Intelligent vehicle highway systems (IVHS) involve the systems integration of many emerging technologies to effectively address the needs, both present and future, of the nation's roadway complex. Here, an introduction to and brief history of IVHS is presented. Then, a more detailed overview of Automated Highway Systems (AHS), the part of IVHS of most interest to control engineers, is given. One focus is on various control issues that must be confronted before an AHS is deployed.

Introduction

The IVHS program is based on both present and perceived future needs of the nation's highway system. Looking ahead to the year 2010, it is estimated that total roadway travel will more than double relative to 1992. Correspondingly, there is an inability to build enough new roads to account for this increase. This arises, in part, from the lack of sufficient land for roadway construction and the high costs of such construction, especially in congested areas.

The problems associated with increasing highway travel will be greatly expanded versions of those that existed in 1992. Safety is obviously one such major problem, with the current cost of accidents estimated at more than $70 billion per year, not including the personal suffering associated with traffic deaths and injuries. Urban freeway delays are estimated to total some 2 billion hours in lost productivity, to generate substantial personal frustration and stress, and to waste some 2 billion gallons of fuel per year. Environment issues are increasingly critical, with vehicle emissions in particular posing an ever-increasing problem to public health.
Clearly, bold, innovative, and effective approaches must be developed both to meet future needs and to ameliorate, to the extent feasible, both these and other problems.

**IVHS—An Overview**

IVHS is the selected approach for addressing the needs, both present and future, of the nation’s roadway complex. It involves the application of advanced systems—information processing/display, communications, control, and sensing—to improve the effectiveness of this complex.

IVHS is comprised of six interrelated areas. The first is Advanced Traffic Management Systems (ATMS), which involves the monitoring and control of traffic on streets and highways. A surveillance system is employed to detect traffic conditions, usually in a metropolitan area and/or on the arterials leading to that area. The collected information is communicated to a traffic management center for processing, and the processed information is used to manage traffic by controlling various traffic signal devices. The technologies involved are associated with vehicle detection, communication, information processing, and control.

Advanced Traveler Information Systems (ATIS) are intended to provide travelers with timely information on travel conditions along the routes to their destinations and, in some cases, to specify a preferred route. This information would be available at different locations including within a vehicle, at sidewalk kiosks, and from portable receivers. A traveler would, of course, obtain information from a source most convenient to his or her current circumstances. The relevant technologies are associated with vehicle detection, communication, information processing, and information display. In particular, there is an essential human factors aspect associated with this area—especially relative to the in-vehicle display of traffic information.

Advanced Vehicle Control Systems (AVCS) involve technologies intended to enhance a driver’s control of his or her vehicle and, ultimately, relieve the driver of some or all of the driving task. Some relevant technologies, which either have been or may soon be deployed, include anti-lock braking systems, adaptive cruise control, and automatic collision avoidance systems. Other technologies, which are in the research stage, include lane-departure warning systems, vision-enhancement systems to aid driver visibility, and systems for control of steering and a vehicle’s longitudinal motion. The ultimate development in this area would be an automated highway system (AHS). As was the case with ATIS, there is an essential human factors component involved in this area.

The above three areas are applicable to all types of roadway traffic, whereas the remaining areas each pertain to a specific subset of roadway users. Commercial Vehicle Operations (CVO) involves the application of those IVHS technologies that will enhance the operations of commercial roadway vehicles such as motor carrier fleets, independent truckers, and intercity buses. IVHS technologies, when applied to such vehicles, should, by making operations more efficient, reduce operating costs for commercial operators and improve the driving environment for vehicle operators. Some relevant technologies include automatic vehicle location (AVL), automatic vehicle identification (AVI), weigh-in motion, and automatic clearance sensing. The widespread deployment of such technologies should save driver time, reduce pollution, and improve both recordkeeping and fee collections for roadway agencies.

