estimated by current market trends, recent developments in related technologies, current levels of institutional support, and an assessment of the nation's level of commitment to research and development in the area. Given that some things are known, and that others are uncertain, effective planning for technology development requires an assessment of current knowledge and intentions as they impinge on the future of the technology in question. It requires reducing the uncertainty wherever possible, understanding the sources of uncertainty where it cannot be influenced, and formulating a common vision for those who are required to act. This is the task we face in assessing the future of "intelligent" transportation systems.

This report presents the results of a survey of experts' opinions on the future of intelligent vehicle-highway systems (IVHS) in North America. IVHS are road transportation systems that use advanced electronics and communications technologies to integrate the information and control functions of the vehicle and the highway, thereby improving the performance of the integrated system, subject to the desires of the driver and/or the traffic manager. Not the least of these opportunities has been the possibility of tapping a large and receptive market for these benefits. In-vehicle route guidance systems that provide motorists with information on the quickest route to their destinations on the basis of real-time data supplied by a traffic control center are an example of an integrated IVHS. Advanced vehicle navigation and information systems, and other IVHS described in this document, are designed to improve the overall performance of road transportation in a number of ways, including providing advice to the driver, assisting the driver with the operation of the vehicle, and/or managing the overall flow of traffic. Desired results include increased mobility, safer streets, a cleaner environment, more effective use of resources, and improved comfort and convenience, to name a few.

The forecasts for a range of IVHS categories, as listed below, were produced by the Delphi technique which is a survey method commonly used for eliciting consensus opinion from a panel of experts. The Delphi technique is often used for forecasting the development of new technologies and policy events that cannot be effectively modeled through extrapolative methods. This particular application assessed the panel's forecasts of market penetration, and related influencing factors, for selected categories of IVHS. It also addressed the expected impacts from implementation of these technologies. The survey emphasized advanced driver information systems (ADIS), advanced traffic management systems (ATMS) and automated vehicle control systems (AVCS), following the programmatic structure of the University of Michigan (UM) program on IVHS.

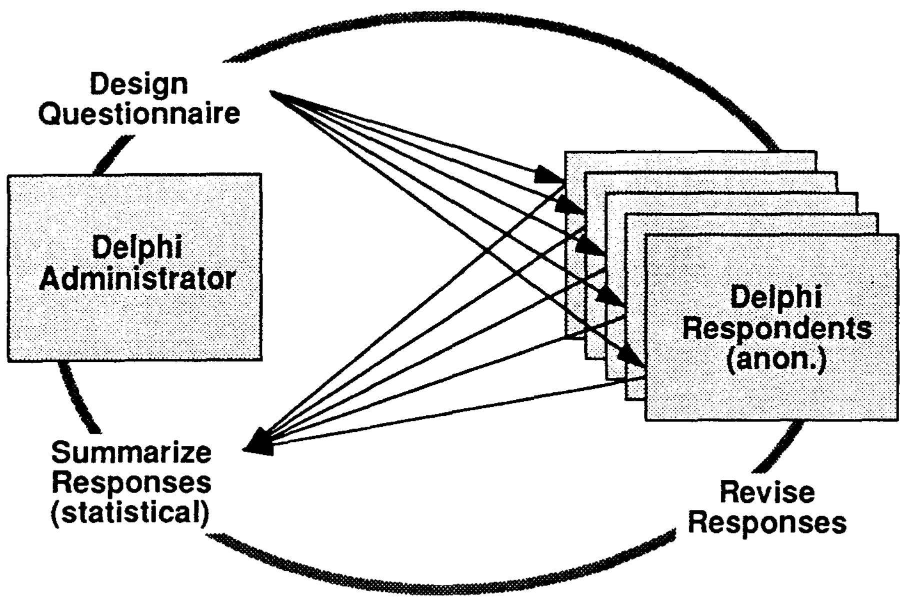

Figure 1. The Delphi Process

Thirty-two experts in automotive transportation, vehicle electronics, and vehicle communications participated in the survey. These individuals were affiliated with organizations represented on the advisory board of the UM's research planning project in IVHS, including the "big three" automotive manufacturers, their suppliers, electronics and computer companies, highway users, several public transportation agencies, and other organizations with interests in IVHS. The participants were asked to assess the rates of market penetration, influencing factors, and expected impacts for each of the following categories of IVHS:

- Automatic tolls and road pricing
- Automatic vehicle location
- Automatic vehicle navigation
- Motorist information
- Cooperative route guidance
- Collision warning
- Collision avoidance
- Speed and headway keeping
- Automated highway
- Automated guideway

To generate the forecasts, the Delphi administrator mailed questionnaries which asked for each of these system categories the future time at which the following levels of market penetration would accrue: (1) laboratory tests would be successfully completed, (2) the systems would be introduced to the market, (3) a majority of commercial vehicles would adopt the system, (4) a majority of automobiles would adopt the system, and (5) vehicles would be required by statute to use the system. Participants were also asked to assess the driving forces for implementation, the barriers to market penetration, government policy initiatives, and possible sociotechnical impacts for each of these technologies. As required by the Delphi process, responses to the initial survey were summarized and returned to the participants for feedback and possible revision. The participants were asked to reaffirm or revise their assessments on the basis of this feedback and to respond again. The sequence of question, response, summary and feedback ran through three cycles before the desired level of consensus was reached.

Included in this report are chapters describing the context for the UM Delphi on IVHS, the methodology for conducting the forecast survey, the market projections and associated factors for the 10 individual IVHS categories, a comparison of the individual and grouped projections, cross-category comparisons of the determining factors, and a comparison of the UM results with other similar Delphi studies.

The primary contributions of this survey were the individualized forecasts of market penetration and the listings of influencing factors for each of the ten categories of systems listed above. The listings of barriers, driving forces, policy initiatives, and sociotechnical impacts were compiled in response to open-ended questions on each of these items. Thus, the process was open to new ideas or perspectives offered by the participants. Many of the ideas and perspectives confirmed commonly-held views the future of IVHS, but a number of responses offered new ideas that enhanced understanding of the future of IVHS, and when combined with the conventional wisdom on the subject, provided further insight on which to base plans for research and development. A brief summary of these findings follows.

The survey revealed that the panelists expected the traffic management systems (i.e., automatic tolls and road pricing) to be the first group of systems to be developed and implemented in North America. These would be followed by driver information systems (i.e., vehicle location, vehicle navigation, motorist information, cooperative route guidance, and collision warning) and the vehicle control systems (i.e, collision avoidance, speed and headway keeping, automated highways, automated guideways), roughly in that order.

The projections for majority use by automobile were 2005 for advanced traffic management, 2015 for advanced driver information, and 2035 for automated vehicle control.

According to our panelists, most of the *advanced driver information systems*, with the exception of cooperative route guidance and collision warning, have already been introduced to market in North America. Cooperative route guidance and collision warning should follow closely behind and be introduced in the year 1995. Majority use by automobiles is predicted to occur for management information systems by the year 2000. Although collision warning has yet to be introduced, it will follow the motorist information systems to majority use by the year 2010. Vehicle navigation, guidance, and location systems should be used by a majority of automobiles somewhere between 2015 and 2020. According to our data, the most likely sequence of implementation for these systems in standard automobiles over the next thirty years is: motorist information, collision warning, guidance and navigation, and vehicle location. Although guidance and navigation systems are likely to enter the market earlier than collision warning systems, the latter are expected to overtake the former in the market during this period.

The results demonstrate convincingly that research and development on *automatic vehicle control systems* will have to overcome a number of technical barriers before the systems come on line. Research on these system will be required through the year 2000 in order to reach the level of successful laboratory tests. The critical topic is system reliability. Human factors research on automated vehicle control will also be required; we will want to find out how drivers will respond to systems that take over the control functions. Similar effort must be applied to collision warning as a precursor of the advanced control systems.

The only other system that will require extensive technical research is cooperative route guidance. Here the primary questions will fall in the areas of system architecture and integration. Basic improvements in traffic-predictive analysis will also be needed. As with most of the driver information systems human factors will be an issue.

The consumers' assessment of the overall value of IVHS may either act as a barrier or a driving force in the adoption of IVHS. Declining technology costs as a result of technology process innovations may play a larger role in determining the future of IVHS than innovations in the technologies themselves. Assessments of the potential system benefits and costs, product markets, and institutional barriers will also be required. Applied social research should focus on these areas.

