Framework for Evaluating Intelligent Vehicle-Highway Systems

STEVEN E. UNDERWOOD AND STEPHEN G. GEHRING

Evaluation of intelligent vehicle-highways systems (IVHS) is a relatively new activity. An evaluation framework useful for those interested in IVHS is presented in which each component of IVHS evaluation offers new challenges. These challenges involve public and private benefits, new product functions, market penetration, abundant data generated from new systems, human interaction, and multisite deployments. Although many methodologies for evaluation exist, some significant challenges need to be addressed to properly evaluate IVHS.

The effects of intelligent vehicle-highway systems (IVHS) are diverse, ranging from the personal security provided by in-vehicle communication systems to improvements in public health provided through more efficient dispatch of emergency vehicles. Although some benefits are available to the public, such as shorter delays at incidents through the use of highway advisory radio, others are enjoyed by those who buy a service, such as the routing improvements of autonomous navigation.

The variety of systems subsumed under the umbrella of IVHS no doubt contributes to this diversity. IVHS includes an ever-increasing list of systems: motorist information systems, route guidance systems, in-vehicle navigation systems, collision warning and avoidance systems, vehicle control and platooning systems, traffic control systems, traffic-monitoring systems, automated toll and vehicle identification systems, and commercial vehicle location systems, to name a few. Each of the foregoing systems has a unique set of impacts and evaluation requirements that makes IVHS evaluation a challenging prospect.

FRAMEWORK FOR BENEFITS ASSESSMENT

The potential for IVHS is uncertain at this time, and decisions on whether to support the development of various systems require data and careful analysis. This is where evaluation helps. The purpose of operational field tests is to provide the participating organizations with a realistic setting in which they can assess the potential benefits of IVHS without assuming the risks of full deployment. Models and other analytical approaches can supplement field tests to assess the prospects of alternative deployment scenarios. The evaluation should address the interests of the general public (with measures such as congestion mitigation, enhanced safety, more efficient travel, etc.) and the traveler (through easier and more efficient travel), as well as manufacturers and suppliers (through market potential, enhanced transportation of goods, etc.). In this sense evaluation is a decision support tool that provides information about the potential benefits and risks of system development. Figure 1 indicates which evaluation methodologies are most appropriate for a particular evaluation component.

Evaluation is a tool to aid decision making. An impact is the product of the interaction between IVHS and society. Direct impacts are those effects directly attributable to IVHS; higher-order impacts are the products of direct effects. A benefit is an advantage, privilege, or cost, or all of these, that accrues to the traveler through use of IVHS compared with use of the system without IVHS. These benefits are often evaluated as a decrease in user cost.

Figure 2 presents four types of benefits that are useful in the evaluation of IVHS. The graph plots the average trip time in minutes under three scenarios: (*a*) the current technology baseline, (*b*) with IVHS deployed, and (*c*) under optimal conditions. Potential benefits are the difference between the optimal average travel time and the current technology baseline. Expected benefits are the difference between the implementation of IVHS and the current technology baseline. Current benefits are those that are experienced at the current time. Future benefits are projected on the basis of demographic trends and forecast diffusion for some time in the future.

Figure 3 enhances Figure 2 by showing several different types of evaluation activities. Current benefits may be measured empirically through evaluation of operational field tests and other direct approaches. Comparative evaluations may be deployed in the field to determine which of several systems is the most cost-effective. Prescriptive evaluation takes a more formal mathematical approach.

Figure 4 presents the various types of evaluation models that are available. The optimization model compares two points in time along the optimal condition curve. The forecast model can be used to compare the various conditions at a future point in time on the basis of demographic, market, and land use models.