The application of IVHS technologies to Advanced Public Transit Systems (APTS) is intended to enhance key aspects of public transit operations—its availability, its attractiveness, and its economics. This would be achieved by supplying both the users and the operators with dynamic, up-to-date information in a convenient and usable form, by improving the vehicle operating environment (such as by traffic signal preemption), and simplifying the fare collection process (such as by using electronic fare collection cards). Two key technologies would be AVL and AVI.

More than 50% of the nation’s roadway accidents occur in rural areas. This was a prime motivating factor for establishing the sixth area—Advanced Rural Transportation Systems (ARTS). This was an especially relevant choice since the needs in implementing IVHS in low-density rural areas are very different from those of high-density urban areas. Some relevant technologies are those associated with AVL, emergency detection and reporting, route guidance, and communications.

**IVHS—A Brief History**

What is now called IVHS had its conceptual beginning at the 1939 World’s Fair. Here, in the General Motors Pavilion, a fantastic vision of the automobile’s future—cars that drove themselves while their drivers relaxed—was introduced to the public. Then, in the late 1950s, the first AHS research efforts were conducted by General Motors Corporation (GMC) in cooperation with the Radio Corporation of America [2].

What might be termed the formal start of IVHS, however, was a far-reaching, broad-based research and development initiative in the late 1960s to improve the safety and efficiency of highway-based travel. This initiative, which was undertaken by the Bureau of Public Roads (BPR, the predecessor to the Federal Highway Administration, FHWA), was based on the premise that advanced communication and control concepts could be applied effectively to the vehicle/highway complex.

A major BPR activity was the Urban Traffic Control System (UTCS) project, an early ATMS system. UTCS involved the connecting of individual signalized intersections to a central controller, which would select the most appropriate timing sequence for each controlled signal. This sequence would be updated as required by changing traffic conditions and, in this sense, UTCS was an adaptive control system. Other efforts in urban traffic control were conducted both prior to and during this effort, which spanned the early-to-mid '70s; however, UTCS was certainly the most sophisticated and far-reaching effort in urban traffic control at that time.

The best-known BPR program was the Electronic Route Guidance System (ERGS). Here, a driver would be provided with routing information as determined from real-time traffic conditions, by an onboard unit—possibly a heads-up display. The General Motors Driver Aid, Information and Routing (DAIR) system was a somewhat earlier related program. Both of these programs were major forerunners of APTS. Unfortunately, ERGS was terminated by Congress in 1971, and the DAIR efforts were ended after the concept of a unified, vehicular communication system was demonstrated.

1 A more detailed account of much of the material in this section has been presented by Saxton [1].
An early BPR effort that pertained to rural driving was the Passing Aid System (PAS). This would signal the presence of oncoming traffic to a driver and whether it was safe to pull out and pass a lead vehicle. The FLASH system was a roadside motorist radio information system intended to provide information on disabled motorists to a central control center.

The most far-reaching part of the BPR initiative was its AHS program. This involved systems analysis studies of AHS, conducted initially by CALSPAN [3] and then by General Motors Corporation [4], and both vehicle control and network control studies at The Ohio State University (OSU) [5].

During the years of the BPR AHS program, other efforts in the United States were also focused on automated ground transportation. These included the Massachusetts Institute of Technology "Glideaway" study [6], a Federal Railroad Administration Northeast Corridor study, one part of which dealt with AHS [7], and a wide-ranging effort by the Urban Mass Transportation Administration [8]. One result of the latter was the automated transit system deployed at Morgantown, West Virginia.

In 1981, the BPR (now FHWA) activities in traffic systems were severely curtailed with the advent of the Reagan administration. Attempts during the early-to-mid '80s to either restart some programs or develop related new programs were unsuccessful.

Individual IVHS-type programs, somewhat similar to those mentioned above, were also under way in Europe and Japan from the mid-1960s onward [9-12].

In the 1980s, traffic congestion became a much more serious national concern. At the same time, technological advances in areas applicable to traffic and advanced transportation concept initiatives in Europe and Japan accompanied a growing recognition among some state departments of transportation that bold, innovative approaches to traffic were required. In 1988, Mobility 2000 was formed to address these concerns. Mobility 2000 was a group of transportation experts who undertook the task of formulating a technology-based national research and development program. Their conclusions were presented in 1990 [13], and their action items became the main elements of the IVHS program. Shortly thereafter, Mobility 2000 was reconstituted as IVHS America.