The principal barriers to implementation of IVHS were social, economic, and institutional. Only system reliability and human factors could be considered technical barriers. In this summary we will address only those forces that cut across a number of system categories. Other system-unique factors are described for each category in chapter 3. The cross-cutting barriers to implementation, listed in order of importance as ranked by the panelists, are: cost to the consumer, obtaining technical reliability, lack of demand, government and manufacturer liability risks, possible system ineffectiveness, setting of appropriate standards, planning for transition to new and more advanced technologies, cost to federal and state governments, human factors in system design, slower traffic, and limited applicability of the systems.

What will lead society to adopt these new systems? The panelists addressed this question by identifying and ranking a number of driving forces for adoption of IVHS. These include, in order of the ranking by the panelists, increasing traffic congestion, desire for improved safety, motorists' desire for comfort and convenience, the public's demand for travel information as they become aware of it, declining cost of technology and operation, an incremental process toward development and adoption of advanced systems, the commuter's preference for highway over rail, the novelty of the technology, and the promise of shorter trip times by traveling on designated lanes.

How will the federal, state, and local governments be able to assist in the development and implementation of IVHS? The responses from our panel included: limit the liability borne by manufacturers and government, establish effective standards, provide federal funding or incentives for research and development, provide Department of Transportation leadership and commitment, provide the necessary public infrastructure, provide federal funding for construction and operation, provide state and local enabling legislation, and dedicate lanes and roadways for priority use by vehicles with cooperative technology.

The list of social impacts is similar to the list of driving forces, except that it also includes several negative outcomes. The cross-cutting items in order of rank are: reduced congestion, improved safety, increased comfort and convenience for motorist, increased driver acceptance of automated control, increased automobile commuting, and smoother flow of traffic.

The forecasts by the University of Michigan, the International Institute for Applied Systems Analysis (IIASA), and the Federal Highway Administration (FHWA) were relatively consistent in terms of the pattern and sequence of system development. There was some contrast in the timing of system introduction in the U.S. with the FHWA placing introduction of most systems about 10 years behind the other surveys. This could be explained by the FHWA's exclusive focus on public highways, as opposed to exclusively private sector implementations of the technologies or other special applications and the absence of private sector experts on the FHWA panel.

Perhaps the most significant finding from our survey is that, given the right conditions, there is likely to be a great deal of progress made in the development of an intelligent vehicle-highway system in North America over the next ten years. As an indication of things to come, the survey indicates that all of the systems, with the exception of the automated highway, will be introduced by the year 2000. This implies significant technical and institutional advances between now and the turn of the century. It also assumes significant levels of government support and cooperation between the public and private sectors. Given the expected rapid development, we intend to repeat the Delphi survey periodically in the future.

CROSS-CATEGORY ANALYSIS

As part of the Delphi exercise we asked the panelists to identify and explain those factors that they considered in estimating the market penetration of the ten categories of IVHS. We specifically asked the panelists to delineate what they viewed as (1) the driving forces for implementation, (2) the barriers to market penetration, (3) constructive government policy initiatives, and (4) the expected sociotechnical impacts from adoption of the systems. They listed factors for each of the ten IVHS categories.

In order to assess the relative importance of the identified items for each of the IVHS categories we constructed rating matrices that presented the rating for each item across each of the IVHS categories. There were four matrices in all, one for each of the general factor categories: driving forces, barriers, government policy initiatives, and sociotechnical impacts.

The matrices were used in two ways. First, they were scanned to identify those items that were important to a relatively large cross-section of the IVHS categories. We looked for items that had rankings in a number of categories, and then compiled a smaller matrix that contained the subset of items that were ranked for at least three categories. These items would be interpreted as cross-cutting concerns that were important because they came into play with a wide range of system types. For example, "planning of the transition to a new technology" is a barrier that was not ranked very high for any of the IVHS categories, but it was ranked for four of the near-term systems, and will no doubt be an important consideration over the next few years. Items that were peculiar to one or two system categories, no matter how important they would be to those categories, were not entered into this cross-cutting concerns matrix. It turned out that the cross-cutting concerns were those items that tend to get a lot of attention in the literature and ongoing discussions in IVHS.

Second, we looked for items that were very important in one or two categories, but were not to be considered cross-cutting concerns. We arbitrarily selected a ranking of five as the low end cut-off point. These items would be concerns that may be of great importance to a single category, but because it did not apply to a number of categories, might not get as much attention as some of the cross-cutting concerns. For example, one barrier for the automated guideways (AG) concept is that it competes with the automated highway (AH) concept. In fact, aside from cost, this was viewed as the most significant problem for widespread adoption of AG systems. Nevertheless, however important this consideration is to AG advocates, this gets little attention because it is confined to a single system that is not considered to come on line, if it ever does, until far into the next century. Insights from this type of analysis were included in the discussion of the individual systems in the previous section.

The remainder of this section will address the cross-cutting driving forces, barriers, policy initiatives, and impacts identified from compilation of the integrated IVHS-item matrices.

DRIVING FORCES FOR IMPLEMENTATION. According to our panelists, increasing traffic congestion, combined with resistance to further freeway construction, is the overriding challenge that will spur interest in IVHS technology as a means of increasing traffic throughput and decreasing traffic delay. The urban traffic situation provides the leading inducement for developing and implementing IVHS, being ranked highest in seven of the ten IVHS categories. It was ranked high for all of the categories. This is not surprising, with intolerable levels of traffic congestion in many of the major cities in the U.S. and forecasts that this situation will only worsen in the foreseeable future, transportation planners and other public officials are under siege to find innovate means of combating this ever present antagonist. Motorists insatiable desire for time produces an enduring conflict with the trend toward increasing urban congestion and provides the primary motivation for exploring IVHS and other approaches to efficient travel. Just the prospect of gaining an advantage over other drivers through better traffic information or the right to travel of designated lanes or guideways may provide some appeal. Real improvements in travel times could very well translate into private and commercial sales of IVHS vehicle components, as well as lead to public demand for publicly sponsored systems. As indicated in a separate category, the public is likely to demand access to motorist information if and when it becomes accessible.

Another serious incentive for investigating and developing IVHS technologies is the public's desire, and the related mandate of the representative public agencies, for increasing traffic safety on the overburdened highway network. Although the expected safety improvements is not as widespread as that of travel time savings, the prospect of improvements in highway safety is nonetheless important, and is a central motivation for governmental involvement in IVHS developments. Although increased safety is viewed by our panelists only as a possible rationale for developments in advanced driver information systems, it does become the primary rationale for advancements in advanced vehicle control systems, with safety being the highest ranked item for collision warning, collision avoidance, and speed and headway keeping. This is also part of the rationale for mandatory use of these systems when adequate levels of reliability have been attained.

Driving can be a direct source of fatigue, frustration, and general motorist stress. The driver information and control systems promise to relieve some of this stress by reducing the driver's (1) time in traffic, (2) uncertainty about travel conditions and delays, and (3) need to attend to demanding driving tasks. As a result, the panelists ranked motorist comfort and convenience to be a significant driving force for implementation of most of the information and control systems. Again, expected improvements in motorist convenience could provide sufficient reason for development of in-vehicle components, where the value could be captured by the vehicle owner and the manufacturer.

Table 1. Cross-cutting Driving Forced for Implementation (1 = highest ranking)

Driving Forces	ATRP	AVL	AVN	MI	CRG	CW	CA	SHK	AH	AG
Traffic congestion	1	1	1	1	1	4	2	3	1	1
Desire for improved safety		4	10	4		1	1	1	2	4
Motorist convenience			3	7	5	6	3	2	4	
Public's demand for travel information			2	2			8			
Declining technology and operating cost			8		3		7		9	
Provides an initial step toward desired advanced systems			5	6	8					
Commuter's preference of highway over rail transportation					7		9	6		
Novelty of the technology			4				11	5		
Prospect for travel on special designated lanes and guideways			11		10		5	4		

Other cross-cutting forces for implementation include declining technology and operating costs, commuters' distinct preference for highway over rail transportation, the novelty of the technology itself, and the opportunity to take an initial incremental step into a more advanced integrated IVHS.

BARRIERS TO MARKET PENETRATION. The cross-cutting barriers appear to be related to the primary system grouping: advanced traffic management systems (ATMS), advanced driver information systems (ADIS), or advanced vehicle control systems (AVCS).

According to our panel's responses the barriers for ADIS appear relatively immediate and pragmatic. Manufacturers will be concerned with the end cost to the consumer and the prospects for selling at a reasonable profit. The panelists expressed general concern with end costs and consumer demand, as indicated by the high rankings of these items in the ADIS categories. Of secondary importance they identified public expenditures, decisions on standards, technical reliability, and human factors in system design. There was also some general concern that these systems would have limited applicability.

