Intelligent Vehicle Highway System Benefits Assessment Framework

DANIEL BRAND

A framework of linked cause and effect relationships (models) is derived for use in intelligent vehicle highway systems (IVHS) project and operational test evaluation. IVHS has the potential for greatly increased mobility, measured in travel opportunities and benefits, as well as considerable potential for improved transportation system operation. The framework avoids serious underestimation of the mobility and other user benefits from IVHS and allows the estimation of the effects of IVHS on aggregate volumes of travel and levels of congestion. The mobility benefits of IVHS must be measured at the level of the individual tripmaker, not on the basis of aggregate measures of flow volumes and travel times on the network. This means that the air pollution, safety, fuel consumption, and other flow volume-related impacts of IVHS do not vary in a straightforward way with the sum of the individual user benefits from IVHS. Therefore, the causal model chain for predicting IVHS impacts will vary from the conventional "planning model." The various predictive models required to evaluate IVHS improvements, including the formulation of model inputs, are described. The evaluation framework is intended to help guide the evaluation and selection of IVHS projects on the basis of their site-specific benefits and costs, rather than the desired results. Although the latter is entirely acceptable for planning a research program whose payoff cannot be known in advance, it is necessary to proceed to the next step of carefully evaluating operational field tests and advancing IVHS into its production mode. The causal framework makes it possible to anticipate the important consequences of IVHS and therefore carry out benefit-cost analyses of new investments as well as collect the appropriate data for planning and evaluating operational field tests.

This paper derives a framework of cause and effect relationships (models) for use in intelligent vehicle highway systems (IVHS) project and operational test evaluation. Both of these require appropriate causal models explaining IVHS impacts. If the important consequences of IVHS cannot be anticipated properly, benefit-cost analyses of new investments cannot be carried out, and the appropriate data for evaluating operational field tests cannot be collected.

IVHS differs considerably from conventional transportation capacity increases and operational improvements. What differentiates IVHS strategies from conventional transportation improvements is the development of a user-friendly information infrastructure to complement and increase the productivity of our massive investment in transportation infrastructure *(1)*. The new user and information orientation in transportation, together with the rapid pace of technological change, accounts for much of the current excitement in transportation and the dramatic increase in the number of transportation options being considered today *(2)*. Les Lamm, the executive director of the Highway Users Federation and president of IVHS America, stated at the 1991 TRB Annual Meeting that "IVHS is the most significant transportation initiative of my generation." This puts IVHS in the same category as the Interstate highway system in the promise and excitement it holds for transportation in America.

Charles River Associates, 200 Clarendon Street, Boston, Mass. 02116-5092.

One would imagine that the benefits of an important transportation program such as IVHS to travelers and society would be well known by now. The truth is that people may be as ignorant now of the consequences of IVHS as they were of the impacts of the Interstate highway program at its inception in the 1950s. The IVHS American "Benefits, Evaluation and Costs" Committee is on record that "substantially lacking are defensible methods for predicting changes (in benefits and costs) which could be brought about as a result of IVHS technology deployment (B. Stephens, personal communication to J. Vostrez, Dec. 2, 1991).

However, transportation planning has changed considerably since the 1950s. Planners now strive to carry out rational investment planning using benefit-cost techniques in an analytic framework. Changed also are the statutory requirements under which transportation improvements are made. The 1990 Clean Air Act Amendments (CAAA) require explicit consideration of whether transportation improvements produce more, rather than less, air pollution. Indeed, the CAAA established the principle of regional emission budgets and conformity to the emission reduction schedules contained in state implementation plans. With the exception of the 1987 congressionally mandated cost-effectiveness requirement for major transit investments, this appears to be the first significant, federally imposed regulatory performance standard for new transportation investments.

The importance of clean air and IVHS, as well as the uncertainty surrounding the impacts of IVHS as a transportation investment, suggests that improved methods for assessing the benefits of IVHS are required. The key impacts of IVHS must be brought together in a framework that will allow credible estimates of IVHS costs and benefits to be developed. However, the air pollution, fuel consumption, safety, and other travel volume-related impacts of IVHS do not vary in a straightforward way with the sum of the individual user benefits from IVHS. Increased user benefits from travel usually lead to more travel, which then gives rise to more impacts of this travel. Because this direct relationship is not the case with IVHS, as will be shown, the causal framework will differ from the conventional planning model shown in Figure 1.

