Radical Approaches to IVHS Goals

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P92-1

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Abstract

Most of the current IVHS projects and field tests around the world, as well as in the United States, appear to be based on incremental approaches in order to realize tangible results in the foreseeable future. While the incremental approach is important in the near future for both the public and private sectors, the expected benefits are understandably limited — for example, route guidance to produce 15 to 25% reduction of traffic delays. In the long run, the traveling public is not likely to be satisfied unless improvements in congestion relief, safety, and environmental quality can ultimately exceed 100% or several hundredfold. In other words, the incremental IVHS solutions that dominate the current field tests may be merely stop-gap measures that can only buy time for the radical solutions to be explored and deployed 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	Automated 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. Each of these solutions taken separately would serve IVHS goals to varying degrees, and might even serve one goal well while becoming counterproductive for another. The time horizon for their real impacts also varies greatly. Due to different conditions and traditions in various regions, the radical solutions may be pursued quite differently in various parts of the United States and in other parts of the world. It is desirable for the IVHS strategic plan(s) to consider appropriate combinations of these (and other) candidates for radical solutions, or at least to consider a process through which these combinations of radical solutions can evolve.

Introduction

The rapidly increasing diversity and activities in Intelligent Vehicle-Highway Systems (IVHS) have become a global phenomenon. Europe, Japan, and North America have each put in place multi-year IVHS program(s) that are supported by more than $100 million per year for research, development and field tests, involving public, private, and academic institutions [Chen and French, 1991]. All of these programs have proclaimed the increase of mobility, safety, productivity, and environmental quality of surface transportation as their goals and justification for the large public expenditure [IVHS AMERICA, 1992]. Most of the current IVHS projects and field tests around the world, as in the United States, however, appear to be based on incremental approaches aimed at realizing tangible results in the near future. The importance of incremental approaches to 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. While the incremental approach is important in the near future, the expected benefits are understandably limited — for example, computer simulation of most route guidance results, assuming a substantial market penetration in urban vehicles, indicates on the average only a 15 to 25% reduction in traffic delays. In the long run, the traveling public is not likely to be satisfied unless improvements in congestion relief, safety, and environmental quality — the IVHS program goals — ultimately exceed 100% or more. In other words, the incremental IVHS innovations that dominate current field tests 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 real potential for substantial improvements on one or several of the above-stated IVHS goals. For the sake of easy memory, these may be called the ABCDE of radical solutions as follows:

A	Automated 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. It is likely that the appeal and effectiveness of these solutions may be quite different for the multiple IVHS goals, and may be quite different in various parts of the United States and other parts of the world. There is also the question of how we might explore the feasibility and effectiveness of these radical solutions and their various combinations over time in a long-term strategic program. The rest of this paper will discuss some of these issues. We will begin by examining the potential benefits and barriers of each of the five radical solutions individually.

Automated Highways

With automated 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, lane width can be narrowed through the use of intelligent lateral control, making it possible to increase the vehicle carrying capacity per urban highway unit area beyond 500%. An intermediate step proceeding toward automated highways is to gather individual vehicles in platoons, better known as electronic convoys in Europe. This approach is one feature of the California PATH Program [Schladover, *et al.*, 1991], and has been demonstrated successfully by Volkswagon. The Japanese Personal Vehicle System (PVS) and SuperSmart Vehicle System (SSVS) have similar objectives and have made tangible achievements on test tracks [Kawashima, 1991].

Concerns about user acceptance, system reliability, and legal liability, however, have caused an abrupt halt of the Volkswagon electronic convoy 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 platooning leave little doubt that research will continue on this approach in many parts of the world. In fact, it has been reported [*Inside IVHS*, 1992] that a major U.S. consortium is being formed to undertake this high-risk research in order to fulfill Congressional mandate to demonstrate platooning successfully on a test track by 1997 and possibly to reach more ambitious goals after 1997. It is not clear which part of the world will be the first to introduce platooning in a real traffic environment, and eventually the more ambitious automated highways which can have significant impacts on interurban as well as intraurban road transportation [Haugen, 1990]. Among the different parts of the world, the difficulty in surmounting the barriers of user acceptance and system reliability of automated highway is similar. The major difference lies in the issue of 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, despite current research activities in California, the U.S. probably would not be the first to implement automated highways, if they ever do.

The barriers of system reliability and user acceptance, which are mutually linked, also appear to be formidable. It has been pointed out [Ervin, 1992] that the achievement of a safety level for automated highways comparable to that for air travel would be extremely challenging, particularly after comparing the competence of an airline pilot versus that of an average driver and comparing the maintenance practices of the airlines versus that of an average vehicle owner.

