IVHS Lessons from European Experience

Kan Chen
University of Michigan

IVHS Technical Report: 92-02

The University of Michigan IVHS
Intelligent Vehicle-Highway Systems
College of Engineering • (313) 764-4432
Professor Kan Chen, 4112 EECS, Ann Arbor, MI 48109-2122, and
University of Michigan Transportation Research Institute • (313) 936-1046
Robert D. Ervin, 2901 Baxter Road, Ann Arbor, MI 48109-2150

IVHS Lessons from European Experience

Kan Chen
University of Michigan

IVHS Technical Report: 92-02

IVHS LESSONS FROM EUROPEAN EXPERIENCE

Kan Chen
University of Michigan
Ann Arbor, MI 48109-2122

ABSTRACT

Although the earliest IVHS work in Europe was stimulated by pioneering research in the U.S., the establishment of the European PROMETHEUS and DRIVE programs gave a significant impetus to the the American IVHS movement in recent years. The precompetitive cooperation among private rivals, and the tripartite collaboration among the academia, the public and the private sectors in these two European programs have set a helpful pattern for the American IVHS initiative. In addition, useful lessons can be learned, especially regarding public/private interplay, from a number of specific European IVHS projects. Among these are smart cards for non-stop toll collection, radio data system (RDS) using FM subcarriers for traffic messages, privately owned TrafficMaster for driver information, private initiative in TravelPilot navigation, beacon-based Ali-Scout route guidance, cellular-based SOCRATES route guidance, advanced vehicle controls developed by automobile companies, and bundling IVHS with business/personal communications to increase marketability of both. Most of the currently available IVHS options, which provide only modest incremental improvements in congestion relief, active safety, and environmental protection, are basically common to both Europe and the U.S. In the long run, radical solutions that can produce substantial improvements must be implemented to satisfy user and societal needs. Among the radical solutions are automatic highways, buses and high-occupancy vehicles, congestion metering, double-deck expressways, and environmental regulations, all of which can be realized or facilitated by IVHS. Due to different conditions and traditions in the two continents, the radical solutions may be pursued quite differently in Europe and the United States. There appear to be plenty of opportunities for mutual learning in IVHS experience between the two continents in both the near-term and the long-term futures.

SECTION I CROSS STIMULATION BETWEEN EUROPE AND U.S.

Intelligent Vehicle-Highway Systems (IVHS), or Road Transport Informatics (RTI) in European terms, are based on the amalgamation of information technology with automotive and highway technologies to help relieve traffic congestion, improve safety, and reduce pollution and energy wastes. The genesis of IVHS began over two decades ago. With the dominant role played by motor vehicles in the total North American transportation system, the efficiency and safety of highway travel have been of continuous concern to the American society. Advanced vehicle-highway systems, ranging from electronic route guidance systems [Stephens *et al.*, 1968] to automated highways [Gardels, 1960] have been an area of research and development in the United States for decades. Before the substantial reduction of the Federal Government's role in civilian technology development during the early 1980s, U.S. research activity in advanced vehicle-highway systems in the Electronic Route Guidance Systems (ERGS) [Rosen *et al.*, 1970] had inspired corresponding work in the European Autofarer Leitung und Informationsystem (ALI) Program [Braegas, 1980], as well as the Japanese Comprehensive Automobile Traffic Control System (CACS) Program [Yumoto *et al.*, 1979]. While the U.S. activities were curtailed in the 1970s and most of the 1980s, the efforts to advance the application of information technology to vehicle/highway interactions in Europe and Japan accelerated, perhaps as a result of the more pressing needs of domestic transportation there, especially in the urban areas, as well as different government policies.

The most important European IVHS programs are PROMETHEUS [Glathe *et al.*, 1990] and DRIVE [DRIVE 1991]. The former was launched in 1986 by a dozen of European car companies, within the framework of EUREKA, a European Economic Community program designed to increase European industrial competitiveness. The 7-year $700 million PROMETHEUS Program has been led by Daimler-Benz which is perhaps the most vertically integrated European automaker which has acquired new subsidiaries with strong electronics capabilities. With only car companies represented on its Steering Committee, PROMETHEUS' precompetitive research has understandably focused on the vehicle side even though one of its seven components (called PRO-GEN) does include the highway infrastructure and socioeconomic aspects of IVHS. By contrast, the DRIVE Program, established in 1989 by a number of European governments, has emphasized the infrastructure side of IVHS. With a total funding of $130 million for its first phase (DRIVE I), split half-and-half by a rigid formula between public and private support, the Program has complemented PROMETHEUS and has taken on a number of tasks from PRO-GEN.

The announcements of PROMETHEUS and DRIVE programs in Europe, along with similar programs in Japan have jolted the U.S., leading to a revival of its activities in advanced vehicle-highway technology with the new name of IVHS. One can say that international competition, along with the push of technological advances and the pull of societal needs for congestion relief and improved safety, are the three most important converging forces behind the accelerated development of IVHS in the U.S.. To draw an analogy in the history of the U.S. space program, we could call the PROMETHEUS and DRIVE programs the "IVHS Sputniks" which helped galvanize U.S. actions.

The revived activities in the U.S. did not simply go back to where it had been left in the 1970s. Under the coordination of the *ad hoc* consortium called Mobility 2000, the renewed efforts have taken on characteristics which differ, both technically and institutionally, from that seen through the 1960s and 1970s. To the extent that the core group of Mobility 2000 studied the contents and organizations of PROMETHEUS and DRIVE, the European experience has helped set the pattern of the U.S. IVHS movement. In terms of technical contents, the American IVHS in recent years, as compared to the pioneering work twenty years ago, has put a much greater emphasis on the nearer-term use of information systems for driver-advisory functions than on the longer-term use of control technologies for automation purposes. Institutionally, there is also a wider range of organizations working in concert from both the private and public sectors than in the past to link the vehicles and highways through information technology, as implied by the program title, Intelligent Vehicle-Highway Systems (IVHS). Thus, instead of GM working as the sole contractor funded by the Federal Highway Administration as in the early days, we saw the Big Three American automakers working together in a precompetitive program, much like the dozen of European car companies working together through PROMETHEUS. Furthermore, the American electronics industry has also been deeply involved, along with public transportation agencies and universities. This multi-sector involvement is very similar to, though not as a rigid requirement as in, the DRIVE Program. The relative enthusiasm in IVHS on the part of General Motors, which had become more vertically integrated with high-tech electronics through the acquisition of Hughes and Electronic Data Systems, is quite parallel to Daimler-Benz's leadership in PROMETHEUS.

While the U.S. IVHS community has certainly picked the desirable characteristics from the European programs, it has also learned what not to imitate from the Europeans. For example, the separate coexistence of privately supported PROMETHEUS and the publicly supported DRIVE has at least increased coordination costs, and may have prevented a more intimate cooperation between the public and private sectors. Some of the important IVHS projects, such as the TrafficMaster driver information system and the Ali-Scout route guidance project, have been outside of both PROMETHEUS and DRIVE. By contrast, IVHS AMERICA, the single coordinating organization for IVHS activities in the U.S. to succeed Mobility 2000, was incorporated in late 1990 jointly by the Highway Users Federation for Safety and Mobility (HUFSAM) representing the private sector and the American Association of State Highway and Transportation Officials (AASHTO) representing the public sector, thus facilitating public-private sector cooperation in the U.S. There are also signs that the European programs have benefited from the U.S. IVHS programs organizationally. Given the U.S. program emphasis on IVHS field tests, it is interesting to note the 1990 reorganization of PROMETHEUS to integrate their multifarious elements (PRO-GEN, etc.) into "Common European Demonstrations" (CED), and the program focus on field tests in DRIVE II, which is the 3-year extension of DRIVE beyond 1992. The parallel development and cross stimulation of IVHS programs in the U.S. and Europe may be summarized by the chronology given in Table 1 below.