Subsequently, in 1990, the United States Department of Transportation (USDOT) established a formal IVHS program office and recognized IVHS America as a utilized Federal Advisory Committee. Then in 1991, Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA), with one part of this Act being the IVHS Act of 1991. The latter ensured that substantial federal funding would be available for current IVHS activities (e.g., $246 million in FY'92) and strongly enhanced the prospect of continued long-range funding. Since the moneys required from all sources over the next 20 years were estimated at over $200 billion, a considerable amount of interest in IVHS has been shown by many entities—a wide variety of industrial concerns, state and local government agencies, academia, and independent organizations. This was one desired effect of the legislation. Another was to ensure that all major efforts be cooperative involving a variety of interested parties; e.g., a typical effort might involve collaboration among a State Department of Transportation, an academic institution, some local industries, and an independent organization.

The ISTEA legislation required that USDOT prepare a strategic plan for IVHS. Such a plan was developed by IVHS America and presented to USDOT in mid-1992 [14]. This is important reading for anyone wishing to engaged in any substantive way in IVHS.

**AHS and Control Engineering**

The IVHS area of greatest interest to control engineers is AVCS, and within AVCS the most challenging control issues are those associated with the automated highway. For this reason, the focus hereafter will be on AHS.

The AHS concept is receiving renewed consideration as a means of alleviating some of the highway problems previously enumerated. Some potential advantages include:

- substantial increases in lane capacity and thus traffic throughput
- an improvement in highway safety
- a significant decrease in both the economic and psychological costs associated with accidents, and
- a lessening of the negative environmental impact of highway vehicles.

The envisioned capacity increases range up to 300% and would result in improvements in traffic throughput and decreases in congestion. The safety aspect would be a result of the virtual elimination of the human driver in vehicle control, and his or her replacement by a faster-reacting, more consistent, and highly reliable automatic control system. Certain types of accidents (e.g., those due to driver inattention) would be virtually eliminated, while others would, in general, tend to be much less severe than at present. In the aggregate, the economic costs of accidents would be decreased as well as the severity of personal injuries. Vehicles would be constrained generally to move at fixed speeds, thereby avoiding both unnecessary fuel consumption and excessive noxious exhaust products—related factors which have a well-documented negative environmental impact.2

At least four approaches can be employed to obtain the large traffic flow rates that are essential if an AHS is to be viable:

- multivehicle pallets uniformly spaced at moderate headways (e.g., 25 m)
- platooning—vehicles would be formed into platoons with small distances (e.g., 1 m) between vehicles within the platoon and much larger distances (e.g., 100 m) between platoons, and
- individual vehicles uniformly spaced at moderate headways.

The first, the use of multivehicle pallets, was deemed impractical for the highway environment as it would result in substantial delays in both loading and unloading the vehicles and excessive energy consumption [16]. The next two are somewhat similar; however, the mechanical coupling of vehicles is usually associated with entrainment and non-mechanical coupling with platooning. Some concerns are: possible excessive delay at entry points due to sorting vehicles for common destinations; rider discomfort associated with inadequate coupling (especially with entrainment); lane changing and the exiting of vehicles from a platoon; and the psychological aspects of operating at very small

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2A more detailed discussion of these matters has been presented by Saxton [15].
intervehicular spacings. Such concerns have probably eliminated entrainment as a viable approach; however, these, as related to platooning, may be resolved by the extensive application of advanced control/computer/communication technologies.

At present, it appears as if platooning and some form of uniform-spacing approach are the most viable candidates for deployment. Because the former, which is the focus of an ongoing, substantial research effort by UC Berkeley/CALTRANS, is discussed in a companion article [17], the remainder of this paper will deal with the latter.