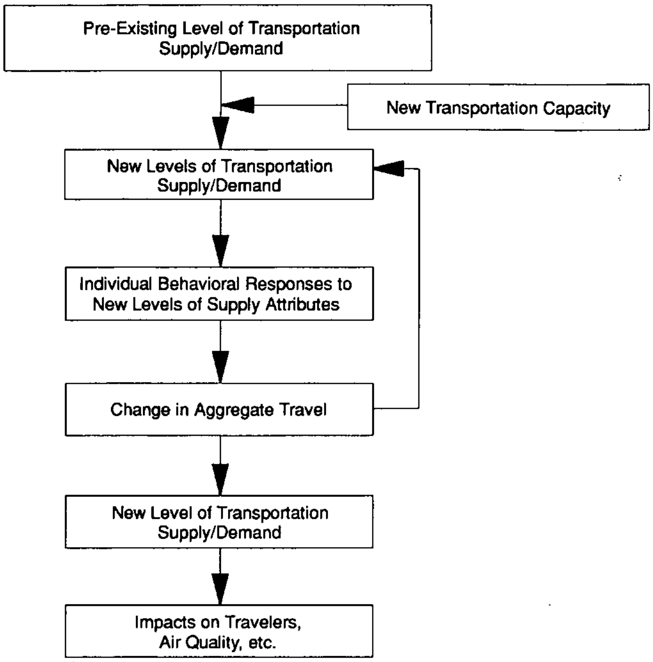

FIGURE 1 Conventional planning model for assessing benefits from changes in transportation capacity.

RELATIONSHIP OF TRANSPORTATION BENEFITS TO IVHS INFORMATION AND CONTROL

IVHS differs from conventional transportation improvements in the way information is communicated and used to increase the benefits from travel and system operation. Information is communicated in real time to the traveler on the transportation system status and operation and on travel services and trip end opportunities. Information is also communicated in real time to the system to improve its traffic (and ultimately its vehicle) control capabilities. Figure 2 shows the relationship of IVHS transportation benefits to various levels of information and control. Control—which is defined here as mandatory—is applicable only at signalized intersections and metered ramps and with degrees of roadway (or guideway) automation. Only vehicles are subject to mandatory control (in a democratic system).

Information/ Control	Applicable		Benefits
	To	Where	
Control	Vehicles	Intersections and metered ramps	Street and freeway link capacity maximization
Information	Travelers	Pretrip or en route	Multimodal network flow optimization
Control	Vehicles	En route	Link and network capacity maximization through automatic control

FIGURE 2 Relationship of transportation benefits to IVHS information and control (I).

On the other hand, as shown in Figure 2, information on highway and multimodal network status, travel conditions, routing, and guidance applies to people (not vehicles). Individual travelers use this information to plan and make all of their travel choices (e.g., mode, time of day, destination, and whether to make the trip at all)—not only the path or mode choice for which the information may be available.

Figure 2 shows that the transportation level-of-service and capacity benefits increase with improved information to the traveler and greater control of the vehicles. Fully automated vehicle operation (with resulting increases in information) will maximize link and network capacity. With automatic vehicle control, it is assumed that users will give up their route and mode control in a pretrip choice to use the system because it provides significant travel time, safety, and other benefits through guideway automation. If users trust the system, they will accept the guidance information on their multimodal options. If they trust the system even more, they will entrust their lives to an automated guideway that maximizes throughput.

RELATIONSHIP OF USER BENEFITS TO IVHS INFORMATION AND CONTROL

The inevitable consequence of the IVHS information infrastructure that will parallel the transportation infrastructure is a paradigm shift in how mobility is measured. When the sole concern was improving the physical transportation infrastructure, improvements were evaluated on the basis of the use of the network. Vehicle miles traveled (VMT) on the network and congestion and travel times on links were the measures of interest. With the development of a parallel information infrastructure, parallel emphasis must be on the use of the information, that is, how travelers use the information to make their travel decisions. Mobility, which is what travelers seek, is measured by the opportunities for, and the benefits from, travel. Figure 3 adds this dimension of information and mobility benefits to the more limited set of network flow benefits shown in Figure 2.

Information/ Control	Applicable		Benefits
	To	Where	
Control	Vehicles	Intersections and metered ramps	Street and freeway link capacity maximization
Information and conditions: Travel modes	Travelers	Pretrip or en route	Multimodal network flow optimization
Information and conditions: Trip-end activities/ services	Travelers	Pretrip or en route	Mobility maximization
Control	Vehicles	En route	Link and network capacity maximization through automatic control

FIGURE 3 Relationship of total benefits to IVHS information and control (II).