Table 1. European and American IVHS Programs

Geographic Regions	Early Programs	Year	Recent Programs	Year
North America (IVHS)	ERGS	1968	Mobility 2000 IVHS AMERICA	1987 1990
Europe (RTI)	ALI	1979	PROMETHEUS DRIVE I DRIVE II	1986 1989 1992

SECTION II PUBLIC/PRIVATE INTERPLAY IN SPECIFIC PROJECTS

Europe got ahead of the U.S. in IVHS development largely due to the hiatus in U.S. activities in this area during the 1970s and early 1980s. However, as indicated in the last section, the U.S. has been able to capitalize on its latecomer's advantage by learning what to do and what not to do on the basis of European experience. Moreover, due to the political diversity in Europe, a plethora of IVHS technologies and subsystems have been developed in various European countries with an interesting mix of public/private interplay, which provides another dimension of learning opportunities for the U.S. IVHS community. By and large, the European traffic authorities have traditionally exerted more power over the traveling public than their U.S. counterparts. For example, route guidance functions are often considered more in the light of traffic control, rather than from the standpoint of providing more information for travelers or drivers to make individual choices. However, there is a relatively wide latitude in this respect among the various European countries and their traffic management authorities. In addition, there is much more emphasis on privatization in some countries, such as the United Kingdom, versus other countries, such as France, even though they are all members of the market-economy OECD bloc of nations. Therefore, the U.S. can have much to learn from a spectrum of specific European IVHS projects, as will be discussed in this section.

1) ELECTRONIC TOLL COLLECTION

Electronic toll collection is an IVHS technology ready for deployment. The first-generation technology is centered around automatic vehicle identification (AVI) using electronic transponders. It may be considered the first wave of IVHS technology entering the mass market. At a relatively low cost (around 10% of the normal toll) and with high reliability (over 99% accurate), both the efficiency of road travellers and the efficiency of infrastructure toll collectors can be increased substantially. In addition, the non-equipped motorists also benefit from the shortening of the queues as the equipped vehicles zip through the toll booths without stopping. It appears to be a "win-win" arrangement for all major stakeholders.

On the other hand, the existence of several AVI technologies and automatic toll collection system designs gives rise to the issue of standardization, which is getting hotter as electronic toll collection spreads and as the various vendors vie for market share and market dominance. As in the case of other information technologies such as computers, there are two general approaches to standardization. One approach is in the marketplace, where the market leader sets the *de facto* standards and compel other suppliers to go along with an obvious disadvantage since the inner working of the standards is often opaque and proprietary. The other approach is in the conference room, where committees consisting of major industrial suppliers, often with the involvement of major users, public authorities and academicians, try to agree upon a minimum set of standards that will allow multiple vendors to coexist with mutually compatible hardware and software products. The market leader approach may be considered as an unfair practice to the dominated suppliers, but is realistic and works as fast as market penetration. The committee approach has usually come up with more open systems that favor the users, but involves a slow process that often appears wasteful and can be overtaken by the market leader approach. Both approaches are being used for electronic toll collection in North America and in Europe. However, the market leader approach appears more dominant in North America while the committee approach has been pursued at least with an earlier start in Europe. The DRIVE project known as VITA

(Vehicle Identification and Transaction Aid) seeks to define and evaluate systems for data exchange between motorway control centers and users, and is run by the motorway toll operators' associations of France, Italy and Spain, which collect tolls on about a third of Europe's motorway network. Another effort is through the European User Committee on Automatic Debiting (EUC). This committee consists of representatives from all European governments actively interested in automatic debiting, together with other major toll facility operators, and provides a forum for the discussion of progress towards a standardized European system for automatic debiting [Catling, 1990].

Perhaps one important reason why standardization for electronic toll collection has been, and perhaps should be, slowed down is the yet-to-be-resolved issue of privacy. The functioning of the toll collection systems that have been described assume that the equipped users have no objection to their identity being revealed to the system, thus allowing their whereabouts at what time knowable to those having access to the system. One way to reduce this concern is to use a technology similar to the prepaid phone cards, whose users' identity is not knowable to the telephone system. Popularly known as smart cards, their use for non-stop toll collection has been widely tested in the European Autostrade project, using a card with the size and thickness of a credit card developed by AT&T. This concept has also picked up support from those who would like to see a multiple application transport card [UK Department of Transport, 1990] that can be used for public transport, parking, and transport-related expenses such as gasoline purchase. Although this toll collection technology has not been adopted in the U.S., the approach has been suggested for providing transport services to welfare recipients who need dial-a-ride or public transit vouchers [Fisher, 1990].

While phone cards have been used in Europe for a number of years with success, the adaptation of the concept to "smart travel card" for automatic toll debiting and other related applications is technically not quite straightforward. Firstly, for electronic toll collection, unlike the pay phone case, there can be no contact between the smart travel card and the interrogating system. Secondly, the required 2-way communication will be a dialog, and not a 2-way monolog as in AVI, since the amount to be debited on the smart travel card will depend on the location and the time of the interrogator signal — and the complicated dialog needs to be completed within a short time if the vehicle is not required to slow down excessively. At present, the cost of smart card system is several times as high as AVI systems. Thus, those working toward a standard for electronic toll collection will have to balance all these factors of technology feasibility, costs, reliability, the preservation of multi-vendor competition, and the protection of privacy. These factors will be further complicated by the concern and interest in promoting, and facilitating, multimodal transport for various interest groups, including the welfare recipients and the goods moving industry.

2) RADIO DATA SYSTEMS (RDS)

Recently radio data systems (RDS) have become available in Europe to provide low-rate (about 1,000 bits per second) coded information to properly designed receivers, utilizing the sidebands of the frequency spectrum assigned to the broadcaster. Within the European industrial circle active in IVHS, Bosch (with its subsidiary Blaupunkt) has taken a strong leadership role in developing this technology as a continuum of its car radio development trend over the last fifty years. Originally designed to provide program identification and alternative frequencies for better reception of the desired radio program or program type, RDS is now being promoted to provide real-time traffic information through a traffic message channel (TMC), which may provide effectively 74 bits per second of traffic information codes to specially equipped radios [Thomas, 1990].

In general, North America is behind Europe in RDS implementation. Over half of European FM radio stations already broadcast, or will soon begin to broadcast, RDS signals. In contrast, as of January 1991, there were only 12 RDS stations in the U.S., of which 5 were put in Detroit by Delco Electronics in January 1991 [LeBow, 1991]. However, RDS is moving ahead in the U.S. vigorously, and RDS for traffic messages will be field tested in Detroit as a part the IVHS activities under the Michigan Department of Transportation [Gilbert, *et al.*, 1991].

There is an active European project working on the standards of RDS/TMC [Davies and Eng, 1989]. The output may be in the form of textual and/or synthetic voice displays — textual display may be more distractive but would not interfere with, or require interruption of, other audio programs. For owners of high-priced (around $300) car radios, the added cost of acquiring the RDS feature is quite marginal. The cost to the stations to add RDS features would be below ten thousand dollars, and the incentive for them to make the investment could be significant due to competition. To go to TMC, however, there would be additional infrastructure costs for traffic data collection and collation, and for message management systems.

While the European RDS standards have practically been set, the Japanese have not been satisfied with these standards and have been developing and testing new approaches, using more sophisticated digital modulation schemes and error correcting codes. One of their FM multiplex broadcasting approaches has been tested for mobile reception, and promises to provide much higher bit rates than the current European approach — 10 to 12kbps versus 1kbps [Yamada, 1991]. These high bit rates can be used to transmit a great deal more traffic information and even projected link times without the need for additional frequency spectrum. Given the still fluid situation regarding RDS in North America, it behooves the traffic management authorities to work with telecommunication policy makers in the U.S. to review all the competing schemes of RDS before the final standards are set, in spite of the pressure from interested parties to adopt the European standard without delay. This is an important policy issue since RDS, or a dedicated public radio channel on a standard frequency, or a combination of both, could become the most economical information downlink from traffic centers to both the vehicles and the roadside equipment for IVHS functions that would benefit a large number of low-cost IVHS users. For those IVHS functions that require only one-way communications, this may be the only needed channel that requires no, or only very limited, frequency allocation.

3) TRAFFICMASTER

A privately owned and operated system for providing real-time traffic information is the TrafficMaster, which has been in operation for the London area since mid-1990 [Martell, 1990]. Average vehicle speed in the fast lane of the motorways around London (M25 and a limited range of other motorways connecting to it) is automatically measured every 2 miles and reported every 3 minutes by infrared sensors. When the speed drops below the threshold of 25 miles per hour, the average speed and location of the congested segment are transmitted over a paging service frequency to owners of the TrafficMaster's simple map display unit, which may be carried by the owners as well as put on top of their vehicle dashboards. For more relevant information, the user may choose to focus on only one of the four quadrants of the M25 ring-shaped motorway. Paging service is also available as an option. The price of TrafficMaster is about $500 for the portable unit, plus about $32 per month service charge, with another $30 per month for the paging service option. By late 1990, there were about 300 customers (35-40% of whom chose the additional paging option), and the number was expected to reach 5,000 by September 1991. Since the breakeven point is only about half that number, TrafficMaster's financial viability appears very promising.