In a uniform-spacing approach, the required intervehicular spacing for traffic moving at a fixed speed is a function of that speed. This spacing may be specified in several ways; however, a “safe” choice should result; e.g., the spacing may be chosen to prevent collisions due to a maximum expected lead-car deceleration. Under peak traffic conditions, cars in a lane would pass a fixed roadside point every Ht seconds, and the maximum capacity (Cmax) of that lane would be:

\[ C_{max} = \frac{3600}{H_t} \text{ (veh/lane/hr) } \]

where \( H_t \) is termed the time headway. One uniform-spacing approach requires that \( H_t \) be fixed over the range of highway mainline speeds. In the OSU studies [18], it was believed that \( H_t = 1 \) sec was achievable over this range resulting in \( C_{max} = 3600 \) veh/lane/hr. If it were possible to safely reduce \( H_t \) to 0.5 sec, then \( C_{max} = 7200 \) veh/lane/hr. For either value, however, \( C_{max} \) is based on a long traffic stream which does not interact with other traffic (e.g., no entry points or intersections would be present). In practice, it appears as if only 80% to 90% of \( C_{max} \) would be achievable—2880 to 3240 veh/lane/hr for \( H_t = 1 \) sec. [19]-[20]. On today’s highways, maximum sustainable flow rates are in the range of 2000 to 2200 veh/lane/hr and, while larger rates are observed, the corresponding traffic stream tends to be unstable; for example, there is an increased likelihood that a disturbance would diminish the flow rate, resulting in congestion and/or an increased probability of a traffic accident.

**System Configuration—Some General Considerations**

An AHS based on a uniform-spacing approach can be configured in many ways. Some relevant considerations are:

- The preferred nature of the traveling units
- The means of vehicle propulsion
- The distribution of intelligence, and
- The technological character of the roadway.

In general terms, the traveling unit may be either an individual vehicle or a single-vehicle, powered pallet. Here, only the former will be considered, as the latter is too energy-inefficient. Dual-mode vehicles capable of operating on both automated and non-automated roads are one possibility, with a second being vehicles which are configured only for automated operations. For the former, the automation equipment could be permanently installed within the vehicle or provided by a Detachable Electronics Package (DEP)—a collection of command, control, and communication electronics. The DEP could be attached or detached as required.

Vehicle propulsion may be achieved by an internal combustion engine or an electric motor. The latter would almost certainly involve battery-powered vehicles in initial operations; subsequently, electrical power could be provided by the roadway.

The intelligence required to make command and control decisions can be concentrated in a central location or assigned to the individual vehicles, or it could be distributed across the system. At present, with the rapid development of small, inexpensive, and very fast computers, it appears as if a substantial amount of intelligence would be present in the vehicle; however, a number of required functions would involve intelligence outside of the vehicle (e.g., the selection of the time to merge into the AHS traffic stream and traffic synchronization at a high-speed interchange).

The terms “active roadway” and “passive roadway” refer to the nature of roadway/roadside-based devices for vehicle communications and/or control. For example, two approaches to acquiring state information for vehicle lateral control are “active” wire-following and “passive” side-looking radar. The former involves the embedding of a current-carrying wire down the center of a traffic lane. Steering is achieved by detecting the resulting magnetic field and appropriate signal processing to obtain vehicle position with respect to lane center [5]. The latter involves irradiating a guardrail with electromagnetic energy and processing the scattered return to obtain vehicle location with respect to lane center. Wire following requires an active source in the roadway, whereas the radar approach involves only a passive guardrail, with the active device in the vehicle. It is noted that FHWA has long favored the use of passive devices in the roadway, to the extent possible, to reduce system operation and maintenance requirements.

This brief discussion by no means exhausts the considerations involved in developing system concepts. A fuller description has been provided in [16], where a number of candidate configurations for an AHS systems analysis are specified. As examples of the range of possibilities, three of these configurations are described below:

**Configuration 1.** The individual vehicle would be powered by an internal combustion engine and have a command, control, and communication (C) package permanently installed. Active sensors onboard the vehicle would detect that vehicle’s state with respect to both a passive roadway and surrounding traffic. This would be a “smart” vehicle, with much of the decision-making necessary for control made onboard; however, some decision-making would be external, especially at traffic interaction points such as AHS entry ramps and high-speed interchanges. One intent of this configuration is to minimize the amount of equipment that is system owned and operated.