On the other hand, if one takes a positive view toward automated highways, one can conceive many ways to overcome current barriers. Regulatory reforms as well as deliberate efforts to limit liability in automated highways through legislative initiatives could alleviate the tort liability problems. Successful implementation of automated highways in other parts of the world may provide safety statistics to help establish an acceptable liability insurance practice in the U.S. A comprehensive research program can be established to study and develop the overall system performance and reliability, including the development of fail-safe and fail-soft approaches to help user acceptance [Meyer, 1991]. After all, electric power was considered extremely hazardous in its early days, but after safety devices and systems were developed to assure fail-safe features that work even in a dilapidated housing environment, electricity became prevalent in almost every household, albeit this had to be accomplished over several decades.

The more fundamental and perhaps problematic argument against automated highways is in regard to their potential benefits, which are very positive for increasing highway capacity, at least neutral for traffic safety, but possibly very negative or counterproductive for environmental quality. The substantial increase of traffic capacity caused by automated highways (and increases in driving comfort) may attract more drivers. The resultant increase of vehicle-miles traveled within the urban area during rush hour may increase air pollution substantially [Cameron, 1991]. While IVHS also can help environmental quality, as will be discussed in the next section, it appears that the very negative environmental impact of automated highways can be alleviated only through regulatory use of alternative fuels (*e.g.,* methanol, electric and hybrid vehicles, *etc.*). Perhaps the most important and realistic benefits of automated highway research is in the potential spin-offs of new technologies — new sensors, collision warning and avoidance systems, *etc.* — which can help increase safety and driving comfort for manually-controlled vehicles as well as automated highways.

Environmental Regulation

Unprecedentedly strict environmental regulations (E) have been proposed to maintain air quality in many cities, such as those in Southern California [South Coast Air Quality Management District, 1990] as well as the requirements in the Clean Air Act Amendments of 1990. Although the primary objective of these regulations is for environmental protection, the side effects on traffic volume could be substantial, and the end result could be a radical reduction of urban congestion as well as high standards of environmental quality. The reason is that, in order to achieve very low or near-zero emissions, alternative-fuel technologies will have to be used. Alternative-fuel vehicles, such as electric vehicles, are generally much smaller in size than conventional automobiles. The radical concepts of "lean machines," which use conventional fuels but are very compact [Sobey, 1988], and electric highways that charge compact electric vehicles on the move [Ross, 1988], also may have environmental appeal. Thus, for the same amount of vehicle-miles driven, much less urban land will be required. Stated alternatively, the same amount of traffic can be handled by the existing highways with much less congestion.

Note that the radical impact of environmental regulations is quite different from the potential environmental benefits that are commonly accrued to incremental approaches in IVHS. In the latter, the environmental benefits of IVHS are expected to stem from the successful application of navigation and route guidance, which results in reduction of inefficient route choice and reduction of stop-and-go driving that accompanies traffic congestion. To the extent that navigation and route guidance are expected to contribute only limited benefits to congestion relief, as discussed previously, the resultant environmental improvements will also be limited — less than 50% even with full market penetration. To the extent that navigation and route guidance attracts more motor traffic, environmental improvements may be offset by the increase of vehicle-miles traveled in urban areas, as in the case of automated highways.

On the other hand, the positive impacts of incremental approaches to IVHS should not be ignored. 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 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, which can be further guided by Ali-Scout to keep the equipped vehicles on the main arterials [Von Tomkewitsch, 1991]. A serendipitous result of Ali-Scout is thus to assure the relief of traffic congestion on the side streets. Furthermore, some IVHS concepts have been proposed seriously to relieve air pollution as a primary goal. For example, 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 expressways 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 is that less air pollutants will be generated per mile traveled by slower moving vehicles (*e.g.,* down from 65 mph to 40 mph on the expressway).

Nevertheless, if revolutionary improvements in environmental quality are to be achieved, alternative fuels dictated by environmental regulations remains as a potentially effective solution. A problem with this solution is public acceptance and the long time horizon for its practical implementation on a national scale. Even in Southern California where air pollution is perceived by the general public as an extremely severe problem, the current path appears to target the use of electric vans over several years. The spread of electricity to other vehicles will take longer, and the public may respond by having hybrid vehicles and/or owning both electric and gasoline vehicles for different trip purposes. Thus, even if a local region chooses to impose strict environmental regulations, the full implementation through alternative fuels will take a long time and the shift of the bulk of motor vehicles nationwide may take decades — on the same order of time scale as automated highways.

Bus, HOV, and Multimodal Travel

It is obvious that buses (B), and high-occupancy vehicles (HOVs) — rideshare, car/van pools, *etc.* — in general improve a highway's capacity for moving people, simply because of an increased number of travelers in fewer vehicles. It is obvious also that multimodal travel, a modal combination of single-occupancy vehicles (SOVs) and HOVs in the same trip, would improve highway capacity to the extent of the HOV proportion. What is not so obvious is the estimate that traffic delays (in vehicle hours) would reduce by 60% if only 20% of drivers would share rides [Fisher, 1991] This is due to the nonlinear relationship between volume (in vehicles per hour) and speed (in miles per hour) near traffic saturation.