The possibility of having the first privately owned and economically viable traffic information system developed in UK had a lot to do with the privatization policy of the Conservative Party there. The installation of privately owned infrared detectors on publicly owned transportation infrastructures was enabled by the British Road Traffic (Driver Licensing and Information Systems) Act, which was passed in 1989 originally designed for the Autoguide route guidance system (to be discussed later). So far, TrafficMaster is the only system that has benefited from that Act. From the perspective of the traffic management authorities, there are several policy issues related to traffic information. The first has to do with the fusion and authentication of traffic information. The second is the concern about potential risk of near-term success of a specific traffic information provider pre-empting certain forms of dynamic route guidance which must use real-time traffic information. Then, there are concerns about safety and standards of the way the traffic information is displayed and conveyed to the driver, especially while the car is moving.

Historically the responsibility for collecting traffic information lies solely with the traffic operation authorities. Sources of data range from loop detectors, remotely controlled television cameras, police reports from highway patrols and helicopters, and emergency calls from citizens. In the future, traffic information may also come from car probes, cellular call-ins, automatic vehicle location signals, and proximity beacons. Each of these sources has its peculiar problems. The policy question is how to combine and fuse the new and conventional sources to provide the highest quality traffic information at the lowest cost. There is a need to consider not only technical issues, but also institutional ones, such as the fusion of information from multiple jurisdictional units (local authorities, weather bureau, etc.) and trading information with new private sources with or without financial compensation.

As in any private service-providing activities, there is a risk of "cream-skimming" so that the easiest and most profitable services are provided while the more difficult but perhaps much needed services are neglected. For example, TrafficMaster has focused on M25 not only because it is the most travelled motorway, but also because the average speed can be measured most conveniently and the operating company needs to deal with only one public authority; *viz.*, the UK Department of Transport. It is encouraging to learn that TrafficMaster has recently considered expanding to the arterials (the A roads) in the London area [*Inside IVHS*, 1991a]. Questions may still be raised, however, as to whether the future extension of TrafficMaster may never measure the traffic in other routes (the B roads as well as the A roads outside of London) which go through multiple jurisdictions and which may provide the best alternative routes for some of the drivers. Also, would the success and dominance of TrafficMaster prevent other service providers to market the more sophisticated systems?

IVHS lessons may be learned from TrafficMaster experience by both the public and the private sectors in the U.S. On the public side, the effectiveness of the British Road Traffic Act, the way the British authorities have tested TrafficMaster before issuing a license for its operation, and the negotiation to guard against cream-skimming should all be valuable. From the private side, the important questions that TrafficMaster can help answer are not just limited to the profitability of its operation and marketing approaches, but should also include the fundamental issues of the amount of details (i.e., the degree of resolution) which most paying drivers really need for traffic information, the economic advantage of piggy-backing low-data-rate traffic information onto existing and future business communication infrastructures, and the business attraction of bundling traffic and business/personal information services.

4) TRAVELPILOT NAVIGATION

A navigator needs to know his present location and a map to show how he can go from the present location to his destination. Under normal traffic conditions, he does not need real-time traffic information from the road infrastructure. The three basic systems for automatic vehicle location are dead reckoning, LORAN (a long-range maritime navigation system which has been applied to vehicle location on land), and GPS (global positioning system using satellites). Each can be augmented by map matching and all can be used to complement one another. Both LORAN and GPS are based on government-operated infrastructures which cost the users nothing except the in-vehicle units that receive and process timed signals from the navigation infrastructures. Digital maps can be stored on electronic media in the vehicle. Therefore navigation systems comprising a digital map database coupled to automatic vehicle locator can be entirely autonomous (i.e., independent of information from the road side) and are naturally suited for private production and consumption.

In Europe, Philips' CARIN system and Bosch's TravelPilot system are both capable of navigation through a combination of dead reckoning and map matching with the digital map information stored in a magnetic tape cassette or a compact disk. A major difference between the two systems is that CARIN guides the driver via a display of directional arrows while TravelPilot accomplishes the same purpose via a display of an electronic map which shows the current location of the vehicle and the destination. Most drivers find it less distractive to follow the directional arrows while driving but prefer to have the map information for an overview of the total route while the car is standing still. To cover a wide area of possible travel (e.g., Western Europe or the entire U.S.), the most practical way to store the vast amount of map information is through the use a compact disk, which is rather expensive. For example, TravelPilot with compact disk, storing digital maps developed by ETAK in the U.S., began to sell in late 1990 for DM6,000 in Europe and was introduced to the U.S. market half a year later for $3,500. This compares reasonably with the Japanese navigation systems selling in their domestic market for $2,500-3,500 per system. An estimate of 10,000 units have been sold in Europe, plus several thousand units converted from ETAK Navigators to Bosch's TravelPilot. This number is rather small compared to about 200,000 navigation systems already on the Japanese market. The U.S. price for TravelPilot has recently dropped to $2,500 per unit. Since the most costly component in the system is the compact disk drive, the cost of which has been dropping rapidly, an optimistic forecast has projected a price of only $300-400 for the navigation system within 3 to 4 years.

The major lesson learned from the European (as well as Japanese) navigation systems experience seems to be that navigation is rather expensive and can be sold initially mainly with luxury automobiles. In a two-tier IVHS system architecture [Ristenbatt, 1991], a fully functional navigation system probably belongs to the more expensive tier. From the perspective of social needs, the worst traffic congestion occurs during the commuting hours, during which most drivers know their regular and alternative routes rather well and do not have critical needs for navigation. Those who get lost or need directions frequently are likely to be salesmen and tourists in unfamiliar areas.

5) DYNAMIC ROUTE GUIDANCE - ALI-SCOUT AND SOCRATES

Since one of the major frustrations in driving is to get caught in unexpected traffic congestion, dynamic route guidance which takes into account real-time traffic information in route guidance is highly desirable. Dynamic route guidance is by no means a new concept. Over the past 20 years, there have been three discernible generations of such systems [TARDIS, 1990]. The first-generation systems include ERGS in the U.S., CACS in Japan, and ALI in Europe (as shown previously in Table I), all using low-rate inductive loops for communication. For example, CACS transmitted 144 bits of information at each intersection at a rate of 4.8 kilobits per second [Kawashima, 1991]. The second generation is typified by Ali-Scout [von Tomkewitsch, 1991], whose development began in the early 1980s, using beacons for short-distance communication at major intersections. At each intersection, the beacon transmits 8 kilobytes of information at a rate of 125 kilobits per second. (The next generation of Ali-Scout, known as Euro-Scout to be ready by 1992, will transmit 30 KB at 500 kbps. The third-generation systems include CARMINAT [Renault, 1990] (one-way wide-area communication into the vehicle via RDS), SOCRATES [Catling, 1990], and ADVANCE [Boyce *et al.*, 1991] (two-way communication via a digital cellular radio link), which are systems under development in the late 1980s and early 1990s. In these systems, information will be transmitted <u>continuously</u> as well as at a relatively high rate — around 9.6 kbps in SOCRATES. As we progressed from the first to the third generation, the required number of equipped intersections on the infrastructure decreased while the typical cost of in-vehicle unit (IVU) increased (from $80 for the first-generation to $250 for the second-generation, to an estimated $800, hopefully, for the third-generation IVUs at a mass production level). This IVU cost increase is due to more and more intelligence put on the vehicle for both data storage (such as for map database) and data processing (such as for optimum route calculation).