Table 2. Cross-cutting Barriers to Market Penetration (1 = highest ranking)

Barriers	ATRP	AVL	AVN	MI	CRG	CW	CA	SHK	AH	AG
Cost to the consumer		3	1	1	1	3	5	4	2	
Reliability: Design of a trusted system	2		8	9		1	1	1	1	5
Consumer resistance, lack of acceptance, and low demand	1	2	2	10		4	3	3	8	
Liability: Manufacturer's and government's willingness to accept			7			2	2	2	3	4
System effectiveness, getting the desired results	3	12				8	4	5		
Standards (equipment and broadcasting)	6	6	4	5	5					
Planning for transition to new technology	12			12	7				5	
Costs (federal government)	9	7		4	2				9	1
Costs (state governments)	7	9		2	4					
Human factors in system design		15	3		8	5				
Penalizes user, drivers must travel at slower pace							9	6	4	
Limited applicability	10	10		11						

There was an entirely different set of priorities concerning the advanced vehicle control systems (AVCS). The overwhelming concern regarding AVCS was system reliability. Will the developers be able to design an affordable and effective system that would meet or even surpass the requirements of the driver? Can they design a "trusted" vehicle-highway system? From a technical perspective these questions address the problem of fault tolerance. The designers must provide reliable computer hardware and software to control the system as well as provide for sufficient redundancy in each system component. Ensuring reliability is a critical technical barrier in most of the control systems. The importance of this barrier demonstrated by the highest rankings assigned to reliability in the categories of collision warning, collision avoidance, speed and headway keeping, and automated highway. Of related concern and importance is the institutional response to system failures. Who will be held liable for damages as a result of system failure? Settlement of the liability issues was the second highest ranking barrier across the AVCS categories.

The panelists also expressed the concern that consumers might not even want systems that would take over the driver control functions. At least they expected a certain amount of resistance to the prospect of driver assistance or complete vehicle control. Even if consumers were to accept the technology, manufacturers and service providers may not tap sufficient demand, depending on use restrictions and consumer costs. This concern is reflected in the panel's nearly across-the-board rankings of consumer resistance and consumer cost.

Finally, the panelists indicated that the control systems might even penalize the driver by requiring driving at a slower pace. This could also affect consumer acceptance.

GOVERNMENT POLICY INITIATIVES. The cross-cutting government policy initiatives seem to fall out of the barriers and driving forces as described above. There was a high level of consensus among the panelists that the government would have to take significant steps toward limiting the liability of public and private service providers and manufacturers. Even if the technology is effective and affordable, even if it improves highway traffic safety, it will not come to market if the manufacturers are vulnerable to large-scale suits. This is especially important with the control systems, but also of concern with the information systems. For example, who will be responsible for accidents that occur while the motorist is reading the digitized map that was installed in the instrument panel? As these technologies come closer to market the urgency of these questions will increase. According to our panel, expeditious government action will be required to attain the expected levels of market penetration.

Table 3. Cross-cutting Government Policy Initiatives (1 = highest ranking)

Government Initiatives	ATRP	AVL	MI	CRG	AVN	CW	CA	SHK	AH	AG
Liability protection (limitation)		11	6		2	1	1	1	2	3
Establishing standards	3	6	2	3	5	3	2	2		
Federal funding or incentives for R&D		8	5		1	5	5		1	1
DOT leadership, initiative, and commitment		3	9	4	4	4			9	5
Provide the necessary public infrastructure		5		2	3	6	9			
Appropriating adequate funding			1	1			4	3	10	
Local, state, and federal legislation to implement	1			5		10				
Dedicated lanes and roadways (increase benefit to purchaser)					9		3	8	3	

Another role of the government in support of rapid progress in IVHS is the wise specification and use of technical standards to assure requisite levels of horizontal and upward compatibility. Government standards are a necessary catalyst for technology development in diverse technical areas such as IVHS, but they can also stifle development and provide an easy target for competitive disputes. Nevertheless, the sentiment of the panel was that the government must get involved early in setting standards for IVHS.

Many of the systems will require roadside infrastructure and other system elements that may fall into the public domain. These elements could include anything from tags on license plates to central computing and information facilities. Depending on the nature of the infrastructure and the jurisdiction, funding and provision of the public portion of IVHS may take on a variety of forms. Despite this flexibility and range in arrangements there was general consensus on the panel that the government would need to provide certain components of selected IVHS.

Other cross-cutting government roles included (1) federal funding of research, development, demonstration, and general implementation and operation, (2) display of leadership and commitment, along with assistance in planning for IVHS, (3) legislating implementation, and (4) the provision of dedicated lanes and guideways and an incentive for use. It seems curious that the panel ranked federal funding of research and development as the top initiative for automatic vehicle navigation systems. One panelist supplied a representative dissenting remark writing "this technology is developed to the point where government funding is not approriate." Yet, that is where it remained after three rounds of responses to the survey, despite considerable dissent on this topic.

SOCIOTECHNICAL IMPACTS. As seen in Table 4 the expected sociotechnical impacts correspond to a great extent with the driving forces for adoption as presented in Table 1. Most of the expected impacts were positive and would serve as driving forces for implementation of the systems. An impact that might possibly have a negative consequence is increased automobile commuting. While IVHS increases the throughput of the system, travel times may not decrease due to increases in the number of trips and commuters.

Table 4. Cross-cutting Sociotechnical Impacts

Social Impacts	ATRP	AVL	AVN	MI	CRG	CW	CA	SHK	AH	AG
Reduced congestion:	1		1	1	1					
Improved Safety:	6	6	3	3	2	1	1	2		1
Improved convenience:			2		12	7	2	4	4	
Consumer acceptance		10	6	7			5	7		
Increased automobile commuting	7						3	8		
Smoother flow of traffic on toll roads	3		9					3		

DISCUSSION OF INDIVIDUAL IVHS TECHNOLOGIES

Discussion of the IVHS categories is organized by their targeted source of control, with either the roadside, the driver, or the vehicle being the targeted control constituent. Three broad categories of IVHS will be used:

- **ATMS** Advanced traffic management systems (roadside control),
- **ADIS** Advanced driver information systems (driver control), and
- **AVCS** Automated vehicle control systems (vehicle control).*

These categories were first delineated at the Mobility 2000 workshop that addressed scenarios for a national agenda in IVHS (Harris & Bridges, 1989). For the purposes of this paper each broad category encompasses a number of specific system categories. Advanced traffic management systems (ATMS) control traffic through *roadside* displays or signals, which may be coordinated, or even optimized, at a central control facility. Although ATMS is a well developed field of application and research, few of these systems involve significant vehicle-highway interaction; automatic tolls and road pricing (ATRP), as a subcategory under ATMS, was included in this study because of the clear linkage between vehicle and highway components.. Advanced driver information systems (ADIS) assist strategic and operational *driver* control functions through effective information distribution, processing, and display. Included in this category are automatic vehicle location, automatic vehicle navigation, motorist service information, cooperative route guidance, and collision warning systems. All of these systems assume driver control of vehicle operations and routing and advise the driver accordingly. Vehicle-highway interaction is mediated by the driver. Finally, automated vehicle control systems transfer control from the driver to the *vehicle* in order to simplify the driving task and improve traffic flow. Vehicle electronics that were strictly autonomous were excluded from consideration. Four types of control systems that involved vehicle-highway interaction were addressed: collision avoidance, speed and headway keeping, automated highway, and automated guideway systems. The distinction between automated highways and automated guideways is that automated guideways use modified vehicles and some form of physical guideway, while automated highways have intelligent vehicles guided by signals or electronic detectors.

In the sections that follow each of the ten system categories are described in terms of their function and components, and illustrated by real-life examples where they exist. Following the system description we present a summary of the panelists' perspectives on consequential barriers, social impacts, driving forces, and required government support.

AUTOMATIC TOLLS AND ROAD PRICING (ATRP). These are systems that can identify individual vehicles in traffic and assess tolls on the basis of usage and other factors. This is accomplished without the effort on the part of the driver or a toll collector. The typical system requires several functional elements including: a vehicle-mounted transponder or tag; a roadside sensor; a computer system for processing and storage of data; and a billing system for assessing and collecting user fees. ATRP may be considered a combination of two systems. First, there is an automatic vehicle identification (AVI) system that identifies the individual passing vehicles. Four types of detection are used for vehicle identification: (1) optical and infrared, (2) induction loops, (3) radio and microwave, and (4) surface acoustic waves. Then, there is a computerized charging and billing system that determines the fees based on the time of day, location, and congestion levels. Systems of this kind are currently being implemented in Dallas Texas, Jacksonville Florida, and on the Dulles Toll Road in Virginia. Earlier experiments were conducted by the New York and New Jersey Port Authorities, Caltrans and the Golden Gate Bridge Authority. An advanced electronic road pricing system (ERPS) received extensive testing in Hong Kong.