CHALLENGES OF IVHS EVALUATION

Evaluation methods are not new with the arrival of IVHS; they have been around for some time. Therefore, a question one might ask is, What is special about IVHS evaluation that requires the development of new methods? For the last few months that is the question that has been raised by those who work with IVHS. In most cases the answer has been there is little difference between IVHS and other evaluation applications, with a few exceptions. The conclusion of this study is that in most cases it is sufficient to apply existing evaluation methods to assess the benefits and costs of IVHS. Only in those cases where there is an exception to standard evaluation conditions is there a reason to consider the development of new methods. This section focuses on those unique characteristics of IVHS that generate a special need for methodological development. The development of new approaches, methods, and tools are needed for the reasons discussed next.

Program in Intelligent Vehicle Highway Systems, University of Michigan, Ann Arbor, Mich. 48109.

	A System Technical Performance	B Safe and Efficient User Interface	C Indiv. Driver Behavior & Impact	D User Attitudes and Preferences	E Traffic Behavior and Impacts	F Environment and Energy Impacts	G Institutional & Socio-economic
1 Field experiment	Most appropriate	Most appropriate	Often appropriate	Often appropriate	Occasionally appropriate	Occasionally appropriate	Least appropriate
2 Field quasi-experiemt	Often appropriate	Often appropriate	Most appropriate	Often appropriate	Most appropriate	Most appropriate	Least appropriate
3 Surveys	Least appropriate	Occasionally appropriate	Occasionally appropriate	Most appropriate	Least appropriate	Least appropriate	Often appropriate
4 Subject debriefing	Occasionally appropriate	Occasionally appropriate	Occasionally appropriate	Most appropriate	Least appropriate	Least appropriate	Occasionally appropriate
5 Cost analysis	Most appropriate	Least appropriate	Often appropriate	Least appropriate	Most appropriate	Most appropriate	Least appropriate
6 Extrap. impact assess.	Least appropriate	Least appropriate	Most appropriate	Least appropriate	Most appropriate	Most appropriate	Least appropriate
7 Narrative case studies	Often appropriate	Occasionally appropriate	Occasionally appropriate	Occasionally appropriate	Occasionally appropriate	Occasionally appropriate	Most appropriate

Most appropriate · Often appropriate · Occasionally appropriate · Least appropriate

FIGURE 1 Evaluation methodologies most appropriate for evaluation components.

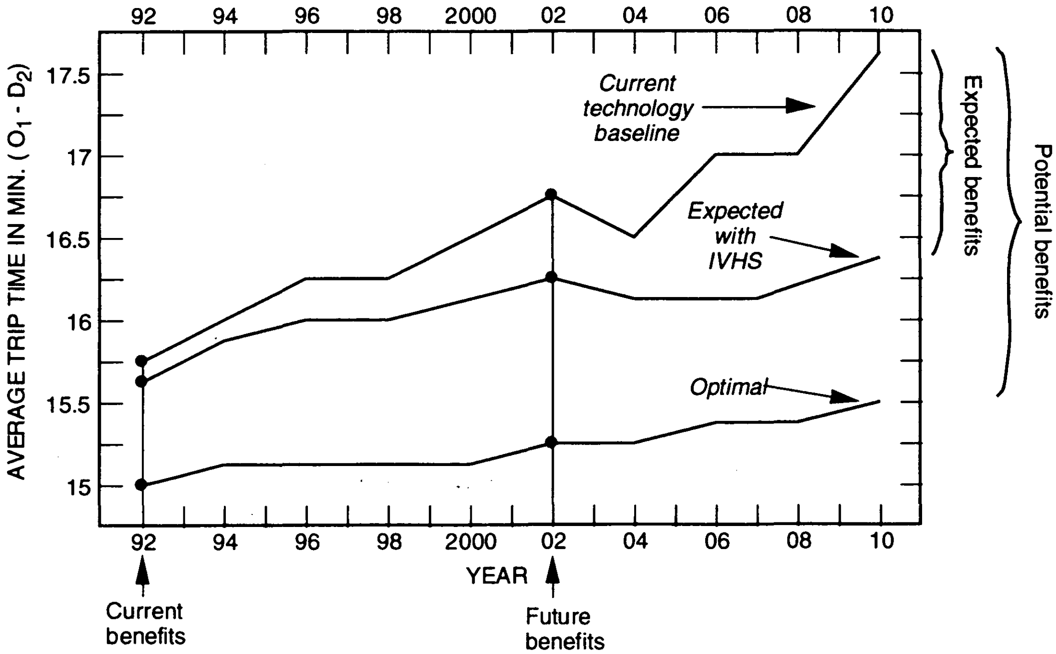

FIGURE 2 Types of benefits.