It is interesting to note that the first two generations of dynamic route guidance systems are infrastructure-based while the third generation is primarily vehicle-based. The former searches for the best routes with equipment on the infrastructure (such as in the case of Ali-Scout), while the latter does that with equipment on board of the vehicle (such as in the case of CARMINAT). It is important to discuss the policy implications of these two types of systems. First is the financial implication which may affect the system viability. Infrastructure-based systems naturally put major capital investment requirements on the infrastructure side. This may be a slow process, not only because of the magnitude of the investment but also because of the need for multijurisdictional cooperation in both system installation and operation. Those drivers who are early investors in the IVUs for such systems may be dissatisfied with their limited usability for a long time. The whole system may then become unacceptable to the users, and the infrastructure costs may be too high for a government or operating company to bear. On the other hand, the vehicle-based systems require rather expensive IVUs and the early users are likely to be the more affluent drivers and the commercial vehicles. If fully functional navigation systems are considered outside the scope of the baseline or first-tier IVHS, as discussed previously, then almost by definition, those route guidance systems which build on top of navigation will be only for the high-end of the IVHS market. As will be explained in more detail, there would still be a substantial amount of capital and operating costs on the infrastructure side for the vehicle-based dynamic route guidance systems. If these high costs are borne by public agencies, questions may be raised as to their justification and fairness to the less affluent non-users.

Secondly, there is a question of who is in control. The infrastructure-based systems would be more amenable to the presumption that traffic should be controlled by a central authority (public or a private surrogate) who will guide the traffic to reach a "system optimum" according to a system-wide objective (such as minimum total vehicle-hours of delays) subject to centrally determined constraints (such as no traffic diversion to schools and residential areas). On the other hand, the vehicle-based systems would be more amenable to the presumption that the driver will determine his own objective function and will search for "user optimum" (such as a weighted average between travel time and tolls paid) subject to privately determined constraints (such as avoiding subjectively perceived high-crime areas).

Of course, each of the two system types may be adapted to a mixture of system and user optima. For example, the infrastructure-based Ali-Scout does provide optimal route guidance for individual drivers as long as their objective functions fall within a small set of prototypes and the centrally determined constraints are used. However, it would be impractical to modify the constraints to suit each individual driver. Furthermore, if a vehicle fails to follow the centrally provided guidance, the vehicle may get lost until it picks up direction from another beacon since there is no map information on board. Putting digital map data on board would increase the IVU cost and defeat an original attractiveness of the infrastructure-based system. On the other hand, the vehicle-based CARMINAT and SOCRATES would need the up-to-date link time information from the infrastructure. Thus, it is possible for the central operator (public or private) to inject system-wide objectives and route constraints by artificially increasing some of the link times. However, this practice may lose the driver's confidence in the link time information and render the whole system unacceptable to the user. The appropriate balance between system-wide traffic objectives and the degree of user acceptance would be a complicated policy decision.

Regardless of which approach to take, the projection of link time (up to about 90 minutes into the future) will be needed for dynamic route optimization and this projection must be done centrally. This implies new tasks and/or improved technologies to be used by the traffic management authorities. For example, credible and reliable projection of link times will need the speedy and accurate estimation of the duration of an incident after it is detected and verified. Such estimations are being done only haphazardly at present. Some form of simple models based on artificial intelligence is needed to predict incident duration as a function of the link location, time of the day, the number of lanes blocked, weather condition, whether bodily injuries are involved, *etc.* At present, the projection of link times in the Ali-Scout system is done by a sort of moving average of current and historical data with modification through link models, which seem to ignore the interactions between links in a network. A more sophisticated real-time simulation model may be needed to provide more accurate link time projections [Kaufman *et al.*, 1991]. However, the reduction of such an approach to practice is yet to be realized, and its realization would require continuing research [Chen and Underwood, 1991]. It is reported that anticipatory route guidance was attempted but abandoned in TravTek while such an approach is still the goal of Advance. To some extent, the projected link times can also be partially controlled in urban areas where there are traffic lights, whose timing may be modified as a function of time and as a function of the traffic flow. How such timing changes should be coordinated with dynamic route guidance is a research and policy question addressed by one of the DRIVE projects [CARGOES, 1989].

Another important task in this area for the traffic management authorities is to provide updated information of road changes (construction, reconfiguration, new roads and roundabouts, new one-way and/or turning lane restrictions, etc.). Such road changes in Berlin, for example, are as frequent as once a day. Autonomous systems that provide navigation and/or static route guidance would need this updated information. As they get such information from the infrastructure, they may as well get the dynamic route guidance information from the infrastructure if that is available. Thus there is a strong motivation to explore dual mode systems that combine the autonomous and infrastructure-based systems (Haessermann, 1990). One example is the combination of TravelPilot with Ali-Scout; another is the combination of CARIN with GSM (Groupe Speciale Mobile: a form of digital cellular radio scheduled to be launched in 1991 in Europe), which can provide the infrastructure-based route choice as well as road changes.

With the coexistence of multiple basic approaches to dynamic route guidance, standardization is clearly a very important policy issue. It is interesting to note that the Japanese have abandoned the infrastructure-based approach as a result of the evaluation survey among drivers involved in the CACS program during the 1970s . The North Americans, notably through TravTek and ADVANCE projects, have been working during the last few years exclusively on vehicle-based systems for dynamic route guidance. The substantive progress being made in SOCRATES may lead to a vehicle-based system in Europe that would be more congruent with the trends in Japan and North America. On the other hand, the low-cost IVU is clearly an attractive feature of infrastructure-based route guidance systems. If a sufficient number of cities in Europe and North America are convinced in the near future to make the substantial investment on the infrastructure for them, such systems as Ali-Scout may pre-empt the market for dynamic route guidance.

From the standpoint of financing, infrastructure-based route guidance systems obviously need more investment on the highway side and therefore are expected to rely more on public financing; whereas vehicle-based route guidance systems need more investment on the vehicle side and would thus rely more on private financing. This may explain why the Autoguide system [UK Department of Transport, 1989], originally designed to imitate the infrastructure-based Ali-Scout, has reportedly switched to a vehicle-based approach [*The Intelligent Highway*, 1991]. The fundamental reason for the switch is probably the British government's insistence on purely private financing of all IVHS, including Autoguide as well as TrafficMaster. On the other hand, with the shortage of public funds or reluctance of public agencies to make huge investment on the beacon infrastructure, Siemens has taken a serious initiative to form a consortium of private financing sources to deploy Euro-Scout (the second generation of Ali-Scout) in all large German cities [*Inside IVHS*, 1991b].

One should understand that vehicle-based route guidance would still need infrastructure investment in order to collect and communicate real-time traffic data to the equipped vehicles. However, the collection of traffic data may be private (as in the case of TrafficMaster); and the communication of traffic information may also be private or piggy-backed on existing communication infrastructures (as in the case of TrafficMaster, digital cellular GSM, or even RDS), which can be much less expensive than a dedicated communication network as in the case of Ali-Scout. Promoters of vehicle-based route guidance (TravTek and ADVANCE in the U.S. as well as SOCRATES in Europe) are probably betting on the rapid cost decrease of on-board equipment, which can be shared among many IVHS functions — yellow page, tourist information, business/personal communication, as well as navigation and route guidance, at least for the high-end of IVHS. Whether one or the other approach will emerge as a clear winner, or whether they will coexist in the future, is not clear. This may be a case where the free market should be allowed to make the decision; early standardization may be unwise.

6) ADVANCED VEHICLE CONTROL

Advanced vehicle control systems, as a means to achieve active safety as well as driver comfort, are clearly on the research agenda of all major car companies around the world. However, the European car companies seem to be much bolder than their American counterparts in experimenting these systems on urban streets and in serious consideration of introducing these systems to the market. In particular, they have little hesitancy to demonstrate in heavy traffic environment what is generally known as intelligent cruise control, which functions like an ordinary cruise control until the vehicle needs to slow down automatically in order to keep a safe distance from another vehicle in front. There are quite a number of such systems under development and testing. Some are more cautious, like one being developed by Philips, which would only control the throttle automatically and leave braking entirely to the driver. Others are bolder, like one being developed by Daimler-Benz, which controls the brakes as well as the throttle. The boldest system, demonstrated by BMW, includes even lateral control to avoid obstacles that can be overriden by the driver when he manually exerts a counteracting torque on the steering wheel.