*Mobility 2000 addressed heavy vehicle and commercial operations as a fourth and separate category. However, commercial issues have been folded into the first three categories.

The panelists viewed the primary advantage of this system over standard toll systems to be relief of congestion at the toll areas and time savings for the motorist. The economic efficiency of user fees was also viewed as an advantage, offering the ability to target specific vehicle and driver characteristics, and to implement peak-hour pricing as a means of managing congestion and redistributing highway costs to road users. The public transportation manager would also be equipped to measure the public's imputed value for new transportation projects and services.

Most panelists agree that "road pricing to reduce or modify demand may not be accepted by the public." This was the primary barrier to implementation of ATRP. Other barriers suggested by the panelists included low system reliability at high speeds, expensive equipment maintenance, and resistance to possible violations of civil liberties. The panelists expected resistance to systems that could provide the means of monitoring individual travel; this would be viewed by many as an invasion of their privacy.

To facilitate adoption of ATRP the appropriate governmental authorities would be expected to pass the required enabling acts. The federal government would be expected to help by establishing equipment standards. The Federal Highway Administration would need to acquire broader powers to upgrade sections of the interstates into toll-billed sections. State and local governments would have to legislate the authority to implement ATRP and fund the necessary improvements.

Table 5 presents an overview of considerations that are unique to ATRP. In addition to the items listed in the table there are a host of other cross-cutting concerns applicable to ATRP that are described above and at greater length in the section of cross-category analysis.

Table 5. Items of Special Interest for ATRP

Driving Forces	Barriers	Government	Impacts
• Redistribution of highway costs to users	• Resistance to user fees	• Address problem of rights to road access	• Reduced peak-hour traffic
• Allocation of costs on basis of vehicle attributes	• Resistance to invasion of privacy	• Powers needed to upgrade interstates to toll roads	• Less resistance to tolls
• User fees new source of highway funding		• Increase state and local funding for ATRP	• Risk of invading privacy
• Measure public's imputed value for projects			

AUTOMATIC VEHICLE LOCATION (AVL). Advanced communication systems would allow fleet managers to monitor vehicles in the field and deploy them more efficiently. This is the primary function of AVL systems which provide vehicle location information to a central authority. The methods for locating the vehicles are, in most cases, identical to those used in automatic vehicle navigation (AVN) systems. Locations are determined through dead-reckoning, proximity beacon, GPS satellite, or Loran-C radio frequency navigation. This information is transmitted to a control center where locations are presented as coordinates or on a video mapping system. Location information can be used with fleet management software to dispatch vehicles most efficiently. One example of this type of system is II-Morrow's Vehicle Tracking System (VTS) that is being used to dispatch emergency vehicles in the City of Detroit. This implementation of AVL has six dispatch stations which monitor some 760 police, fire, and emergency vehicles. The vehicle tracking system, operating on the Loran-C navigational network, allows dispatchers at computerized graphic workstations to route the nearest vehicles to the scene of an emergency.

This type of system would be of most use to fleet operators and dispatch services; with their increasing complex distribution logistics AVL could improve management of "just-in-time" deliveries where trucks could serve as mobile warehouses, reducing delivery and inventory costs. It could also facilitate charging usage for routes and reduce traffic congestion by routing trucks along more efficient paths. With this secondary reduction in congestion vehicles without AVL would also benefit. The panel expected AVL to lead to improved truck driver performance, resistance by truck drivers to retain privacy, and increasingly sophisticated methods employed by truck drivers to evade detection by the systems. The ability to locate vehicles would also deter hijacking and improve the recovery of stolen goods. With large-scale public tracking systems the government authority could conceivably assess user fees, although this is seen as highly unlikely in the current social and political environment.

Nevertheless, sluggish demand due to questionable cost-effectiveness and low user acceptance would serve as the major barriers to market penetration. Invasion of privacy would be as big an issue in private fleet management systems as it would be in public dispatch systems. In public systems there would be great concern over who would do the monitoring and how it would be done, also who would pay for the system. Technical considerations were not recognized by the panelists as major barriers. The panelists expected that it would take some time to compile map databases that were required for map matching.

The government would have several roles in support of AVL. State and local governments would need to communicate the need for emergency dispatch and public fleet management, perhaps eventually requiring uniform and economically effective systems in major urban areas.

The federal DOT would have to provide support through leadership and assistance with system planning.

Table 6. Items of Special Interest for AVL

Driving Forces	Barriers	Government	Impacts
• Need for new sources of highway funding	• Opposition on basis of right to privacy	• Demonstration and public awareness projects	• Efficient dispatch and fleet management
• Industry's need for efficient delivery	• Justifying public funding for public systems		• Improved fleet and goods monitoring
• Trend toward automated billing	• Settling who will provide, operate, and maintain		• Charging usage for routes
• Complexity of commercial distribution systems	• Lack complete map database		• Risk some loss of privacy

AUTOMATIC VEHICLE NAVIGATION (AVN). Automatic vehicle navigation uses a variety of methods to determine the present position, heading, direction and/or distance of the vehicle in relation to a selected destination. The driver is informed of his position relative to a selected address and/or the existing street geometry, helping the driver navigate the vehicle to the desired destination. These systems would generally include devices for positioning, stored digital road maps, a computer, and some form of visual display or voice synthesis.

Navigation techniques currently under development include dead reckoning, proximity beacons, ground-based radio (e.g., Loran-C and cellular), satellite, and map matching. Dead reckoning calculates the vehicle's position by keeping track of the vehicle's travel distances and directions from a known starting point. Proximity beacons communicate location information to the vehicles using short-range radio, microwaves, or infrared signals. Loran-C is an example of a radio navigation system in which the vehicle's position is determined from differences in the arrival time of signals from three or more land-based transmitters. The Navstar Global Positioning System (GPS) will have 24 satellites spaced in orbits to enable vehicles to determine their positions by analyzing the travel times of signals from at least four satellite transmitters. Finally map matching methods, like that used in the Etak Navigator, use artificial intelligence to locate the vehicle by comparing the vehicle's path with the road patterns of a digitized map and using a deductive algorithm. Each approach has a particular set of devices and configuration. All five existing methods may be used separately or in combination, and other methods under development may supersede these in the future.

A number of automobile navigation systems are at various stages of development and testing worldwide, some of which have already reached various markets in limited application. The Toyota Crown offers the option of an AVN device to the upscale consumer market in Japan; it has been a popular option.

The primary advantage offered by AVN was reduced trip times for the system owner, according to our panel. Small reductions in congestion due to improved knowledge or route alternatives was ranked second by the panelists. However, a navigation device would not display nonrecurrent congestion and therefore would not facilitate incident detection and traffic diversion. Reduced driver stress was also noted as a benefit of the system. Convenience and novelty were seen as benefits that would appeal to the consumer and would lead to early adoption. There was some dispute over whether ANV would increase vehicle safety. While some of the panelists predicted increases in safety due to better informed drivers; others viewed the in-vehicle monitor as a distraction, possibly resulting in less safe driving conditions. Drivers' responses to display monitors mounted on the instrument panel is a crucial human factors issue that needs to be addressed in the near future.

Table 7. Items of Special Interest for AVN

Driving Forces	Barriers	Government	Impacts
none	• Public-private sector cooperation • Lack map database	none	none

Cost was seen as the primary barrier to market acceptance. As one panelist commented, "the majority of consumers are unlikely to purchase a stand-alone system unless it costs 50 to 100 dollars." It was questioned whether a system could be designed and installed at a price acceptable to the general consumer. Closely related to the cost issue was the prospect of building consumer acceptance and demand. Could the anticipated benefits be sold to the general buying public? Other than the human factors considerations and perhaps agreement on technical standards, technical issues were not seen as prominent barriers. The panelists did expect some difficulty in compiling huge map databases required for use in the map-matching systems. The question of legal liability for possible damages, injuries, and deaths while using a navigation system was tied to the safety question and seen as another possible barrier to widespread use of AVN.