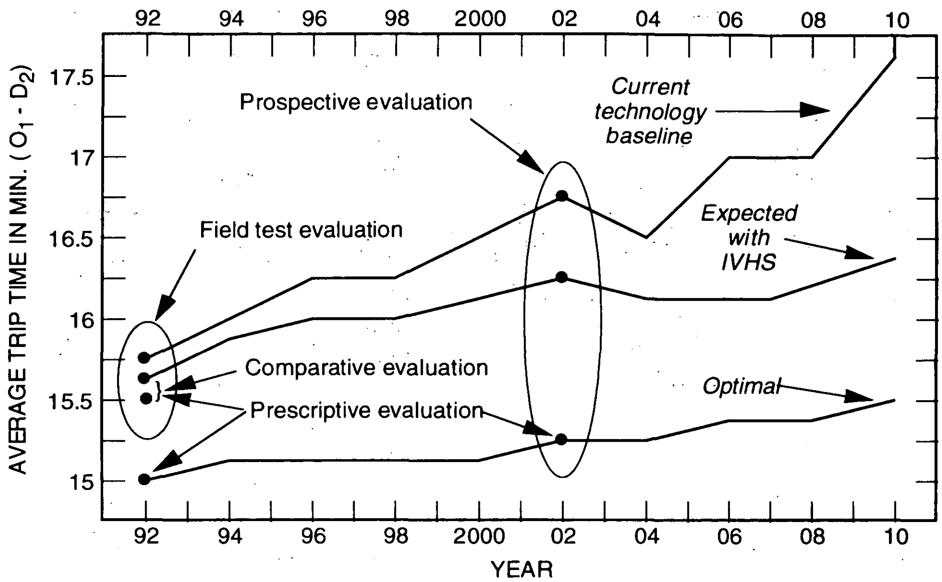

FIGURE 3 Types of evaluation.

Public and Private Benefits

Most IVHS provide both private and public benefits. It is useful at this point to reflect on why one should evaluate the potential benefits of IVHS in the first place. A number of responsible people advocate a Darwinian approach to IVHS deployment in which the survival of the fittest IVHS will ensure that the user gets the best product and service possible. Although this approach may be effective in a perfectly competitive market, the mix of public and private benefits expected from IVHS renders the "natural" selection process less than completely effective. This competitive process may be appropriate in a perfectly competitive market. However, the mixture of public and private benefits requires a more formal and deliberate selection process.

Public decisions will be made about whether to continue to support the development of IVHS or to support some other worthwhile public program. In this type of arena IVHS will have to be justified on the expected benefit to the public. For example, an in-vehicle dynamic route guidance system may guide the vehicle owner to the shortest time path through the network. The time saved is a private benefit. Diverting this vehicle away from the congested area, however, will also reduce the area's congestion by a single vehicle. Therefore, the vehicles without the route guidance systems also benefit through a marginal reduction in congestion. The public benefit is small in this single-vehicle example. However, when 5 or 10 percent of the drivers adopt route guidance, the public benefits may become significant. Within this context, there is a need for methods that discern both public and private benefits (and drawbacks) that integrate these benefits into a logical consistent manner.

For example, improvements in traffic management and safety are by-products of driver information and control systems; they benefit the general public as well as consumers who buy the information and control products for their vehicles. If left to market forces alone, IVHS services may be underproduced because there is no market for IVHS externalities.