**Configuration 2.** As in Configuration 1, the individual vehicle would be powered by an internal-combustion engine and have a C package permanently installed. Alternatively, the C functions could be contained in a DEP. Sensors onboard the vehicle would detect the vehicle’s state with respect to an active roadway and surrounding traffic. It would be an “average-intelligence” vehicle with the decision-making for control shared between the vehicle and a hierarchical control structure employed for network op-
operations. Much more equipment would be system owned and operated than with Configuration 1.

- **Configuration 3.** The individual vehicle would be electrically powered, with the power for non-AHS operations obtained from batteries and for AHS operations from electrified roadways. This power would be obtained by inductive means, and the induction field could provide lateral state data to the vehicle; i.e., an active reference.

Beyond lateral control, the C functions could be realized as in either of the first two configurations. The amount of equipment owned and operated by the operating authority would depend on the choices made.

**Some Thoughts on AHS Control**

In terms of the required control, two broad questions exist:

- **How can network control be achieved?** i.e., how can thousands of individual vehicles be simultaneously controlled in a safe, efficient, and economical manner?
- **How can individual vehicle control be achieved?**

The answers to these questions are, in part, configuration-dependent.

**Network Control**

Numerous studies of network control or vehicle management were done during the 1960s and 1970s. Generally speaking, these involved either synchronous or asynchronous control strategies. In the former, the roadway was envisioned as an electronic conveyor belt divided into equally spaced units called slots, with no more than one vehicle occupying a slot. Network-wide synchronization would be required so that when two lanes merged, for example, the slots in each lane would coincide at the merging junction. In its simplest form, a vehicle, upon entering an AHS, would be assigned a slot, which it would occupy until it exited from the AHS; however, this approach is too restrictive, and various researchers suggested less rigid alternatives. For example, Boyd and Lucas [21] controlled vehicle entries so that the capacity of network nodes (e.g., intersections) was not exceeded. This frequently required vehicles to adjust their slot assignment, by moving either forward or backward, prior to entering a merging junction. As a second example, Rule [19] employed a combination of path reservations through interchanges as each one was approached, and maneuvering-space reservations for the next interchange along a selected route.

Asynchronous control, as the name suggests, involves vehicles entering an AHS at random times and proceeding toward their destinations without reference to a system-wide timing signal. Vehicles would either travel individually at a system-fixed speed or "car follow" behind other controlled vehicles at that speed. It would, of course, be necessary to effect maneuvering at merging junctions so as to avoid collisions. Note that this type of control is similar to what exists on today's highways.

Regardless of the type of control chosen, it appears as if the intelligence required would be distributed, to a greater or lesser extent, across the overall system. As one possibility, consider one synchronous approach to controlling the roadway configuration of Fig. 1, which represents a general urban AHS that is interfaced with conventional city freeways, streets, and intercity highways. Its main features include an outerbelt, an innerbelt surrounding a central business district, connecting radial links, interchanges, and entrance-exit facilities.

A network control computer would be employed to control network operations and to supervise the operation of semi-autonomous regional computers—one of which would be assigned to each geographic region of the network. Each region would be composed of discrete geographic entities wherein a sector computer would control local traffic under the supervision of its regional computer. The lowest level of control would be that associated with each individual vehicle.

Both scheduling and routing assignments would be made by the network computer. A vehicle, upon arriving at an entrance facility, would be scheduled to merge into guideway traffic and proceed along a computer-selected route. A regional computer would control each interchange (more generally, a regional computer would oversee operations at a number of interchanges with the number depending on the geographic extent of a region).

Each sector computer would receive from its supervising regional computer the required schedule, route, and trajectory for each vehicle, as well as information pertaining to either abnormal or potentially abnormal system operations.