Many of the panelists submitted that the government should not be involved in the development of autonomous vehicle systems beyond the natural adjudication of liability complaints and possibly facilitating the setting of standards. However, some panelists viewed the role of government in the development of AVN to be a provider of adequate funding for research and development. If this is the case, a suggested topic for research funding would be the human factors considerations in AVN because of the public safety concern and liability questions. In systems where ground equipment is required, as with proximity beacons, the government would be required to possibly fund, install, and maintain the equipment, or at least monitor the operations of a contractor.

MOTORIST INFORMATION (MI). This is one of the more eclectic system categories representing all systems that communicate travel, traffic, road, and vehicle information to the motorist. Applications might include digitized road maps, local traffic regulations, emergency broadcasts, public service messages (e.g., weather, traffic, incidents, construction, parking availability, etc.), roadside service information (e.g., service stations, food and lodging, rest areas, shopping, etc.), and other forms of information either useful or entertaining to the motorist. Although automatic vehicle location (AVL) and automatic vehicle navigation (AVN) systems are closely related to MI, these two system types are sufficiently distinct to have their own category and therefore are not included here. Limiting MI to at most one-way communication links, from an information transmission center and to the vehicle, distinguishes this category from the two-way cooperative route guidance (CRG) systems.

External linkage may be provided through common mobile communications techniques including proximity beacons (e.g., UHF, microwave, infrared), AM/FM broadcasts, subsidiary carrier authority broadcasts, national weather radio broadcasts, land mobile radio, and possibly cellular radio. A good example of an externally-linked system is automatic interrupt radio providing current traffic, accident, weather, and road conditions for a local area. Highway advisory radio (HAR) has been used for some time to inform drivers about traffic congestion due to highway construction, large events like football games, or seasonal airport use. Some MI systems include autonomous data storage and processing capabilities containing relatively static information of interest to the motorist. Examples of static information would be electronic yellow pages or tourist information. However, even in these examples, a linkage with the highway side through AVN would help keep the selection and processing of the most relevant static information for display to the motorist. Mobile office capabilities are also included under this category providing features to assist in office communications, freight management, and database management.

Several forms of these systems have already been introduced on a limited basis in Europe, Japan, and the United States. These include highway advisory radio, the German ARI (Autofahrer Rundfunk Information) and ARIAM (ARI aufgrund Aktueller Messdaten) systems, and the European Radio Data System. As mentioned earlier, highway advisory radio has been in use in the U.S. for quite some time. One panelist from a government agency related that "we have seven systems in operation, some using digital voice storage (remotely changed), and others using AM band 530, 1610, and 1200 KHz." The panelists were also aware of the the European Broadcasting Union's ongoing implementation of the Radio Data System (RDS) in the UK, the Netherlands, France, Germany, and Ireland. RDS enables digitally encoded data to be superimposed on the signal of a conventional FM broadcast and decoded by a suitably adapted car radio. Most panelists noted that in the U.S. some of the regional coverage functions were already available through standard commercial radio traffic advisories. One quote summarizes much of the discussion on these systems in the U.S.:

> The key word is "system." *Ad hoc* advisory services are not sufficiently standardized or filtered to merit the "system" title. For example, C.B. (citizen band) radio is an exercise in anarchy, and will never be useful in dense areas such as Los Angeles, though it is quite useful in the Mojave desert."

The panelists agreed that the most important benefit from a MI would be reduced trip times as a result of diverted traffic and reduced congestion in incident areas. Diversion would be achieved by informing drivers of traffic incidents and conditions; the driver would then presumably avoid problematic areas by altering routes and departure times, or by possibly eliminating the trip altogether. Diversion of traffic would have the related effect of increasing the burden of secondary roads. However, the total throughput of the system would be increased. Modification of the demand patterns and information of weather, traffic, and road conditions would also result in increased traffic safety, as the driver would be more aware of nonrecurrent hazards on the road ahead. Related impacts would include energy conservation , improved air quality, and perhaps some long-run modifications of land use patterns. Commercial users might find that traffic information would result in more efficient operations and lower transport costs. Although it was mentioned, pleasure trip planning and even business service information was not viewed by the panelists as a significant force in adoption as compared with general traffic information.

Again, the panelists viewed cost as the most significant barrier to market penetration. The cost to the vehicle owner, the manufacturer and supplier, and the agency in charge of maintaining the infrastructure and providing the information were all of primary concern. There was some dissent on this issue because a basic MI would demand a relatively inexpensive and slightly modified car radio that most panelists thought would be affordable. However, the implicit costs of information distribution were a matter of greater concern. Collection of current traffic information and maintaining the MI databases were seen as especially formidable tasks. One panelist observed that while RDS is already available in Europe, "the complex issues in the U.S. are (1) to establish the infrastructure, and more so (2) to create the updated information on relevant geographic basis." There was a general belief that this would take a commitment to generate a nationwide network of compatible systems with common communication protocols and broadcast standards. Cooperation between public and private sector providers, including deciding on who will provide the service and deciding on who will pay for the devices, infrastructure, and information , was seen as another significant hurdle. Technical issues, other than ensuring technical reliability, were not seen as barriers.

Suggested government involvement included (1) the provision of adequate funding for installation, maintenance, and operation of the information control and broadcasting centers, (2) supporting the establishment of equipment standards, and (3) the provision of incentives for support of public/private cooperation. This would require commitment to establishing a nationwide network of control centers and provision of the right of way for the essential infrastructure. Federal funding of research and development would also be required.

Table 8. Items of Special Interest for MI

Driving Forces	Barriers	Government	Impacts
• Public's awareness of available information and technical capabilities	• Task of keeping the information current	• Support for public-private cooperation	• Redistribution of traffic from primary to secondary roads
• Recognized commercial potential	• Public-private cooperation and coordination	• Commitment to nation-wide network of information centers	• More effective use of transportation facilities
			• Reduced energy consumption for vehicle miles traveled
			• Improved air quality

COOPERATIVE ROUTE GUIDANCE (CRG). A logical extension of the motorist information and automatic vehicle navigation systems is to establish two-way communication between the vehicle equipment and a traffic control center. The advantage of these closed-loop systems over one-way motorist information systems described above is that (1) the traffic control center can monitor specific vehicles to improve their assessments of area-wide traffic conditions, and (2) they can potentially provide better navigation information to the driver by taking account of real-time traffic conditions. CRG systems are of two types: those which use long-range radio broadcasts to link the vehicle with a traffic control center, and those which also use short-range communications to link the vehicle to roadside infrastructure (Castle Rock Consultants, 1988).

An example of the first type is the Pathfinder experimental demonstration project that is designed to test the feasibility of using a CRG to assist motorists in avoiding adverse traffic conditions. The experiment, which is a collaborative effort between the Federal Highway Administration (FHWA), the California Department of Transportation (Caltrans), and General Motors Corporation (GMC), is being conducted along the Santa Monica Freeway in California. In this case the CRG configuration includes an Etak Navigator linked by radio to a packet radio system, which, in turn, is linked by radio to a central workstation, providing two-way communication between the workstation and the vehicle. The motorist sends information on the vehicle's location, heading, and speed via radio link to the central workstation, where it is processed along with freeway and arterial data to determine real-time congestion levels, and later relayed back to the equipped vehicles. The motorist receives information on the levels and location of congestion in the form of symbols on the Etak Navigator, text, and voice synthesis. The Advanced Mobile Traffic Information and Communication System (AMTICS) being tested by the Japan's National Police Agency is a similar, but more comprehensive system, relying on a teleterminal system for small-zone radio communication, combined with static service information supplied through recording medium.

Examples of systems using short-range communication and beacons are ALI-SCOUT in West Germany, AUTOGUIDE in the United Kingdom, and the Road/Automobile Communication System (RACS) in Japan. The ALI-SCOUT system is a cooperative effort by Bosch/Blaupunkt and Siemens using post-mounted infrared transceivers along the roadside and dead-reckoning navigation in the vehicles providing some computational capability in the vehicle as well as two-way communication between the vehicle and a central computer. Equipped vehicles transmit their travel times to the beacons, which are then relayed to a central computer where they are used to calculate route recommendations. These recommendations are then relayed to the beacons and transmitted back to the vehicle along with part of a city map. The AUTOGUIDE system being tested by the Transport and Road Research Laboratory (TRRL) in London is similar to ALI-SCOUT in that it uses infrared transceivers mounted on beacons to to establish two-way communication between the equipped vehicles and a central computer. The Japanese Ministry of Construction's RACS demonstration also uses a similar approach, but relies on microwave communication between the vehicle and the beacons. In addition, the two-way communications include voice messages and facsimile services between the motorist and a wide range of locations (home, office, etc.) beyond the central computer similar to, but much simpler than, cellular telephones.