New Products and Functions

Most IVHS functions are new and unfamiliar to potential users. Procedures to educate potential users may be required before preference, perception, and performance measures are of any value. For example, 20 years ago it would have been difficult for most people to say with any degree of confidence how frequently they would use an automatic teller machine, a video telephone, a video cassette recorder, or even a notebook computer. It would have been difficult for them to say what they would be willing to pay for the new functionality provided by these products. If they can use the system for a while under natural conditions, then their responses may have more value. Similarly, potential users cannot be expected to operate the systems adequately without having time to learn the system. All operational performance measures need to include time of exposure measures to account for learning effects.

A serious drawback of allowing potential customers to use prototypes is that the devices and user interfaces may have idiosyncratic characteristics that are not of design intent and are not essential to the system's design. Nevertheless these characteristics are a source of distraction to the user. For example, if a prototype system is not as reliable as it should be, the use of the prototype may negatively bias the consumer's reaction. It is critical in all user acceptance and performance studies of new product functions to weigh this trade-off between the positive and negative sides of user exposure.

Systems Management Evaluation

Subtle system improvements require detailed models and sensitive measures. Most IVHS, like motorist information systems and traffic control systems, are likely to produce subtle improvements in the flow of network traffic. For example, once congestion builds to a critical point on the primary highway system, some of the traffic may be diverted to less congested secondary roads. This method

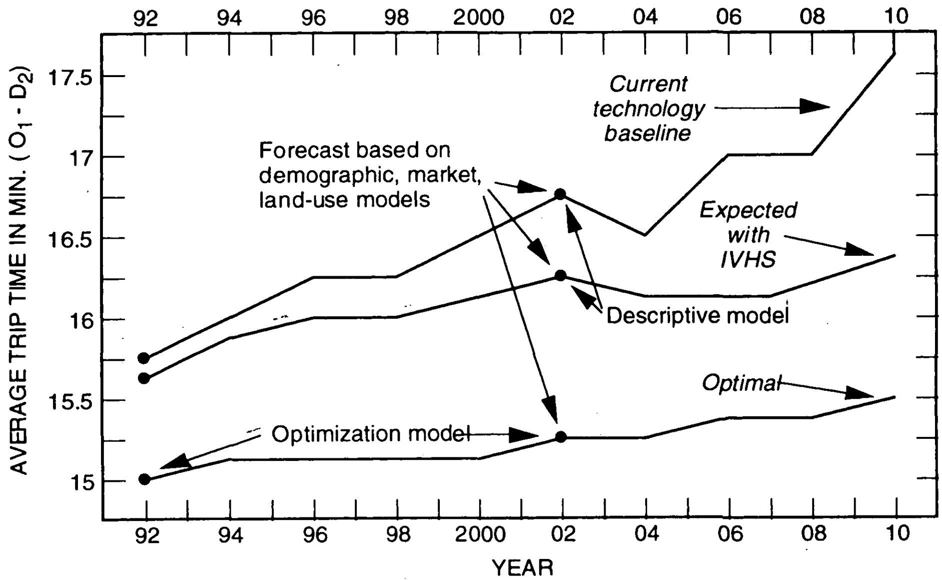

FIGURE 4 Types of evaluation models.

should improve travel conditions for both diverted and nondiverted drivers. The common notion is that travel demand varies by the time of day; therefore, when traffic builds it makes sense to spread the traffic over a larger geographic area to stem the growth of recurrent and nonrecurrent congestion.

Most existing traffic models were developed to evaluate road construction or traffic control options that are not so subtle, and the traffic modelers could make do with assumptions of static demand, static equilibrium assignment, optimal routing of all vehicles, subnetwork optimization, separation of freeways and surface streets, and macroscopic representation of vehicles. Also, most existing models do not have the ability to reflect IVHS functions such as various routing schemes, adaptive traffic control, driver-routing and departure heuristics, and the like. In other words, these existing models do not adequately represent time dependency and other essential details of IVHS and therefore are inadequate for IVHS evaluation.