The key technical challenge in intelligent cruise control is obstacle detection, which may not be perfectly reliable — giving too many false alarms as well as occasional missed alarms. Various media have been tried over the past decades. The current status is summarized well by an expert as follows [Grimes, 1989]: "At highway speeds and sensing ranges of 80 to 100 meters, the relatively low speed of sound and possible beam displacement by cross winds make sonar data too stale and too unreliable. Lidar can be reliably used to detect dark or dirty, uncooperative targets to a maximum range of only 40 to 50 meters, and a minimum range of 80 meters is needed for adaptive cruise control and safety warning. Neither can lidar be modulated to obtain accurate and independent readings of range and closing speed. This leaves radar. Although the difference between roadway clutter and desired targets cannot be determined well enough in the radar front end, considerable progress has been made using processing algorithms... The remaining high-cost radar problem is the antenna. An antenna is needed that can be designed into the front of small vehicles, is low in cost, and is capable of providing target angle, range, and closing speed." Current research and development seems to be focusing on cutting the radar cost. For example, Philips was able to reduce the cost of one complicated radar part from $2,000 to less than $2 through an ingenious manufacturing scheme.

However, substantial cost reduction and increase of reliability might not be sufficient to put intelligent cruise control on the market. From the car companies' viewpoint, the issue of legal liability is very important. A recent American study on this issue [Syverud, 1990] warns that legal liability can indeed threaten any commercial consideration of marketing "control dilution" systems — and intelligent cruise control is clearly control-diluting. The suggestion of installing "black boxes" in all vehicle to record vehicle control and movements during an accident, as in the case of the airlines, would not answer the legal question on the limit of liability — the airline liability limit issue had been resolved by the Warsaw agreement long before the black boxes were installed. Some government action is probably necessary to clear the cloud over the legal liability issue. For example, a legislative action may be taken to limit the liability of certain forms of advanced vehicle control. Another example is the total absolution of any legal liability on the part of the car companies in case injury or death results from someone getting tied down by the seat belt in a car accident after the use of standardized seat belts is mandated by law. Public authorities have to weigh the social risks versus benefits of intelligent cruise control and other advanced vehicle control technologies in order to determine the appropriate legislative actions affecting legal liability.

7) BUNDLING IVHS WITH BUSINESS/PERSONAL COMMUNICATIONS

The provision of business and personal communication to drivers on the move used to be considered a luxury, at least for noncommercial vehicles. However, with the decreasing cost of information technology and the increasing demand for such services in our information society, provision for business and personal information is deemed highly desirable if not essential for long-distance commuters, tourists, high-level executives, as well as drivers of commercial vehicles — trucks, taxis, ambulances, police cars, *etc.*, some of which are not strictly "commercial".

Personal information can now be conveyed to the motorist (driver and passenger) by car phone, facsimile, or paging — some luxurious cars, especially in Japan, even have commercial television for the passengers, or for the driver while the car is standing still. Clearly some of these communication channels may be used for traffic information and route guidance as well. As mentioned previously, TrafficMaster provides real-time traffic information via a paging service frequency. The cellular car phone system may be used to provide link time information for on-board route optimization, especially after the cellular system becomes digital as in the future GSM in Europe. Recently a new American company has demonstrated the feasibility of using activated car phones to automatically provide approximate location of the vehicle, thus usable for traffic surveillance as well as fleet management and other IVHS functions [KSI, 1991]. With the expected advent of personal communication network (PCN) which may one day replace both the home phone and the car phone, its continuing development will sooner or later converge with IVHS applications.

Tourist and other yellow-page information is expected to be provided to drivers on the move as a feature of IVHS. For example, TravTek features the provision of tourist information around Disney World. The automobile clubs (both the AA in Europe and AAA in the United States) have libraries with rich tourist information that can be made readily available. There are strong commercial interests in making yellow page available in digital form to facilitate information search and to make two-way communication for yellow-page transactions such as hotel reservation practical. This growing business, and advertising interests, can be bundled with IVHS functions to make the total package economically attractive. In other words, financially the bundling of personal and traffic information may sway the purchasing decision for a traffic-oriented service which may not be marketable in isolation. As indicated previously, 35-40% of the subscribers of TrafficMaster also opted for the paging service. Technically the provision for large volume of yellow page information may preclude or favor certain technology. For example, it has been reported that although infrared (IR) beacons have convincing advantages of low cost and low interference (due to the incoherence of IR waves) [Von Tomkowitch, 1990], the low data rate capability of the first generation Ali-Scout for handling yellow page information has hampered its acceptance by many car companies, at least in the near future.

From a public policy perspective, the regulation and frequency allocation for business and personal communication seems to be entirely in the domain of telecommunication authorities. However, to the extent that the technology and communication media for IVHS, and its financing viability, are of central concern to traffic management authorities, the latter cannot ignore the policy implications of the bundled service. There are also driving safety issues in the use of some of business and personal information systems that would require evaluation and regulation activities of the traffic management authorities.

SECTION III A NORMATIVE FUTURE SCENARIO

Given the cross stimulation between the European and American IVHS activities in the past decades, and the recent European leadership in specific IVHS technologies and projects, what can the U.S. learn from the European experience that can help insure societal benefit from IVHS in the U.S.? This author is of the opinion that the answer to this question may be quite different depending on the future time horizon.

Due to the hiatus in U.S. IVHS activities in the 1970s and early 1980s, the U.S. is playing catch-up in the near future. An incremental approach in IVHS has been recognized by both the public and private sectors in the U.S. for practical implementation of IVHS — the private sector needs an early economic return as an incentive for their IVHS investment, and the public sector needs an early winner to demonstrate IVHS feasibility and potential benefit to the taxpayers to assure their voting support in the next election or referendum. Therefore many of the specific IVHS projects that have been successfully launched in Europe, as described in the last section, have found or will soon find their ways to the U.S. The public policy concerns and actions considered by the European authorities regarding the IVHS functions incorporated by these specific projects can thus provide useful clues to the above-stated question. However, the incremental solutions in the near future are not expected to produce revolutionary changes that the traveling public demands. Therefore, in the long-term future, after the U.S. has caught up with the European (and the Japanese) in IVHS activities, each nation bloc may seek radical solutions to the tremendous traffic congestion problems in a way that is most suitable to its venue. The nature of the regional problems, the urban development patterns, and the social norms and traditions in the three country blocs may be such that their radical solutions to urban traffic congestion, with or without IVHS, may be quite different in the long run.

The public policy concerns regarding the IVHS functions and the specific ways they are provided by the IVHS technologies in Europe were discussed by the author and the European policy analysts, especially those in the British Department of Transport, during the author's European visit in late 1990 [Chen, 1992]. Many of these concerns were discussed in the last section. The following matrix summarizes and compares their relative impacts in Europe versus their impacts in the U.S., based on the author's own opinion.

As shown in the matrix, differences (indicated by boldfaced symbols) between policy impacts of IVHS activities in Europe and in the U.S. are relatively few and minor, among the IVHS functions and projects discussed in Section II. The differences are mainly in the areas of privacy, which is more of an issue in Europe, and legal liability, which is more of an issue in the U.S. The former explains less testing of smart cards for electronic toll collection in the U.S., and the latter explains more testing of active safety technologies in Europe. Other policy issues are equally strong or equally mild in both regions. This suggests that the U.S. can benefit from the public policy debates and actions regarding IVHS in Europe in the near term.

RELATIVE POLICY IMPACTS OF IVHS

X - Europe Y **- U.S.**

Policy Impacts	Electronic Toll	Route Guidance	Active Safety	Business Bundling
Privacy	**XX** **Y**	X Y		
Standards	XX YY	XX YY	X Y	X Y
Financing	X Y	XX YY		X Y
Multijurisdiction	X Y	XX YY		
Safety		X Y	XX YY	X Y
Legal Liability			**X** **YY**	

(Double X or double Y indicates major impacts.)

Although the many European IVHS projects described in Section II, which will soon be introduced to or emulated by the U.S., have both technological challenges and tangible benefits, they are expected to provide only incremental relief to urban traffic congestion. In Europe, the social benefits of IVHS as a means for relieving traffic congestion and increasing driving safety have been assessed, not so much in terms of helping the equipped vehicles to reduce their travel times, but in terms of assessing the total system traffic and safety impacts from the perspective of traffic management authorities. These evaluation projects have been launched in a number of countries including the UK [*e.g.*, Stevens and Bartlam, 1990]. Preliminary assessment of dynamic route guidance has indicated that the typical reduction of vehicle-hours of delays would be in the range of 7 to 15% [JMP, 1987]. Recently more detailed evaluation using computer models has indicated some interesting but problematical results. For example, the user benefits have been shown to decrease, and may even become negative, under certain circumstances as the percentage of cars equipped with Ali-Scout system increases beyond around 15%. This was based on the assumption that drivers of equipped cars would follow the routes along the main roads determined by the traffic center while the drivers of unequipped cars who know the local geography would "rat race" through the small urban streets.