With current real-time traffic information the traffic control center has a greater capacity for effective traffic management. According to our panelists, the most significant impact will be diminished congestion, closely coupled with reduced travel times for the individual driver using the system. With the traffic distributed more efficiently throughout the network the panelists predict related improvements in driving convenience, traffic safety, traffic flow, fuel efficiency, and air quality. CRG may also be used in lieu of vehicle location and dispatch systems to increase the efficiency of fleets. Somewhat removed from traffic impacts is another major consideration and possible benefit --

international competitiveness in intelligent vehicle and highway technologies. This may be seen as a driving force for adoption in the U.S. because of the concern for industrial and technological competitiveness The promise of major national contracts for suppliers of the systems is seen as another driving force.

The panelists ranked cost, both public and private, as the primary barrier to market penetration. The cost of in-vehicle devices and the roadside infrastructure, and how the costs will be allocated, are of critical importance. The end-user's perceptions of benefits and costs, whether from the perspective of a potential customer or potential taxpayer, will ultimately determine the success of CRG. Assessing and communicating the likely benefits is another element of this obstacle. Innovative schemes for cost allocation may be essential. Beyond cost considerations, the federal government needs to be involved in establishing standards and ensuring compatibility between commercial systems. Issues for governmental standardization bodies to address include technologies for vehicle to roadside communication of both data and voice, radio frequency allocations, and common in-vehicle circuit boards. Coordination and planning of system research, development , demonstration, and implementation was the last major barrier mentioned by the panel. The enormous scope of this endeavor and the large number of parties involved makes the introduction of CRG a complex and difficult administrative and political conundrum. Of all the system categories, CRG probably requires most cooperation among most parties. Where should we start -- with the vehicle or the control center? Who will provide the leadership -- government or industry? How will the efforts of industry and government be co-ordinated? These are difficult questions that will have to be answered in order to mount a collective campaign. The panelists also identified the resolution of liability issues and assuring system reliability as concerns for implementing CRG.

Table 9. Items of Special Interest for CRG

Driving Forces	Barriers	Government	Impacts
• Public's awareness of available information and technical capabilities • International competition	• Conflicts over distributing and allocation of costs	none	• More effective use of transportation facilities • Reduced energy consumption per vehicle mile traveled • Improved air quality

COLLISION WARNING (CW). In-vehicle warning systems caution the driver when on a collision course with another vehicle or object. Not only is the area in front of the car scanned to detect a rapidly closing potential collision, but the driver's blind spots in the rear outermost corners of the vehicle are monitored to facilitate lane changes in traffic. Once an obstacle is detected a signal or message is delivered to a display on the instrument panel, the windshield (as in a head-up display), or on the rear-view mirror (e.g., for lane changes). The detection component of the system can be based on radar, sonar, infrared, or laser technology. Laser, radar, and infrared are generally preferred for front and rear interval control in existing applications. Ultrasonic waves are likely to be used for monitoring blind spots on the side of the vehicle. CW systems are to be distinguished from incident detection systems which provide motorists with information concerning collisions and other incidents far enough in advance so the motorist can modify his or her route. General Motors (GM) has equipped a number of their vehicles with near obstacle detection systems (NODS) that warn the driver of objects that are in the near-field vehicle's path, but are not necessarily in the driver's view. One vehicle has a detector mounted near the back bumper to warn the driver about objects while backing up. Another GM vehicle warns the driver of objects in the blind spots.

Collision warning systems represent a distinct category of IVHS and a step toward automated vehicle control. The purposes of CW and collision avoidance (CA), the first automated control system to be addressed, are similar, and they share sensor and detection technologies. However, the functions are distinct; collision warning systems inform the driver of oncoming objects while collision avoidance systems send signals to processors and actuators that control the vehicle braking and throttle functions. Although the systems are related, collision warning is unquestionably a driver advisory function, just as collision avoidance is certainly a control function.

The primary motivation for the development of collision warning systems is the desire to reduce traffic accidents, fatalities, and property damage, and to improve overall traffic safety. Trusted CW systems have the potential to relieve some of the stress and fatigue of driving. A related benefit would be reductions in insurance rates for drivers of modified vehicles. However, should CW become widely accepted by motorists, the panel also expected an antagonistic drift toward increased driver risk-taking. So there is a tradeoff between faster vehicles and relief of driver stress that will ultimately be settled by decisions on appropriate speed limits. If the speed limit is increased and the number of traffic incidents does not increase, then increased system throughput would also be expected. When, and if, CW systems are proven to be reliable, consumers may become more likely to trust other warning and control devices. This is where CW becomes an entree to more advanced automated control systems, especially collision avoidance systems.

According to our panel the serious impediments to consumer acceptance of CW are of a technical and legal nature. These also apply, perhaps to a greater degree, to collision avoidance and the automated control systems that will be discussed in the next section. The panel emphasized that system reliability must improve for widespread acceptance of CW. Accordingly, system design must address detection and diagnosis of incipient failures. Target discrimination must be near-perfect and false alarms must be kept to a minimum. A related concern is liability. To what extent will private vendors and public agencies be liable for accidents when the system is in use? According to one of our experts, current CW systems have "excessive false alarm and error rates compared to humans -- the liability potential is frightening." Performance standards and inspections are likely requirements. Finally, the benefits must offset the cost to the consumer. Consumers may have to be educated and convinced that CW is worthwhile.

The panel suggested that the federal government will be called upon to take a leadership position in paving the way for collision warning. This will entail providing adequate funding for research and development, coordinating and financing demonstration projects, assuring uniform implementation of selected systems among the states, modifying the roadways if required, and establishing technological and performance standards. Undoubtedly the paramount issue facing government will be liability. The legislative system is likely be called upon to to resolve the inherent threat of increasing manufacturer liability.

Table 10. Items of Special Interest for CW

Driving Forces	Barriers	Government	Impacts
• Possible savings on auto insurance • Possible legal requirement on new vehicles • Technological advances in automated control	none	• Demonstration and public awareness programs • Encourage insurance differentials for equipped vehicles	• Increased risk taking by drivers • Increased consumer trust in non-human systems • Motorists will drive faster

COLLISION AVOIDANCE (CA). Automatic braking is the principal component of a collision avoidance system. CA is a logical extension of the collision warning (CW) which detects rapidly approaching objects but does not provide automatic braking for the driver. Like collision warning systems, CA systems use radar, sonar, infrared, and/or laser detection to sense approaching targets. However, once an approaching object is detected signal is sent to a signal processor which calculates and analyzes the distance and relative velocity of the object, as well as the ground speed of the vehicle, to determine the probability of collision. For example, if a collision is deemed probable, electromagnetic actuators may deploy the brakes to an appropriate degree. Radar technology is currently the preferred approach because it is the most resilient in inclement weather. Throttle and steering control are other possible elements of an advanced CA system but is not considered in this discussion or projection.

As with collision warning, the interest in collision avoidance stems from the desire to reduce traffic accidents, injuries and fatalities, and property damage, and to generally improve traffic safety. The panelists ranked safety far above the other projected advantages. The second leading advantage from CA was easing driver stress by providing backups for safer vehicle operation. A reliable CA system should offer a more relaxed environment for vehicle operators with and without CA installations. With fewer accidents insurance rates should fall. Differential insurance rates should be provided for drivers with CA installations. The panelists also predicted increased use of the automobile relative to other modes of transportation and perhaps increases in congestion with greater throughput.

System reliability is the principal barrier to development of an effective system. The panelists agreed that "trusted" or "fail-safe" system design was the primary concern for CA. This appears to be a critical research and development issue. There was also consensus that liability might be too great for component manufacturers and government to implement such a system, even if it offers the potential for aggregate improvements in traffic safety. One panelist pessimistically asserted that "the U.S. legal climate almost dooms such technologically refined systems from the start." Another issue that is unique to the automatic control systems is the driver's acceptance of active controls. Panelists expressed uncertainty about whether drivers would want or use such a system even if it were available at a reasonable cost. They may feel uncomfortable with the loss of control. As with all the system categories, cost and consumer demand were also a concern.

Table 11. Items of Special Interest for CA

Driving Forces	Barriers	Government	Impacts
• Legal requirement on new vehicles	none	• Encourage insurance differentials for equipped vehicles	• Increased litigation

The panelists saw the government getting involved by helping to limit public and private liability, setting standards, funding and offering incentives for research and development, and offering purchase incentives through schemes like reserving special lanes for equipped vehicles.