In some cases the more detailed existing models may be upgraded, and every effort must be taken to make the most of what currently exists. In many cases however, existing models will have to yield to new models that incorporate these required features as fundamental elements of their structure. Therefore, new models are needed that incorporate both the functionalities of IVHS and their likely impacts on traffic. Furthermore, operational field tests must employ measures tuned to the benefits and costs expected from each of the respective systems. The field tests also should be designed as an opportunity to collect data to validate and calibrate the new models.

Market Penetration Effects

The benefits of IVHS should increase with increases in market penetration. The relationship between market penetration and benefits, however, may not always be linear. For example, imagine that the United States adopts a standard for radio broadcast data systems (RBDS), and the proportion of vehicles that come off the production line with FM sideband-capable radios increases steadily over a 10-year period. Also, assume that all vehicles equipped with the system receive the same filtered messages at any particular location. The early users of the system report significant improvements in their ability to avoid congestion and other traffic-related problems. As the proportion of vehicles equipped with RBDS continues to increase, however, the marginal benefits to individual drivers may drop because other drivers with RBDS are congesting the alternative routes. Furthermore, those drivers without systems seem to benefit more because there is less traffic on the original route. As full market penetration is approached, assuming that drivers become aware of these effects, it becomes harder to predict driver behavior.

This short example demonstrates two things. First, it may be difficult to predict what types of impacts that increases in market penetration will produce. Second, it may be inappropriate to extrapolate from operational field tests where there is a minuscule deployment of equipped vehicles to high levels of market penetration.

Abundant Data

Advanced traffic-monitoring systems may provide an abundance of data that can be used in benefits assessment. Probe vehicles may provide dynamic travel times, whereas wide area traffic detection will provide data on congestion, incidents, speeds, and queue lengths. As a result, the traditional transportation planning and evaluation models that were designed to function with sparse data may give way to newer models that take advantage of the new information inherent to the technology. The development of methods for sifting through the data is a priority at this time.

Human Factor

The effectiveness of advanced traveler information systems depends on how the traveler uses the information. One cannot assume