Some thought should reveal many of the control issues associated with such a network. Perhaps the most difficult of these is the response to a wide range of abnormal and/or emergency situations. A major thrust of AHS is the achieving of high throughput capacity; however, if an emergency condition shut down a lane for any considerable period of time, that capacity would not be achieved. Effective and efficient failure management is of major concern.

At this writing, no preferred approach to network control has been adopted. This is clearly an area in which substantial efforts must be undertaken. There is a rich lode of interesting and challenging control problems here.

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Footnotes:

1. Such activities virtually ceased in the 1980s with the severe cutbacks in both the FHWA and the Urban Mass Transit Administration research programs.

2. The feasibility of controlling this network with a quasi-synchronous control policy was evaluated by Rule [19]. A number of other network have been evaluated using other control policies as reviewed by Bender [4].

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Individual Vehicle Control

More effort was expended on individual vehicle control in the 1960s and 1970s than on network control. Several organizations, both in this country and abroad, designed and field-tested controllers for both the lateral and longitudinal modes of operation.

Most of the lateral-control studies involved the use of a wire-following reference to provide guidance information to controlled vehicles. Relatively simple models of lateral dynamics, valid for small lateral accelerations, were employed to design controllers that were evaluated in field tests at speeds ranging from 0 to 30 m/s. Excellent lateral control, “tight” tracking of lane center, and a comfortable ride were obtained for all normal (non-emergency) conditions [22]; however, while models which were valid for large lateral accelerations were available, very little effort was expended on the maneuvering of automated vehicles in various emergency situations.

One study involved the use of a side-looking radar to provide lateral guidance information; however, field tests were conducted at only at low speeds—0 to 15 m/s [23]. A third approach to obtaining such information, which was apparently due to a German researcher, involved the use of buried magnets. This approach received limited attention until the onset of the recent UC Berkeley/CALTRANS efforts. A principal difference between this approach and the others is its discrete nature—it provides a signal at discrete values of time, whereas both the wire-follower reference and the side-looking radar provide a continuous indication of a vehicle’s lateral position. Computer vision, which is a possibility for future use, would also provide a discrete signal.

Excellent models of vehicle lateral dynamics are available, and design of a lateral controller that provides both excellent tracking and a comfortable ride over all expected normal operating conditions and a wide range of both disturbance and road conditions should not be difficult. Vehicle control under off-normal or emergency conditions is a more difficult problem. Closely related is the need for a lateral reference system that can function effectively, providing necessary state information to a controlled vehicle under all expected conditions. It is this writer’s belief that the reference poses the greater problem of the two, as no approach evaluated to date can provide adequate control information except along restricted, well-defined paths. For example, with a wire-following reference, lane-changing can be accomplished only at specified locations. In an emergency, a desired path defined a priori may not be available.

The longitudinal control of a vehicle involves a number of maneuvers which can occur at speeds ranging from 0-30 m/s. These include:

- merging an initially stationary vehicle into a high-speed traffic stream
- maintenance of a vehicle’s state within a string of moving traffic
- required maneuvering prior to a traffic interaction point, and
- emergency operations.

Such maneuvers must be accomplished in an effective manner under a wide variety of disturbance and/or environmental conditions.

Many theoretical and simulation studies of the longitudinal control of highway vehicles were conducted in the ‘60s and ‘70s; however, only two studies in the United States, one at OSU and the second at GMC, progressed to field testing of designed controllers. In the OSU study, a model of an automobile’s longitudinal dynamics was developed from field test data [24], a longitudinal controller was designed and installed in a test automobile, and vehicle control was evaluated for a variety of expected normal operational conditions [25]. Excellent tracking of a longitudinal reference signal and a comfortable ride were obtained at speeds from 0 to 30 m/s for a variety of environmental conditions. The GMC study, which involved the use of a bus-like vehicle, also resulted in excellent tracking and a comfortable ride for a variety of normal operations over the speed range from 0 to 15 m/s [26].