While one can debate the issues regarding the degree and the means of control that should be exercised by the traffic management authority to discourage rat race and to make dynamic route guidance attractive to those who have invested in the system, and regarding the tradeoff between efficiency and safety since safety may be reduced as drivers are diverted from motorways to urban streets, the most important issue stemming from the preliminary assessment of IVHS is whether the fractional reduction of traffic delays (even up to 50%) is worth the enormous social investment in IVHS. Even if the benefit-to-cost ratio can justify the investment, the traveling public is not likely to be satisfied in the long run unless improvements in congestion relief, safety, and environmental quality can ultimately exceed 100% or several hundred percent. In other words, the incremental IVHS solutions that dominate the current field tests around the world may be merely stop-gap measures that can only buy time for the radical solutions to be explored for the long term future.

In this author's opinion, there are five candidates for radical solutions that can have really substantial improvements on one or several of the IVHS goals of congestion relief, safety, and environmental protection. For the sake of easy memory, these may be called the ABCDE of radical solutions as follows:

- A Automatic highways
- B Bus, HOV, and multimodal travel
- C Congestion metering or road pricing
- D Double-deck expressway construction
- E Environmental regulation

Although some of these solutions may not require IVHS, it is possible for IVHS to help implement most if not all of them. The important question at hand, however, is whether these solutions will have equal appeal to European and American societies, and to what extent the U.S. can learn from Europe now and in the future. The rest of this section will try to answer this question for all the five candidate solutions, although not in the alphabetical order given above.

With automatic highways (A), the design goal is to reduce the spacing between vehicles traveling at expressway speeds from the order of 100 feet down to a few feet with intelligent longitudinal control, thus increasing the vehicle carrying capacity per highway lane by 300-400%. In addition, the lane width can also be narrower with intelligent lateral control, making it possible to increase the vehicle carrying capacity per urban highway unit area beyond 500%. The intermediate step toward automatic highways is to gather individual vehicles in platoons, better known as electronic convoys in Europe. This approach is a main feature of the California PATH Program, and has been successfully demonstrated by Volkswagon. However, the concerns about user acceptance, system reliability, and legal liability have caused the abrupt halt of the Volkswagon project, and the discontinuity of the project under the aegis of PROMETHEUS has been confirmed by a member of its Steering Committee [de Charentenay, 1991]. On the other hand, the significant benefits promised by the approach leave little doubt that some research will continue on this approach in many parts of the world. It is not clear which part of the world will be the first to introduce this approach to real traffic environment. Among the different parts of the world, there would be little basic difference in user acceptance and system reliability. The major difference is probably legal liability. Although an international comparison of product liability would be complicated, an interesting comparison has been made in terms of gross tort costs as a share of GNP among various countries. The following figures for 1987 [Litan, 1991] should give an approximate measure of legal liability concerns in the U.S. versus Europe and Japan:

INTERNATIONAL COMPARISON OF GROSS TORT COSTS AS SHARE OF GNP (OR GDP) - 1987

United States	2.6
Japan	0.4
United Kingdom	0.5
West Germany	0.5

The above figures suggest that, in spite of the current research activities in California, the U.S. may be the last one to implement automatic highways in the future, if at all.

If automatic highways can be considered the high-tech radical solution, double-deck (D) highway construction may be considered the low-tech radical solution to urban traffic congestion. This solution is usually dismissed by IVHS experts who are accustomed to working with the premise that we can no longer solve our traffic problem by building more highways because we are running out of urban lands. However, double-deck highway is a possible solution precisely because it requires little or no more urban lands. It is obvious that the vehicle carrying capacity per urban land unit area should be approximately proportional to the number of expressways that can be stacked above one another, assuming the same traffic speed. In the recent Highway Bill passed by Congress, a lion's share of the authorization and appropriation is still for building more highways even though an increased portion is dedicated to infrastructure maintenance and IVHS. In addition, double-deck expressways are common phenomena outside the U.S., and especially in Japan where many expressways are built on top of rivers and canals. In this author's opinion, IVHS experts should not ignore this radical solution and should, instead, consider the many ways to use IVHS to help solve the traffic problems associated with access and egress of double-deck expressways, including electronic toll collection and sophisticated traffic light controls to help move the high-density traffic moving into and from these expressways, and using real-time traffic management and guidance to keep the traffic flowing smoothly on them. Given the existence of more double-deck expressways in Europe than in the U.S., there should be valuable European (and Japanese) experience for the U.S. to learn from for this radical solution.

Unprecedentedly strict environmental regulations (E) have been proposed to maintain air quality in many cities, both in Europe and in Southern California. Although the primary objective of these regulations is for environmental protection, the side effect on traffic volume can be substantial and the end result could be a radical reduction of urban congestion as well as high standards of environmental quality. In Europe, the "Green Parties" are politically strong in a number of countries. Some of the consequences have been felt through IVHS projects. For example, due to the green party's insistence, the speed limit of the side streets in West Berlin is very low — in the order of 10 mile per hour, thus freeing the residential districts from both noise and air pollution generated by heavy motor traffic. A serendipitous result is the relief of traffic congestion in these side streets. One of the DRIVE projects, PREDICT, is designed to limit or stop motor traffic coming into such cities as Athens, through changeable message signs and traffic light controls, when the air pollution in the central district exceeds a threshold [Ayland *et al.*, 1991]. Even today, the speed limit on the expressway outside of a number of German cities, such as Stuttgart, is reduced and conveyed to the motorist through changeable electronic speed limit signs when the air pollution level exceeds a predetermined level. The underlying assumption here is that less air pollutants will be generated per mile traveled by slower moving vehicles (down from 65 mph to 40 mph on the expressway). On the other hand, the degree of incentive and coercion for motorist to switch from gasoline engines to alternative fuels including electricity is not as much in Europe at this time as in Southern California [South Coast Air Quality Management District, 1990]. The degree to which unprecedentedly strict environmental regulations in Southern California may potentially impact urban traffic congestion there has not been assessed, and the actual confirmation of such impact assessment, of course, will have to wait for many years. There seems to be much to be gained by both the Americans and the Europeans to learn from each other's experience in this radical solution to traffic congestion.

It is obvious that buses (B), and in general high-occupancy vehicles (HOVs) through rideshare or car/van pools, improve a highway's capacity for moving people simply because of an increased number of travelers in fewer vehicles. What is not so obvious is the estimate of 60% reduction of traffic delays (in vehicle hours) resulting from only 20% of single drivers sharing rides [Fisher, 1991], due to the nonlinear relationship between volume (in vehicles per hour) and speed (in miles per hour) near traffic saturation. It has been pointed out that public transportation (bus or rail transit) would not be a ready solution for urban traffic congestion in the U.S., partly because of the American traveling habit and premium for individual freedom, but also due to the suburbanization of the U.S. population in metropolitan areas. In contrast, public transportation has traditionally been a common mode of travel in Europe where the urban population distribution is much more compact, and many IVHS applications to transit have been successfully demonstrated in Europe, ranging from fleet management to signal pre-emption for buses, to convenient information for multimodal pretrip planning [Dunhaupt *et al.*, 1991]. One of the most impressive developments in Germany is the IVHS smart bus, which has integrated the multifaceted functions of fare collection using smart cards, signal pre-emption to let the bus through heavy traffic on a priority basis, station and destination annunciation to passengers at the stops as well as on board, automatic vehicle location for the dispatcher, automatic vehicle performance monitor for non-routine maintenance, *etc.* These functions are expected to attract riders as well as to increase operating efficiency of the bus system in Germany. On the other hand, rideshare and exclusive HOV lane operations have been experienced in a number of American cities, such as Houston and Washington, D.C. With the recent passage of the American Disabled Act (ADA), transit vehicles and systems will receive additional support to provide a vital service to the disabled as well as disadvantaged people. Thus, this radical solution to urban traffic congestion is another two-way street for mutual learning between Europe and the U.S.