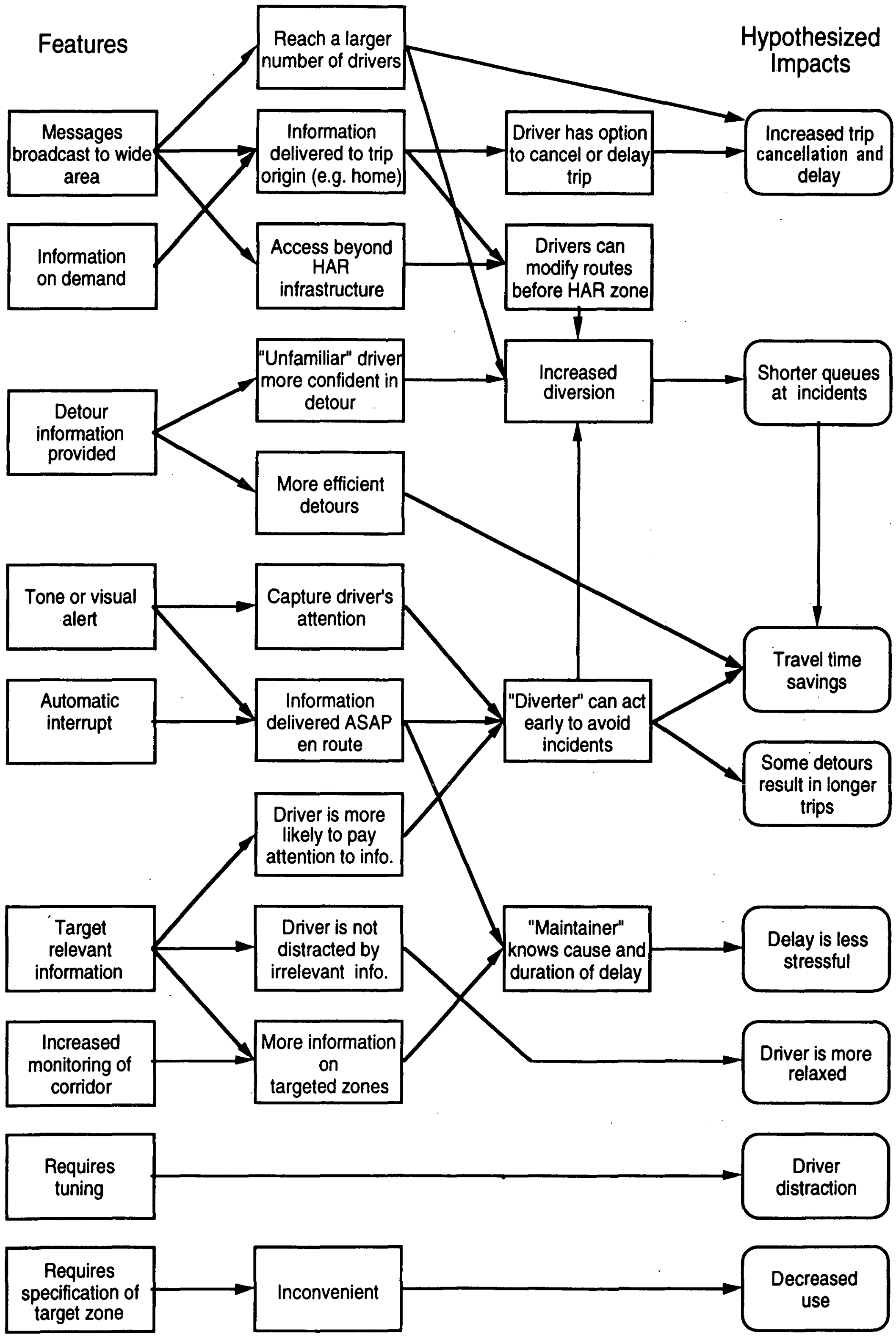

FIGURE 5 Features and hypothesized impacts of motorist information system.

that, because a driver has access to turn-by-turn route guidance instructions, while on a trip he or she will comply with these instructions. In a similar sense, one does not know how drivers will respond to traffic reports coming over RBDS or cellular telephones. Furthermore, benefits from the implementation of IVHS may be overshadowed by resulting induced travel demand behavior.

The driver's actual behavior is influenced by a host of mediating factors, including previous experience, knowledge of the area, and what other drivers are doing. There may be some benefits that do not require action. For example, a driver that chooses not to divert in response to a report may be satisfied to wait in congestion knowing what the options are. To predict the benefits one must know how travelers are likely to use the information and how they are likely to benefit, both in objective and subjective terms. Figure 5 shows the relationships between system features and expected benefits for a motorist information system. Figure 6 shows the variables that mediate the relationship between the system implementation and the level of satisfaction experienced by the user. These illustrate the importance of the human factor in evaluating the impact of IVHS.

The point of this figure is that the path from the information system box to the driver attitude box is indirect and mediated by numerous confounding variables. To really understand the relationship between implementing an information system and the satisfaction of the user requires a complex understanding of how the system works and how the driver is going to use the system. The only way to sort this out is to understand the process and to control for possible confounding variables.

Institutional Factors

IVHS will be deployed in institutional environments that may or may not support their intended function. These environments can be assessed to isolate features that either support or suppress the successful deployment and operation of IVHS. Quite separate from the institutional environment for deployment, which can be considered a supplemental enabling mechanism, are the socioeconomic impacts that may result from the widespread deployment of IVHS. These impacts include such things as land use development patterns, migration and population patterns, work and travel norms, mode shift effects, impacts on urban form and culture, and induced travel demand.