Very little experimental work was focused on AHS emergency operations; however, anti-lock braking studies, which have been conducted by automobile manufacturers and suppliers, would certainly be applicable to AHS.

The longitudinal control required is, in part, a function of the control strategy employed. For example, with a synchronous strategy, a point-follower controller would maintain the vehicle near a desired point within its assigned slot. If maneuvering were necessary, the point motion would be appropriately adjusted to provide the desired reference to accomplish the maneuver. A moving point can be generated in many ways; however, all reported approaches require active electronics in the roadbed or at roadside [27-28].

In contrast, if an asynchronous, car-following strategy were employed, a car-following controller would maintain the vehicle at some desired state within a string of vehicles. It is expected that the control signals in this case would be derived from a vehicle’s forward-looking radar and data communicated from other vehicles and/or roadside devices.

As in the lateral case, excellent models of vehicle longitudinal dynamics are now available, and it should not be difficult to design controllers that provide excellent performance over all expected normal operating conditions and a wide range of disturbance and/or environmental conditions. Vehicle control under off-normal and/or emergency conditions will undoubtedly be a much more difficult task. Under all conditions, there is a need to provide essential state information to the controlled vehicle. As in the lateral case, fulfilling this need will be at least as great a challenge as controller design.

Closure

Clearly, a variety of technical issues must be resolved before an AHS is deployed. All solutions must be such that any corresponding required hardware is extremely reliable. This may be easier to accomplish, it is presumed, for system-owned and operated equipment than for the subsystems required on many thousands of privately owned vehicles. In essence, sophisticated C3 systems in individual vehicles must function at a very high level of reliability, as must the vehicles themselves. Vehicle breakdowns must be minimized; e.g., some breakdowns would block a lane, at least for a short period of time, and result in a less-than-desired capacity and an increased probability of an accident.

This discussion of AHS has, thus far, focused solely on technical issues; however, in terms of ultimate deployment, various nontechnical issues are, at least, equally important. In brief, some of these are as follows:
Social
- Who will be the prime beneficiaries of an AHS?
- How will implementation and start-up costs be shared?
- What mechanism will provide funds for operations and maintenance?
- Alternately, will an AHS be self-supporting with regard to such funds?
- Will an AHS be viewed as impinging on contemporary lifestyles, privacy, and individual autonomy?

Safety
- What types of accidents can be expected to occur, in what numbers, and with what consequences? How do such numbers, in the aggregate, compare with those associated with today's highways?
- What will be the public perception of the safety of an AHS—as opposed to its actual safety?

Legal
- What are the legal implications of an accident, especially if it were caused by system error and/or system oversight or lack thereof? Much current law would not fit situations expected with an AHS; it may be necessary to determine a new body of legal theory to deal with such issues.

Political
- A large-scale AHS will cover a number of political jurisdictions: state, county, township, and urban. How will the resulting political issues involved be handled?

Organizational
- What group will benefit the most from an AHS? Will commercial vehicles be included? Transit vehicles? If so, would separate lanes be employed for such vehicles?

Environmental
- Substantial capacity increases are anticipated and thus more vehicles discharging pollutants in the region surrounding an AHS will be present. Clearly, much cleaner vehicles must be employed to overcome the "more vehicles equals more pollution" syndrome.

Evolutionary aspects
- How can we evolve from the highways of today to the fully automated highways of the future?
Numerous other similar questions can be raised; however, this list should provide some insight into the many-dimensional aspects of an AHS.

Such nontechnical issues and a wide variety of technical issues must be resolved before an AHS is deployed. Currently, substantial funding is available for work in this area, and Congress has specified that an AHS demonstration will be implemented in 1997. Much interesting and challenging work in control must be accomplished prior to that date.

Suggestions for Further Reading

A more detailed overview of both IVHS and AHS activities, especially those conducted prior to 1990, can be obtained from the following:


Two more recent documents, which were critical to the establishment of IVHS as it exists today, are:


A detailed rationale for AHS development is contained in:


References


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