Public transportation traditionally has been a common mode of travel in those parts of the world where the urban population distribution is relatively compact. In these areas, many IVHS applications designed to improve transit operations have been demonstrated successfully, ranging from fleet management, to signal pre-emption for buses, to convenient information for multimodal pre-trip planning. 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, introduced signal pre-emption to let the bus through heavy traffic on a priority basis, implemented station and destination annunciation to passengers at the stops and on the buses, added automatic vehicle location for the dispatcher, and installed 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. The current level of the use of transit in Europe and the expected expansion of multimodal travel in Europe are such that route guidance systems for passenger vehicles, such as EuroScout (the second generation of Ali-Scout), has included multimodal travel as an IVHS function for the immediate future.

Such success stories have not been overlooked in the U.S. Private companies as well as public agencies have been looking seriously at the concept of the smart bus [Kushner, 1992]. The use of smart cards as a central technological piece to implement the various concepts of the smart traveler is being developed in both the U.S. [Fisher, 1991] and Canada [Hemily, 1992]. However, as compared to Europe and other parts of the world, public transportation (bus or rail transit) is not expected to be a radical solution to relieve urban traffic congestion and air pollution in the U.S. This is 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. Any fundamental arrestment or reversal of urban sprawl is either unlikely or will take years to occur. Meanwhile, financial deficits of transit authorities are expected to remain a chronic problem in U.S. cities. Funding and efficiency improvement through privatization, along with IVHS technologies applied to transit, would help . With the recent passage of the Americans with Disabilities Act (ADA), transit vehicles and systems will receive additional support to provide a vital service to the disabled as well as disadvantaged people. However, the major use of buses alone to relieve congestion and air pollution in the U.S. on a nationwide basis is not likely to occur in the near future.

What does appear to be more practical for many American suburban commuters in the foreseeable future is ridesharing in private vehicles, multimodal travel, and exclusive HOV lane operations. Such approaches, including their variations, have already been tried in a number of American cities, including Houston, San Francisco, and Washington, D.C. The use of information technology in the context of IVHS can also facilitate ridematching and instant carpooling [Niles, 1992]. One of the major incentives for ridesharing is the exclusive use of HOV lanes, which shorten travel time in most cases and which are the only reasonable routes during peak hours along some city routes. Given the appropriate policy, this radical solution has a chance to spread relatively fast and widely. However, the conversion of existing lanes on expressways to HOV lanes has frequently run into serious public objections, while the dedication of new highway lanes as HOV lanes has usually gone through smoothly [Bridges, 1991]. This suggests a prudent mix of HOV and new highway construction as a radical solution that would be acceptable to the public in many American cities. Furthermore, for HOV and other related concepts to work realistically, "transit" and "auto" should no longer be considered mutually exclusive, and automobile-based public transportation modes enabled by IVHS must be included in future creative design of Advanced Public Transportation Systems (APTS) [Behnke, 1992].

Double-Deck Expressway Construction

If automated highways can be considered a high-tech radical solution, double-deck (D) highway construction may be considered a low-tech radical solution to urban traffic congestion. This solution is usually dismissed by IVHS experts who are accustomed to working under the premise that we can no longer solve our traffic problem by building more highways because we are running out of urban lands. However, the double-deck highway is a possible solution precisely because it requires use of little or no more urban land. 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 Intermodal Surface Transportation Efficiency Act of 1991, 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 of the U.S., especially in Japan, where many expressways are built on top of rivers and canals. 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 on to and off 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 other parts of the world, there should be valuable European and Japanese experience for the U.S. to learn from in this area.

A more serious obstacle to double-deck expressways is the potential increase of air pollution during the peak period in their proximity. Perhaps the additional expressway capacity should be dedicated to HOVs exclusively. This would also avoid the public objection to the conversion of existing expressway lanes to HOV lanes, as discussed in the last section. In the long run, the additional lanes of the double-deck expressways may also be used for electric vehicles operated in the automated highway system, as discussed previously. In other words, double-deck expressways are a radical solution which can best be used in combination with other radical solutions in order to meet the multiple IVHS goals.

Congestion Metering or Road Pricing

Finally, congestion metering (C) — a new form of road pricing — is the only one of the five radical solutions discussed here that has produced dramatic impact on urban traffic congestion (in Singapore), and has also resulted in a serendipitous improvement of air quality and public transportation ridership. 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 it 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, increasing highway capacity through road building or automation would simply attract more traffic to the new roads, and the previous level of congestion would return as the system finds a new equilibrium. In the long run, the only way to reduce congestion is by charging the less urgent users — some critics would say the less affluent users — sufficiently to keep them off of the congested routes. While this concept does not require IVHS to be implemented, 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 or take a taxi in.