Finally, congestion metering (C) is a new form of road pricing, which is the only of the five radical solutions discussed here that has produced dramatic impact on urban traffic congestion (in Singapore). Basically, road pricing works through the provision of economic incentive or disincentive to influence drivers' behavior; i.e., demand management. The concept is not new as it dates back to the 1920s [Pigou, 1920] but has been reassessed and improved at different times [Walters, 1961; Small *et al.*, 1990]. The concept has been attractive to economists who argue that excessive congestion is a phenomenon of inefficient allocation of scarce resources. An efficient way to reduce congestion is thus to introduce a market mechanism to road transport. Without road pricing, more road building, and applying other radical solutions discussed earlier in this section, would simply attract more traffic to the new roads and the previous level of congestion returns as the system seeks a new equilibrium. In the long run, the only way to reduce congestion is by charging the less urgent users — some opponents would say the less affluent users — sufficiently to keep them off the congested routes. While this concept does not require IVHS to implement, the electronic toll collection technology has made road pricing practical and has given the concept a new life [Small *et al.*,1990].

Interestingly IVHS was not used in Singapore to set up its current road pricing scheme although some form of electronic toll collection is expected to be installed there soon to facilitate its future expansion and management. In Singapore, a manually operated road pricing system (an Area Licensing Scheme) to keep most of the motor traffic from its central business district has been in operation since the mid-1980s. The scheme was dramatically successful in reducing traffic congestion in the central business district. In fact, it was overly successful to the extent that the roads became highly underutilized in the district, and the price was reduced from $3 to less than $2 for any vehicle to enter the restricted zone during "peak hours." [Field, 1991]. Those who used to drive to the central district now either ride the subway or drive to the periphery of the central district and walk in.

While road pricing has been successful in Singapore, it has not been accepted in other congested cities. In fact, the first attempt of electronic road pricing was actually made by Hong Kong in the mid-1980s, where motor traffic congestion and pollution in the central business district became intolerable. However, even after money and efforts had been spent to install such a system, it was never put to use due to political unacceptability. In a recent interview by the author, the Hong Kong authorities attributed the public rejection to the unfortunate timing in the road pricing installation. The Hong Kong authorities did not anticipate that, shortly after the installation, UK and China signed the treaty to have Hong Kong reverted back to China in 1997. The Hong Kong populace became highly suspicious that the road pricing system might be the beginning of Big Brother watching the residents' movement. Thus, although road pricing is still an official policy in Hong Kong, the authorities resorted to an increase of car ownership taxes as the more practical means to achieve a marked, though perhaps temporary, traffic reduction in Hong Kong.

In Europe, there is a joint manual and automatic toll cordon for Oslo, Norway, and similar plans are under consideration for Stockholm, Sweden. The Dutch Government initiated the now-tabled "Rekening Rijden" (traveling accounting) project which was due to implement the first part of the road pricing system by 1992, with complete coverage of the Randstat (Rotterdam, Amsterdam and the Hague) by 1996. In the United Kingdom, serious consideration for road pricing has been coupled with very innovative ideas for its implementation. For example, a "Timezone" concept has been proposed for London, which would be ringed with roughly concentric circles representing progressively more expensive tolls as one approached the center [Green, 1990]. This approach would prevent traffic diversion at zone boundaries as has happened around the central business district of Singapore, causing congestion around its boundaries. It is reported that GEC will begin a pilot test of this concept in early 1992 in the southwest London borough of Richmond upon Thames, using a radio frequency communications link that activates an in-vehicle meter [*Inside IVHS*, 1991c]. An even more radical concept, known as 'congestion metering', is under consideration by the City of Cambridge [Oldridge, 1990]. Unlike the usual road pricing scheme as in Hong Kong, where a congested zone is predetermined and a fixed fee for entry is charged whether the zone turns out to be congested or not, congestion metering will levy a charge only when a vehicle experiences actual congestion (defined by a threshold of vehicle speed and/or numbers of stops per unit distance). It is believed that such a scheme will induce a more economically rational behavior from the driver and will result in more effective relief of congestion. Because of the unpopularity of road pricing, the Cambridge term, congestion metering, has apparently been adopted to replace road pricing to represent the generic concept of demand management through economic incentives.

The rejection of, or hesitancy in, adopting the radical solution of road pricing has led to a number of analyses of the problem of its political unacceptability. Road pricing has many opponents. Besides those who feel that road pricing favors the rich, the strongest public sentiment against road pricing is its appearance as another tax. The general public feels that they have already paid too many taxes. Moreover, the high gasoline taxes at both the national and the state levels have not been used entirely for road construction and maintenance. Why not use some of those taxes for roads instead of charging more for road use?! All the car manufacturers and most of the highway users are against road pricing, which is considered as a deterrent for automobile travel and another potential imposition to favor public transit versus car use. The privacy issue as discussed previously has also been raised as a negative factor by the opponents of road pricing which is to be implemented with AVI.

On a rational basis, the proponents of road pricing seem to have answers to all the objections that have been mentioned [Green, 1990]. For example, reduced rates may be charged to the poor; privacy may be protected by the use of anonymously prepaid smart cards; *etc.* Depending on the economic assumptions made, no net increased taxes or costs would result from road pricing; families would be induced to own multiple vehicles; and the automotive industry might even get a 13% increase of market [Karlsson, 1990]! Perhaps the best conclusion on the political controversy of road pricing is that although the net social benefit is maximized by the introduction of road pricing, the realistic distribution of this benefit has left some of the interest parties worse off than the status quo, and the strong opposition from these parties have usually succeeded in blocking the implementation of road pricing [Nemoto and Jansson, 1991]. Any realistic introduction of road pricing must consider some sort of innovative compensation arrangement so that all major interest parties would be better off through road pricing than the status quo. While this debate continues, resolution of the key issues and consensus forming would be difficult without some field tests.

One of the field tests being considered by a team including the author may serve to illustrate this point [Stafford and Chen, 1992]. The specific context is the issue of a privately provided service to truck fleets on I-75 in Michigan. For a subscription fee and a per use of service fee trucks would have the benefit of electronic weigh-in-motion, messages from the private fleet dispatcher, real-time traffic information, *etc.* — all IVHS functions which were discussed in Section II. The fee revenue would be divided between the private service provider and the transportation authority. At certain points along the route which are subject to periods of congestion, the public partner would offer financial incentives for the truckers to divert or possibly postpone to a less congested time trips by motor carriers. The incentive would be in the form of a reduced monthly charge for each diversion or "frequent diverter" credits, taken from the portion of the revenue shared by the public authority. This incentive is in reality a form of road pricing or congestion metering. However, instead of a charge to the trucker who has not had to pay any tolls in the status quo, the demand management is through an economic incentive in the form of reduction of charges collected for additional services that are not available in the status quo. For the public authority, the incentive taken from its revenue share is justified as long as the amount is less (and usually much less) than the cost for providing additional lanes to accommodate the congested traffic. Thus, a win-win arrangement would be realized in which all major interest parties would be better off than the status quo. Whether this scheme would work in the real world or not can only be determined after the actual field test. However, the point should be clear that any congestion metering or road pricing scheme must try, for the sake of political acceptability, to provide some gain to all major interest parties over the status quo. Also, as the number of public and private toll roads increases, and as the public is compelled to choose between congestion metering and unpalatable alternatives (such as extremely strict environmental regulations), win-win arrangements for congestion metering will be easier to develop in the future.

The five radical solutions discussed in this section may be chosen in any combination by the U.S. that may or may not be the same as in Europe. Due to different conditions and traditions in the two continents, the radical solutions in the long run are likely to be quite different between Europe and the U.S., and may even be quite different in various parts of the U.S. At this early juncture of the IVHS movement, there is much to be gained from trying out many options rather than narrowing down too soon, as long as a process of continuing mutual learning is established with good intentions on both sides for international cooperation.

REFERENCES

Ayland, N., Bonazountas, M., Mitropoulos, S., and Stathopoulos, A., "Pollution Reduction through Information and Control Techniques," *Advanced Telematics in Road Transport* (2), 1241-1261, 1991.

Boyce, D.E., Kirson, A., and Schofer, J.L., "Design and Implementation of ADVANCE: The Illinois Dynamic Navigation and Route Guidance Demonstration Program," *Proceedings of the 2nd Vehicle Navigation and Information Systems*, Pt. 1, IEEE/SAE, 415-426, 1991.