With IVHS, plans can be made to maximize the mobility benefits from travel, rather than produce an elusive level-of-service performance standard. One can anticipate that the new transportation information environment created through IVHS will provide more benefits as a result of the information it gives to travelers than from the shortened trip times it provides. This will result in higher-value use of personal time and resources for work and leisure activities and more productive use of commercial and industrial resources.

This means that IVHS systems will reduce or modify demand in response to the information they provide on congestion and trip end opportunities while providing benefits from increases in effective network capacity. Their contributions to user benefits will therefore result from demand management at the level of trip generation, as well as at the level of route and mode choice, which makes more effective use of existing capacity in the network. In other words, the benefits from such systems will come as much or more from user interactions with the system as from increases in effective network capacity that these systems supply. How this happens is discussed in the next section.

IVHS BENEFITS ASSESSMENT FRAMEWORK

Travel decisions involve a series of trade-offs between the times and costs of travel on all available alternatives and the benefits of travel from engaging in activities at the trip ends. Without adding capacity, the information from IVHS will increase the informed nature of these trade-offs and all of the adjustments people make to minimize their cost of travel (e.g., avoiding congestion). For example, with reliable travel time information, many travelers for whom the benefits of certain trips are small will choose to travel shorter distances, change modes, or forego or defer trips when congestion is heavy. Others may choose to travel to destinations that are farther away or else make more frequent trips with the confidence that they will not be caught in heavy congestion. The net increase in user travel benefits from these travel decisions will be substantial, yet aggregate reductions in VMT and travel times are not likely to reflect these benefits. In fact, the aggregate reductions are likely to be small. They may even be negative.

Another type of IVHS system is one that provides reliable attraction location information and travel directions to unfamiliar drivers at popular tourist destinations (for example, as supplied by the 1992–1993 Travtek demonstration in Orlando). This system is intended to improve travel routing efficiency and minimize the time one spends lost in a strange city. The system, however, is also likely to encourage tourists to visit more attractions and increase the entertainment value of tourists' vacations. Aggregate VMT and time spent traveling may increase, but mobility and user benefits will increase even more. It is reasonable to conclude that in this case also, the user benefits of IVHS will be much greater than those resulting from reductions (if any) in aggregate travel time and delay.

The traveler utility functions used in assessing the benefits from, and forecasting the travel impacts of, IVHS must therefore be redefined. Doing so will avoid serious underestimation of the user benefits of IVHS while allowing accurate estimation of the resulting aggregate numbers of trips and the link-specific vehicle volumes and conditions of travel on which the flow-related physical impacts of IVHS are based (e.g., accidents, fuel use, air quality). These concepts are brought together in Figure 4, which shows the proposed IVHS benefits assessment framework.

Differences from Conventional Planning Model

The major difference between the IVHS benefits assessment framework in Figure 4 and the conventional "planning model" in Figure 1 is that the travel volumes and flow conditions used in calculating the impacts on air quality, energy use, and so on, of an IVHS improvement are not used in calculating the user benefits from the improvement. The IVHS evaluation framework splits the benefit calculations in two parts, with the introduction of real-time travel and trip-end opportunity information provided by IVHS. User benefits are calculated separately from the link travel volumes in the behavioral travel demand model. Therefore, the air pollution, fuel consumption, and other travel volume–related impacts of IVHS are not directly related to the sum of the individual user benefits of IVHS. (Note, however, that Figures 1 and 4 both adhere to the same supply and demand mechanism governing the assessment of benefits from transportation improvements.)

IVHS evaluation therefore requires that changes be made to the data input to the travel demand models. Current travel models are based on average travel times and costs on highway links or scheduled times on transit links. Travel forecasts to evaluate IVHS systems must receive, as input from a traffic simulation model, the travel times and costs on the various