While road pricing has been successful in Singapore, it has not been accepted in other congested cities. In fact, the first attempt at electronic road pricing was actually made by Hong Kong in the mid-1980s, when motor traffic congestion and pollution in the central business district became intolerable. However, even after money and effort had been spent to install such a system, it was never put to use due to political unacceptability. In a recent interview with 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, the United Kingdom and China would sign 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 a 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 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 was reported that GEC would 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*, 1991]. An even more radical concept, known as "congestion metering," has been 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, <u>congestion metering</u>, has apparently been adopted in place of 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 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?! Most of the highway users are against road pricing, which is considered as a deterrent for automobile travel and another potential imposition that favors 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 automatic vehicle identification (AVI) technology.

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 increase in 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 in market [Karlsson, 1990]! Perhaps the best conclusion to 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 will leave some of the interested parties worse off than the status quo, and strong opposition from these parties has 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 interested parties will be better off through road pricing than the status quo. While this debate continues, resolution of the key issues and consensus forming will be difficult without field tests.

One of the field tests being considered (by a team including the author) may serve to illustrate this point [Chen and Stafford, 1992]. The specific context is the issue of a privately provided, self-financed service to truck fleets on the expressways. For a subscription fee and a per use of service fee, trucks would have the benefit of a number of IVHS functions — electronic weigh-in-motion, messages from the private fleet dispatcher, real-time traffic information, *etc.* The fee revenues would be divided between the private service provider and the transportation authority. At certain points along the route that are subject to periods of congestion, the public partner would offer financial incentives for the truckers to divert to a longer but less congested route, or possibly postpone their trip to a less congested time. 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 essence a form of negative road pricing that is equivalent to positive rerouting incentives. Instead of a charge to the trucker who has not had to pay any tolls in the status quo, the proposed demand management is through an economic incentive in the form of reduction of charges that are collected for additional services not available previously.

This institutional arrangement should be more acceptable to the truckers as highway users as a discount for diverting may be far more acceptable to users than a fee for not diverting. 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 are better off than the status quo.

Whether or not this scheme would work in the real world can be determined only after an 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 interested parties over the status quo. Also, as the number of public and private toll roads increases, and as the public is compelled to face unpalatable alternatives (such as extremely strict environmental regulations), win-win arrangements for rerouting incentives and congestion metering will be easier to develop in the future.

Combination of Solutions and Strategic Implications

The five radical solutions discussed in this paper may be mixed in various combinations, and different regions may choose different combinations to suit their local values and situations. Each radical solution has its own proponents and opponents, as well as its own time horizon for potential feasibility and effectiveness. In this author's judgment, automated highways (as applied to the urban environment) and environmental regulation may need to go together for the reasons given previously and may take the longest time to become effective. In a shorter time frame, smart buses and HOVs may be more implementable in American suburbs if new exclusive lanes are provided with new or double-decked expressway constructions. Congestion metering is a radical approach that has been proven successful in some countries and offers the most fundamental solution that can work in both the near-term and the long-term future. However, it should not be considered an alternative to IVHS as some may argue. Instead, we should try to facilitate its implementation with IVHS technologies (*e.g.*, AVI) in combination with other radical solutions (*e.g.*, new toll roads and smart buses) and using creative institutional arrangements (*e.g.*, bundling fees for IVHS functions with rerouting incentives) in order to draw political support from all major interested parties.

At this time, it is too early to determine the extent to which various radical solutions, or their specific combinations, may work effectively in different parts of the U.S. and elsewhere. It behooves us all to identify all radical solutions — some of which may exist but have not been discussed in this paper [*e.g.,* Ward, 1991; Baird, 1992], and others may need to be generated through a creative process. Alternative combinations, in the form of specific scenarios, may be developed and assessed through a process known as "policy exercise" [Underwood, 1988]. As has been used for strategic planning in large (Fortune 500) companies and for assessing the implications of complex issues like global warming, the procedure of policy exercise can bring together stakeholders, policy makers, and substantive experts in a workshop to develop "gamed scenarios" and "future histories" as a means for synthesizing alternative radical solutions that integrate technical and institutional aspects. The result can then be used to update the IVHS strategic plan periodically, with some check points and specific goals along the future time horizon. It has been commented that most of the current IVHS field tests have been designed to prove technological concepts in real traffic situations and that they should be evaluated also for their institutional and environmental implications [Horan, 1992]. This author would suggest a further step — that the portfolio of future field tests should include various radical approaches, separately or in deliberate combinations, as discussed in this paper. 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 strategic development and continuous learning by doing is established involving all interested parties.

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