SPEED AND HEADWAY KEEPING (SHK). These systems combine throttle control with possibly some limited radar braking capabilities in order to assure safe and efficient distances between vehicles on the roadway. Current implementations of throttle control customarily employ pneumatic servos which operate the throttle in response to a vacuum obtained from the engine's intake manifold. Cruise control is one form of throttle control that responds to feedback on vehicle speed. As in the collision avoidance (CA) systems, radar braking would involve target sensing, signal processing, vehicle ground speed measurement, command logic and controls, and electro-mechanical actuators. However, in the most basic system "intelligent cruise control" would only employ throttle control, and perhaps some light braking, adjusting the vehicle's speed in light of information on road and traffic conditions, speed of other vehicles, obstacles, and/or electronic speed limits. SHK systems promise to allow for shorter headways between vehicles thereby increasing the capacity of the roadway. For example, a number of similarly equipped vehicles would be able to form a platoon, with compressed headways, and travel at relatively stable speeds. Like cruise control, SHK also promises to reduce the overall driving effort. One panelist reported that Volkswagen, Mercedes-Benz, and the German Army Research and Development Center have demonstrated driverless control at 100 kilometers per hour with clear lateral definition. The Martin Marietta Autonomous Land Vehicle is a similar concept.

The panelists indicated that safety is the most important benefit of SHK. Safety is likely to be the driving force for adoption and eventually for mandatory use. Increased throughput and traffic efficiency is also important. The possibility of reducing headways and platooning vehicles promised to improve traffic flow and resultant travel times. The panelists also noted that the consumers may desire SHK because it reduces the effort and stress of driving, although some consumers may not prefer active controls. One can draw a parallel with cruise control; some drivers cherish cruise control, others are uncomfortable with it. Unless cost is prohibitively high consumer demand is not likely to be a major issue.

Again, system reliability is expected to be the major barrier to market acceptance. Reliable system design is likely to be the central thrust of most research and development efforts. In the institutional domain the liability issue is again present. If the manufacturers are held completely liable for accidents while the systems are deployed they are not likely to make the system available for widespread use. Demand will be influenced by price and performance. Production costs and market price will be of central concern to the manufacturers. The consumer will demand proven reliability and safety.

According to our panel the government must take steps to limit corporate and government liability. They also suggested that the government take steps to establish effective standards and to increase funding for research, development and demonstration. Federal or state governments could also play a role in periodic certification of in-vehicle subsystems.

Table 12. Items of Special Interest for SHK

Driving Forces	Barriers	Government	Impacts
• Desire to reduce insurance rates	none	• Periodic certification of in-vehicle subsystems	• Increased efficiency in traffic flow • Vulnerability to control breakdown

AUTOMATED HIGHWAY (AH). This is the most advanced form of vehicle control, combining elements of speed and headway keeping (SHK) and collision avoidance (CA), and adding further control features, to enable vehicles to travel on their own, without any form of continuous control by the motorist. Vehicles would be totally automated in all aspects of control. In an automated highway environment the vehicle would, in effect, operate itself, taking itself from origin to destination according to programmed instructions. Elements of the total control function have been discussed under SHK and CA. However, AH requires more than automated steering, braking, and throttle control. The AH concept calls for full longitudinal and lateral control of the individual vehicle combined with automated approaches for navigation, entering, egressing, and merging. All issues of control at both the microscopic (individual vehicle) and macroscopic (traffic) levels would have to be resolved. Furthermore, the control systems would have to be fail-safe. Many of these issues have been addressed in the development of automatic guided vehicle systems (AGVS) which have been implemented for materials transport in factories and for traversing hazardous areas. However, the routing and control problem is much more complex in a dynamic highway environment.

Because the full implementation of AH is expected to occur far into the 21st century the benefits of AH are also viewed in this time frame. The panel expected AH to come to fruition at a time when society will be facing intolerable traffic congestion on urban freeways. The FHWA has projected that urban freeway travel will increase almost 50 percent up to 492 billion vehicle-miles travelled by the year 2005; total traffic delay in 2005 is expected to be five times the 1987 delay. This level of delay is difficult to imagine, but if this is the case, what levels of delay can we expect for the year 2050 when AH is expected to reach majority use? It is hard to say, but time savings and increased vehicle throughput were seen by our panel as the most important impacts of AH systems. Demand for AH would be the greatest in the most densely populated areas, although rapid intercity travel might also have some support. The panel acknowledged the need for other modes of transportation in this congested environment, but they predicted that the automobile would still be needed to access contiguous, high-density population areas as a complement to bus, rail, and air transportation. Assuming that these systems would not reach the market unless they were completely reliable, the other predominant impact is increased traffic safety. Another of the primary benefits was reduced driver stress.

Some expected negative impacts included debates over where these systems would be implemented, diminished mobility as travel gradually moved from the non-equipped automobile to AH systems, and major changes in the trucking industry including diminishing need for truck drivers. If throughput was increased significantly one would also expect a significant change in land-use patterns. One panelist predicted that personal travel would increase on all modes for trips up to 500 miles. There could also be a shift from the airlines to the automobile as shorter intercity trips were made on AH systems.

The principal barrier to developments in AH was technical reliability and trusted system design. Liability and cost were the other predominant issues. One panelist contended that AH would "require enormous amounts of government funding, on the order of putting a man on the moon." Technical barriers included needed advancements in sensing, information integration, and vehicle control as described in the introduction above. Inter-vehicle dynamics were viewed as an important issue, especially the integration of equipped and non-equipped vehicles in the system. Many of the control technology issues were the same as with CA and SHK.

Table 13. Items of Special Interest for AH

Driving Forces	Barriers	Government	Impacts
• Increasing dispersion of population in noncontiguous urban centers	none	• Establish a federal operating organization similar in scope to NASA • Improve roadway standards and maintenance	• Debates over whether to allocate resources to equipping lanes and roadways • Diminished freedom of mobility • Changing employment opportunities in transportation sector • Reduced need for truck drivers

Our panelists believed that the federal and state governments would be called upon to fund the development of AH systems. They would have to be committed to funding research, development, and demonstrations over the long haul if advances were to be made. Many of the panelists believed that a new federal operating organization would be required approaching the size and scope of NASA. At an operational level the government would coordinate transportation planning, certify vehicles, restrict access to dedicated lanes, and improve roadway standards and maintenance.

AUTOMATED GUIDEWAY (AG). This category aims to combine the advantages of automated guideway transit (AGT) and normal street vehicles. AGT is a class of transportation systems where unmanned vehicles travel along guideways with exclusive right of way. A common form of AGT is the urban shuttle which moves back and forth an a single elevated guideway or around a closed loop; the Detroit People Mover would be an example, but this is not the type of system that the panelists addressed here. The dual-mode form of automated guideway was addressed by our panel where private vehicles are used in a conventional way in local traffic but are switched to a guideway in dense corridors. One could imagine a system where everyday vehicles would travel on the conventional street system in most areas and then switch to a specially equipped guideway at certain access points where pallet cars would carry the vehicles along a guided network. The pallets would conceivably move the vehicles with short headways at a uniform and fast speed. Dual-mode mag-lev systems also fall into this category. The key distinction between AG and AH is that AG uses standard vehicles and some form of physical guideway whereas AH has intelligent vehicles guided by signals or electronic detectors.

Table 14. Items of Special Interest for AG

Driving Forces	Barriers	Government	Impacts
• Trend toward increasing automation	• Guideways are fixed routes which limit motorist flexibility	• Funding for construction and operation of guideways	• More reliable trip times
• Use of guideways to complement other modes	• AG is in direct competition with AH	• Building of guideways	• Huge guideway building program
• Inefficiencies of short-range air travel	• Limited access to approved vehicles	• Acquire right-of-way for guideways	• Increased recreational vehicle travel
• Desire for improved mobility			

The panelists viewed the primary benefit of AG as being increased throughput and faster travel times. It would not require major alterations of the vehicles as automated highways would require. The primary impediment to the development of AG was what the panelists viewed as a competitive disadvantage with AH. Most panelists saw AH as a more feasible alternative. Other barriers included the need of the right-of-way and construction of a guideway, the cost of the public infrastructure, and the physical intrusiveness of the guideway. There was a general skepticism whether systems of this type would ever be developed.