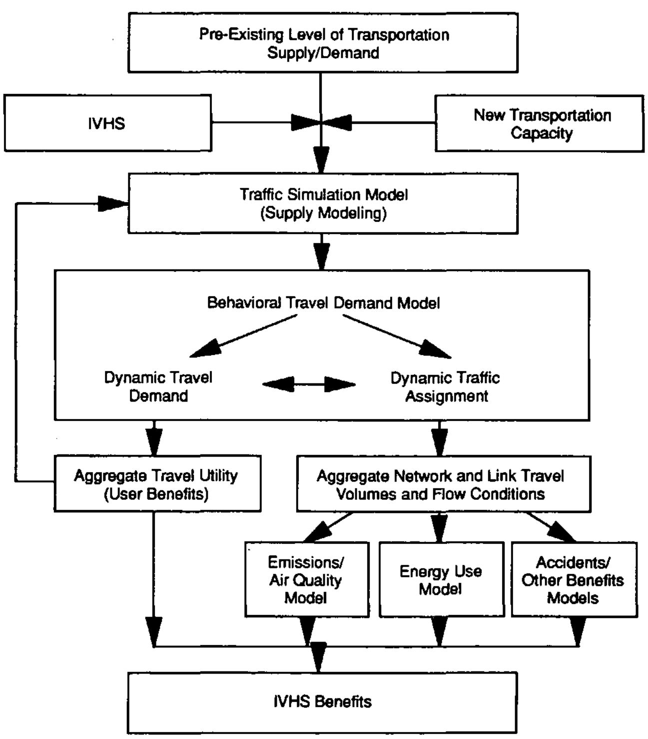

FIGURE 4 IVHS benefits assessment framework.

travel choices provided to travelers in real time. This avoids serious underestimation of the user benefits of IVHS while allowing estimation of the resulting aggregate numbers of trips and the link-specific vehicle volumes and conditions of travel on which the flow-produced physical impacts (e.g., fuel use, safety, and air quality) of IVHS are based.

Demand models for evaluating IVHS must also take into account the fact that information given to travelers on, for instance, highway congestion and route guidance may affect all the travel choices of travelers, not only the route choice for which the information is provided. Behavioral travel models must be able to forecast these changes in trip frequency, destination choice, departure time, mode choice, and so forth. These changes must be predicted at the level of the behavioral unit—the trip itself. Similarly, when evaluating an operational test, the model cannot be restricted to anticipating and measuring only changes in path characteristics (e.g., link volume and travel times). To do so would be to overlook many of the important impacts of IVHS improvements.

Specification of Traveler Utility Functions

The utility functions for our travel demand models must also incorporate variables representing the mobility benefits from engaging in the trip-end activities in the traveler's newly expanded choice set. These variables are required to calculate the net increase in benefits from, for example, high-value trips to destinations further away, or trips made more frequently with the information from IVHS that the traveler will not be caught in heavy congestion. If motility benefits are not included, comparisons between the new and old (without IVHS) travel times may show negative user benefits from the longer (higher-value) trips made with improved travel information from IVHS.

The utility functions for demand models also will need to incorporate not only the "traditional" travel time and cost variables but also variables describing the IVHS information itself. These may include human factor variables on information sequencing and display and variables describing the new dimensions that the information adds to the value of the traditional level-of-service variables normally included in demand-model utility functions.

The two most important examples of the new variables are likely to be the reliability of the information and the degree of control over the person's time and life that the new information provides. Travel time reliability has been recognized for decades as an important variable for travel demand forecasting. Its valuation (quantification) in traveler utility functions, however, has been almost entirely lacking. It is currently measured by the variance in travel times on a highway or transit (door-to-door) route. The traveler perceives reliability as the difference between his or her average travel time and day-to-day travel time actually experienced.

There is considerable psychological evidence that a few large negative travel time experiences are much more highly valued than many positive values (negative reinforcement). This is consistent with evidence that as they come to depend on more reliable information, travelers value it highly. This has already happened in logistics and with overnight package delivery. Small package delivery companies track package movements at every step. The fax machine is another example of how new technology has escalated our concern for service quality.

In the case of IVHS, the transportation system will be more able to respond in its allocations of highway and transit capacity to additional traffic and passenger loadings, thus decreasing the severity of travel time fluctuations under many conditions. In addition, as IVHS systems monitor travel conditions in real time and are improved to the extent that they can predict future system loadings and future travel conditions, they will significantly reduce the error in the travel times on the various travel choices presented to travelers by IVHS (i.e., the variance between the travel time presented to travelers and the times they actually encounter).

As important as time is, the most important variable to be considered may be the added control over time that IVHS may ultimately provide. It has been stated that "metropolitan areas have a strong hold on the externalities that promote population growth. Suburbanites want control over the temporal and spatial dimensions of their travel and will pay large sums of money for these" *(3)*.

The desire to control one's use of time will increase as one's ability to control it increases. IVHS will allow travelers to control, or at least better manage, their use of time at their trip destinations and the levels of congestion or delays that characterize their travel to those destinations. Thus the control over time that IVHS will provide should make travel time even more valuable.

Valuing IVHS User Benefits

Valuing the user benefits from IVHS requires the use of behavioral travel demand models, as shown in Figure 4. As noted earlier, demand models and survey data at the level of the individual traveler are needed to measure the mobility improvements provided by IVHS. The disaggregate data required to estimate the demand models can be developed from stated preference surveys and carefully evaluated operational tests.