Braegas, P., "Function, Equipment and Field Testing of a Route Guidance and Information System for Drivers (ALI)," *IEEE Transactions on Vehicular Technology*, VT-29(2), 216-225, 1980.

CARGOES, DRIVE Project V1011, "Integration of Dynamic Route Guidance and Traffic Control," April 1989.

Catling, I. and McQueen, B., "Road Transport Informatics in Europe - A Summary of Current Development," *Proceedings of the 5th Jerusalem Conference on Information Technology*, 702-715, October 1990.

Catling, I., Op de Beek, F., Casimir, C., Mannings, R., Zuderhand, F., Zechnall, W., and Hellaker, J., "SOCRATES: System of Cellular Radio for Traffic Efficiency and Safety," *Advanced Telematics in Road Transport* (1), 28-43, 1991.

Chen, K. "Policy Implications of Driver Information Systems," TRB Paper No. 921016, 71st Annual Meeting of the Transportation Research Board, January, 1992.

Chen, K. and Underwood, Steven E., "Research on Anticipatory Route Guidance," *Proceedings of the 2nd Vehicle Navigation and Information Systems*, Pt. 1, IEEE/SAE, 427-439, 1991.

Davies, P. and Eng, C., "Radio Data System — Traffic Message Channel," *Proceedings of the 1st Vehicle Navigation and Information Systems*, A44-A48, 1989.

De Charenteney, F., luncheon keynote address at the IVHS AMERICA Coordinating Council Meeting in Crystal City, Virginia, October 3, 1991.

DRIVE Conference Proceedings, *Advanced Telematics in Road Transport*, 2 volumes, Elsevier, 1991.

Field, B. G., "From Area Licensing to Electronic Road Pricing: A Case Study in Vehicle Restraint," SAE Paper 911677, Society for Automotive Engineers, 1991.

Fisher, R.J., "Smart Travelers of the 1990s," *ITE Journal*, 17-19, January 1991.

Gilbert, R.K., Underwood, S.E., and DeFrain, L.E., "DIRECT: Comparison of Alternative Driver Information Systems," *Proceedings of the 2nd Vehicle Navigation and Information Systems*, Pt. 1, IEEE/SAE, 397-406, 1991.

Gardels, K., "Automatic Car Controls for Electric Highways," General Motors Research Laboratories, GMR-276, Warren Michigan, June 1960.

Glathe, P., Karlsson, L., Brusaglino, G.P., and Calandrino, L., "The Prometheus Programme - Objectives, Concepts and Technology for Future Road Traffic," FISITA Paper 905180, pp. 477-484, 1990.

Green, N., "London 'Timezone'", paper presented at the National Economic Development Organization (NEDO) Conference on Information Technology & Traffic Management, London, November 1990.

Grimes, D.M., "Guest Editorial," *IEEE Transactions on Vehicular Technology*, 38(3), 110-111, 1989.

Haessermann, P, "Route Guidance Systems: Combination of Autonomous Systems with Infrastructure Based Systems," presentation at SITEV '90, Geneva, Switzerland, May 1990.

Inside IVHS, 1(12), "Trafficmaster Seeks Expansion of Network onto London A Roads," 6-7, June 10, 1991a.

Inside IVHS, 1(17), "Siemens Banks on Holding Co. to Finance IR Beacons Network," 1-3, September 3, 1991b.

Inside IVHS, 1(20), "London Borough Sets Road Pricing Trial of GEC Built System," 4-5, October 14, 1991c.

JMP Consultants Ltd., "Study to Show the Benefits of Autoguide in London," Final report to Transport and Road Research Laboratory, February 1987.

Karlsson, T., "Financing," (Working Paper k:\secfo\docs\SC0259); "Road-Pricing," (Working Paper k:\secfo\docs\SC0261); "Privacy," (Working Paper k:\secfo\docs\SC0274); DRIVE Program, March 1990.

Kaufman, D.E., Wunderlich, K.E., & Smith, R.L., "An Iterative Routing/Assignment Method for Anticipatory Real-Time Route Guidance," IVHS Technical Report 91-02, University of Michigan, May 1991.

Kawashima, H., "Present Status of Japanese Research Programmes on Vehicle Information and Intelligent Vehicle Systems," presented at the DRIVE Conference, Brussels, 6 February, 1991a.

KSI, "DFLS: Direction Finding Localization System," KSI Inc., Annandale, VA, 1991.

LeBow, G., Sage Broadcasting Corporation, presentation on Radio Data Systems at the Transportation Research Board (TRB) Committee on Communication Meeting, Washington, D.C.,14 January 1991.

Litan, R.E., "The Liability Explosion and American Trade Performance: Myths and Realities," *Tort Law and the Public Interest*, Schuck, P. (ed.), 127-150, Norton, 1991.

Martell, D., "Navigation Systems," paper presented at the National Economic Development Organization (NEDO) Conference on Information Technology & Traffic Management, London, November 1990.

Nemoto, T. and Jansson, J.O., "Road Pricing — Political Controversy and Its Modelling," Discussion Paper No. 16, DRIVE/SECFO, February 1991.

Oldridge, B., "Electronic Pricing: An Answer to Congestion," paper presented at the National Economic Development Organization (NEDO) Conference on Information Technology & Traffic Management, London, November 1990.

Pigou, A.C., *Wealth and Welfare*, 1920.

Rillings, J. H. and Lewis, J.W., "TravTek," *Proceedings of the 2nd Vehicle Navigation and Information Systems*, Pt. 2, IEEE/SAE, 729-737, 1991..

Ristenbatt, M. P., "A Communications Architecture Concept for ATIS," *Proceedings of the 2nd Vehicle Navigation and Information Systems*, Pt. 2, IEEE/SAE, 949-955, 1991.

Rosen, D., Mammano, F., and Favout, R., "An Electronic Route-Guidance System for Highway Vehicles," *IEEE Transactions on Vehicular Technology* , VT-19(1), 143-152, 1970.

Small, K., Winston, C., and Evans, C.A., *Roadwork*, Brookings Institution, Washington, D.C., 1989.

South Coast Air Quality Management District, Public Workshop Notice. *Proposed Rule 1601 - Fleet Conversion for Passenger, Light-Duty, and Medium-Duty Vehicles.* February 26, 1990.

Stafford, F.P. and Chen, K., "A Sociotechnological Perspective on Public-Private Partnership for IVHS Infrastructures," a white paper prepared for the Federal Highway Administration, draft to be completed in January 1992.

Stephens, B.W., Rosen, D.A., Mammano, F.J., and Gibbs, W.L., "Third Generation Destination Signing: An Electronic Route Guidance System," in *Route Guidance*, Highway Research Record No. 265, 1968.

Stevens, A. and Bartlam, M., "Safety and Traffic Impact Evaluation of Driver Information Systems," paper presented at PROMETHEUS Pro-General Workshop, London, November 1990.

Syverud, K., "Liability and Insurance Implications of IVHS Technology," SAE Paper 901508, Society for Automotive Engineers, 1990.

TARDIS (Traffic And Roads - DRIVE Integrated Systems, The Total Traffic Management Environment), DRIVE Project V1018, "Dynamic Route Guidance," Working Package 2.2, November 1990.

The Intelligent Highway, "Changes for London's Autoguide," (18), 1-2, November 1991.

Thomas, M., "Telecommunications: the Backbone of DRIVE," *Traffic Engineering + Control*, 209-213, April 1990.

UK Department of Transport, *Autoguide*, Pilot stage proposals - A Consultation Document, 1989.

UK Department of Transport, *Paying for Parking*, Approval of Parking Control Equipment and Devices - A Discussion Document, November 1990.

Von Tomkewitsch, R., "Dynamic Route Guidance and Interactive Transport Management with Infrared Beacons," report issued by Siemens AG, Munich, Germany, 1990.

Von Tomkewitsch, R., "Dynamic Route Guidance and Interactive Transport Management with ALI-SCOUT," *IEEE Transactions on Vehicle Technology* 40(1), 45-50, 1991.

Walters, A.A., "The Theory and Measurement of Private and Social Cost of Highway Congestion," *Econometrica*, 29(4), 1961..

Yamada, O, NHK Science and Technical Research Laboratories, private communication, April 1991.

Yumoto, N., Ihara, H., Tabe, T., and Naniwada, M., "Outline of the CACS Pilot Test Systems," paper presented at the 58th Transportation Research Board Annual Meeting, 1979.