CONCLUSIONS

This Delphi study combined both exploratory and normative approaches to forecasting in order to assist the UM IVHS research planning project in anticipating near-term events and in developing a research and administrative strategy designed to meet realistic goals. The individual *system forecasts* were exploratory in the sense that they predicted market penetration on the basis of selected assumptions. The forecasts describe the near-term limits to IVHS developments given sufficient institutional support for these efforts. The *listing of factors* that may influence the development of these systems is more normative in nature; these lists may serve to illuminate potential opportunities and roadblocks along the path to developing an IVHS capability in North America. Knowledge of these factors also helps to circumscribe reasonable goals and strategies for research and development in the area. This section describes the limitations of the exploratory forecast and how the normative assessment, along with our plan for periodic updates of the Delphi study, provides a sound basis for formulating a research strategy in IVHS.

The survey shows that progress in the development and the implementation of IVHS will depend on significant technical and institutional advances over the next ten years. The technical problems appear to be fairly well-defined; the design of driver information systems being the most immediate technical concern and the reliability of the advanced vehicle control systems being the crucial long-run issue. The institutional considerations are much less certain. Our survey indicates that the turbulent institutional environment has the potential to slow, or even halt, the progress toward a comprehensive IVHS capability in the U.S. In fact, the most likely and consequential near-term barriers to development and implementation of IVHS are the possible lack of consumer demand for and acceptance of these new transportation alternatives and the failure of our institutions to support the cooperative development of IVHS. Thus, the successful implementation of IVHS in North America will require a concerted effort on the part of the participating manufacturers, government agencies, and other interest groups to cooperate in resolving the issues of liability, standards, and support for research, development and demonstrations. Cooperation among the key participants will need to continue through implementation and operation of many of the systems presented in this report because both the vehicle and the highway elements will be fused into a unified whole. It is our opinion that existing institutional arrangements are unlikely to provide adequate support for these efforts and that institutional innovation must be sought. The unconventional nature of the institutional problems posed by IVHS limits our ability to predict relevant social, political, and economic events with any degree of certainty.

In his respected critique of forecasting methods in public policy making, William Ascher (1978) contends that the predictive value of a forecast is determined primarily by the core assumptions on which it was based. If the core assumptions are uncertain or wrong, then the conclusions of the forecast are likely to correspond. If the assumptions are accurate, then the forecast is likely to have greater predictive value. Ascher's insights have significant bearing on the strategy for and use of forecasting in deliberations on the future of IVHS. Because the institutional arrangements are so critical to the progress in IVHS, any forecast of technical advances in this area will be extremely sensitive to anomalies in the institutional arena.

The primary difficulty in providing accurate predictions of developments in IVHS is precisely that the environment for social decision making in North America is complex and rapidly changing, limiting our ability to anticipate events in a turbulent institutional environment. The core institutional assumptions for our survey were highly optimistic and uncertain; should the assumed institutional mechanisms fail to produce the anticipated levels of support, then the predictive value of the forecasts will diminish. For example, should the federal government fail to support the development of IVHS, or should the central institutional actors fail in their efforts to collaborate in this area, then little progress should be expected in the area of cooperative route guidance, which requires substantial levels of government support and institutional cooperation. Therefore, the expert forecasts that resulted from this survey should be viewed with an understanding of the optimistic assumptions on which it was based, and used more as a tool for setting goals and making near-term decisions rather than for predicting the long-run future. The optimistic exploratory forecasts are most useful in assessing the technological feasibility of meeting societal goals regarding the development of particular systems. They should be interpreted as the lower threshold for advancements in these technologies.

With the limitations of our forecasting methodology in mind we developed a strategy for anticipating institutional events and technological breakthroughs for the purpose of developing and revising our research strategy. First, as the report reflected, we placed great emphasis in the Delphi study on identifying and prioritizing a number of impinging factors, including possible barriers to implementation, driving forces for implementation, government policy initiatives, and the social impacts of IVHS. Knowledge of and sensitivity to these factors will assist us in anticipating possible difficulties that lay ahead and in channeling our research and administrative efforts more effectively. We took a relatively open-ended approach in this portion of the survey to encourage originality on the part of the participants and to avoid the possibility of overlooking important factors. Second, it is our plan to repeat the Delphi on a periodic basis to update our assessments as events unfold. This will help us avoid what Ascher terms "assumption drag" where the forecast relies on outdated core assumptions, which accounts for the gross inaccuracies of many policy-related forecasts. This initial Delphi study was designed with the intention to provide a foundation for a series of similar studies in the years to come. For example, the structure of the next Delphi should emerge from the results of the initial study.

Institutional issues notwithstanding, the prospects for rapid development of intelligent vehicle-highway systems in North America suggest that organizations with stakes in the future of road transportation get organized to guide progress in this area and respond swiftly to opportunities as they arise. Motorists demand the freedom of mobility delivered by the automobile. To the extent that IVHS can increase the throughput of existing roadways, reduce vehicle travel times, increase the motorists' comfort, convenience and safety, and generally provide the motorist with information that either makes the driving time less aversive, more productive, and possibly more entertaining, the motorists freedoms will be extended and a market for these products will be assured. If IVHS can deliver these advantages as expected, the primary question becomes one of cost -- cost to vehicle manufacturer, automobile insurance companies and ultimately the vehicle owner, cost to the government operating organization and the local taxpayer, cost to the Department of Transportation and the U.S. taxpayers. As the cost of these systems tumble the markets for the products and services will surface.

Elements of IVHS have already been introduced, but the full market potential of IVHS will not be realized until the key actors in the public and private sectors commit to a common vision of "smart" road transportation. The results of our Delphi survey indicate that, under the right institutional conditions, the commercial and noncommercial market will arise in relatively short order. *Majority* commercial use of most advanced driver information systems is expected by the year 2000. Adoption by the general public is not far behind. This implies a lot of work between now and the imminent turn of the century. Research on system integration and the human consequences of IVHS must be supported and conducted at an internationally competitive level, systems must be designed and demonstrated to be effective and reliable, new technical standards will need to be set, potential shifts in liability risks must be reconciled, operating organizations must be established, and a host of other milestones must be accomplished before a fully integrated and supported IVHS capability is established in North America. Our survey of experts was directed at determining feasible progress in IVHS in the years to come and at issues that will require action if this is to be achieved. Perhaps the results can serve to inform the individual stakeholders about what is possible and to help shape a shared vision of IVHS in North America.

REFERENCES

Ascher, W. (1978). *Forecasting: An appraisal for policy makers and planners.* Baltimore, MD: Johns Hopkins University Press.

Belcher, P.L., & Catling, I. (1989). *Autoguide: Electronic route guidance in London and the UK.* Proceedings of the 20th International Symposium on Automotive Technology and Automation, Florence, Volume 2, Italy, May 29-June 2, 1989.

Belohoubek, E.F. (1982). Radar control for automotive collision mitigation and headway spacing. *IEE Transactions on Vehicular Technology, VT-31*(2).

Bender, J.G., et al. (1982). *Systems studies of automated highway systems.* General Motors Corp., Warren, MI, Report FHWA/RD-82-003, July.

Bolger, J.G., & Kirsten, F.A. (1977). *Investigation of the feasibility of a dial mode electric transportation system.* Lawrence Berkley Laboratory, University of California, Berkeley, CA.

Brockhaus, W., & Mickelsen, J.F. (1977). An analysis of prior Delphi applications and some observations on its future applicability. *Technological Forecasting and Social Change, 10*(1), 103-110.

Castle Rock Consultants. (1988). *Assessment of advanced technologies for relieving urban traffic congestion.* Prepared for the National Cooperative Highway Research Program.

Chan, C.C., & Gatling, I. (1986). *Area traffic control systems and electronic road pricing in Hong Kong.* In Proceedings of the 2nd International Conference on Road Traffic Control, London, England.

Chen, K., & Ervin, R.D. (1989). *Developing a Program in Intelligent Vehicle-Highway Systems in North America.* Proceedings of the 20th International Symposium on Technology & Automation, Volume 2, Florence, Italy, May 29-June 2, 1989.

Coates, J.F. (1975). Review of the Sackman Report. *Technological Forecasting and Social Change,* 7(2), 193-194.

Dalkey, N.C. (1972). *Studies in the quality of life: Delphi and decision-making.* Lexington, MA: Lexington Books.

Davies, P. & Hill, C. *The heavy vehicle electronic license plate (HELP) programme.* Proceedings of the 20th International Symposium on Automotive Technology and Automation, Volume 2, Florence, Italy, May 29-June 2, 1989.

Davies, P., Sommerville, F., & Ayland, N. (1989). *Automatic toll collection in Virginia.* Proceedings of the 20th International Symposium on Automotive Technology and Automation, Volume 2, Florence, Italy, May 29-June 2, 1989.