Many of the secondary socioeconomic impacts eventually feed back to the transportation sector through shifts in travel demand. These higher-order effects should be integral to long-range forecasting efforts. The inclusion of higher-order effects, however, increases the uncertainty of most forecasts, so it will become essential that the IVHS community base their long-run assessments of future developments on the development of multiple scenarios. These scenarios can be developed by assessing a reasonable range of strategic institutional factors, parameters for endogenous factors, and assumptions for endogenous factors.

Multisite Deployment

If different architectures providing the same IVHS functionality are to be compared in the field, then it is desirable to have all of the alternatives deployed at the same location, controlling for possible confounding effects such as differences in climate, network, time of day, and subjects. Given the political realities of IVHS deployment in the United States, however, it is unlikely that many of the operational field tests will involve comparisons of multiple competing systems at the same site. The deployment of different, competing systems at different sites is more likely. This deployment pattern will prevent valid comparisons between systems, especially if the unit of analysis is the network, such as in the case of motorist information and route guidance systems.

Multisite comparison becomes more reasonable when it is possible to control confounding variables. For example, a comparison of incident detection algorithms at different sites may be reasonable when weather, traffic flow, road type, detector deployment, and number of lanes are controlled. In most cases where comparison is the objective, however, single-site comparisons are superior.

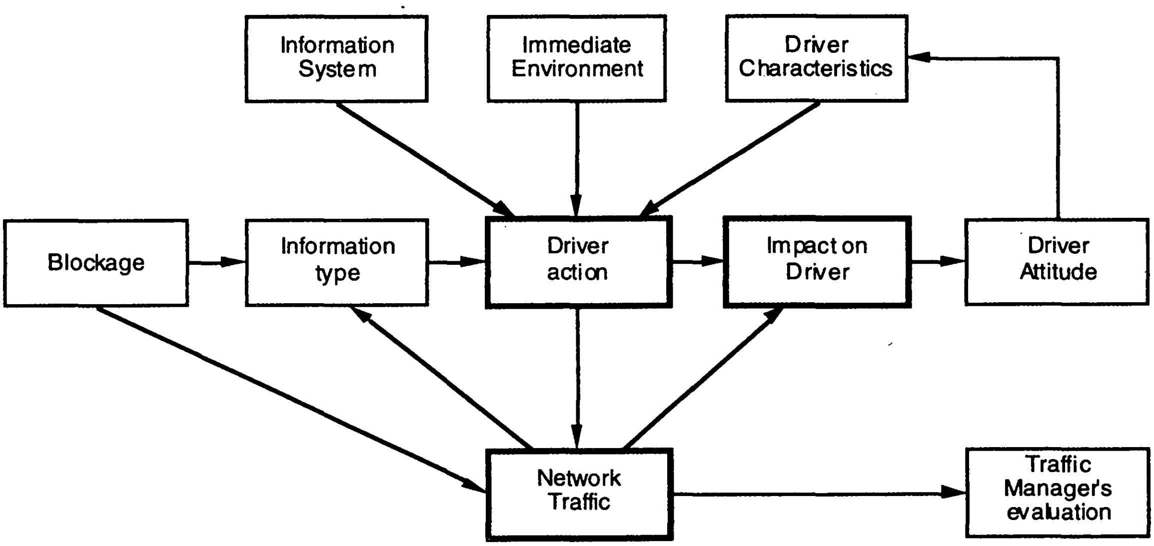

FIGURE 6 Determinants of driver perception and attitude.

Multisite deployment provides an opportunity for testing the robustness of system type under a variety of conditions. If competing systems are to be deployed at multiple sites, the assessment of these systems can focus on robustness, not on comparative effectiveness.

When comparisons are to be made it is best to deploy the alternative systems on the same site. In either case, whether the objective is to compare systems or to assess generalizability between sites, it is essential to develop and adopt a set of standards for evaluation measures, instruments, and methods that will facilitate cross-site synthesis at some later time.

Publication of this paper sponsored by Committee on Intelligent Vehicle Highway Systems.