In general, the only transportation system change that should be included in valuing the user benefit of a transportation improvement is the item being changed. For example, in an evaluation of a conventional transit improvement, the only transportation system change that should be input to the demand model is the transit system change. User benefits from this change accrue both to existing transit users and to automobile users who divert to transit as a result of the change. However, the user benefit from an automobile trip diverted to transit is only the change in the utility function value used by the traveler in deciding to switch from automobile to transit. The automobile costs do not enter into this change; only the transit "costs" change. This applies even if automobile service is improved in the process.

In the IVHS context, the change is the (valid) information on the chosen trip, including the trip-end benefit from the trip. A person makes the travel choice that yields the highest utility from weighting the variables in his or her utility function. The utility function is used in the behavioral model to calculate the change in traveler benefit, which is needed to explain (cause) the shift in travel behavior (e.g., route, mode, departure time) predicted for the IVHS improvement or observed in the IVHS operational test. Valuing the user benefit includes the user's valuation of change in all of the variables included in the properly specified traveler utility function. The change can be valued monetarily at the change in travel cost (price) that is equivalent to the change in the traveler's utility. Half of this value can be used in the usual manner to quantify the area in the consumer surplus triangle relating to induced travel, whereas the entire area in the consumer surplus rectangle can be used to calculate the value of the IVHS benefits for existing travel.

These observations are made here to emphasize that a proper accounting of the user benefits of IVHS improvements is very important. The changes being evaluated are the IVHS information presented to the traveler and the improvements in system operation made possible with this information. Valuation of these benefits from the IVHS improvement must include the changes in all of the mobility and information attributes in properly specified traveler utility functions that are incorporated in behavioral travel demand models. Significant improvements in these models are needed, as discussed in the next section.

Behavioral Travel Demand Models

In the evaluation framework shown in Figure 4, the behavioral demand model is used to forecast the changes in all of the travel choices (path, mode, departure time, trip frequency, destination) to

- Quantify the user benefits from the information supplied to travelers and the improved system performance and
- Calculate the flow volumes and travel conditions on links in the network, which are required as inputs to the models of flow-related physical impacts.

Behavioral travel demand models are needed that explain individual travel behavior. Figure 5 illustrates a model of individual behavior that incorporates IVHS information on activity and travel opportunities *(4)*. The individual has information about a set of opportunities to engage in activities at various locations, some or all of which may involve travel.

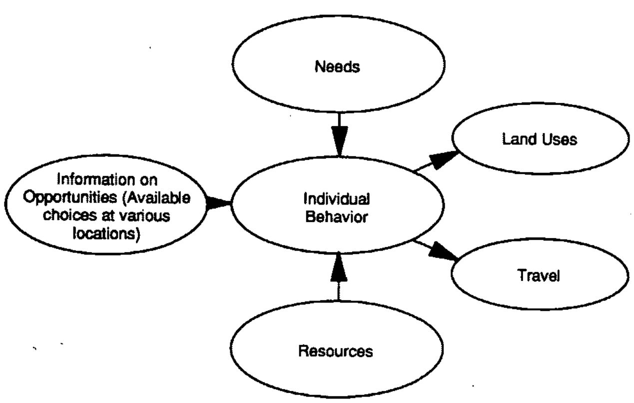

FIGURE 5 Suggested paradigm of individual behavior incorporating IVHS information.

The individual also has needs—to work, shop, play, and be safe and also to have a home. These condition how the individual chooses from among various activity opportunities that involve travel. The individual also has resources (e.g., time and money) that affect his or her response to opportunities to travel and engage in activities at various places and prices.

The lack of a direct causal relationship between land use and travel is shown in Figure 5. A third variable drives them both, namely individuals responding to opportunities, needs, and resources to "consume" both land and travel. Empirically, the presence of the third variable has been amply demonstrated; individuals consume both more land and more travel as their income increases *(5)*.

The sequential aggregate travel demand models used today in urban transportation planning are well known to be highly deficient in their sensitivity to changes in even conventional transportation capacity. Trip generation equations are almost always totally insensitive to travel conditions. Trip distribution is modeled as a function of a simple description of trip lengths that prevailed at the equilibrium between supply and demand, represented in trip data, and so on *(6)*. These sequential models are not adequate to evaluate IVHS improvements, both because they are not capable of incorporating properly specified travel utility functions and because they are much too cumbersome to operate in the context of dynamically changing travel conditions.

More likely than not, the selected models of individual travel choice behavior incorporating the traveler utility functions that are necessary for valuing user benefits will be "direct demand" models. Current direct (travel) demand models forecast travel directly by mode between origins and destinations as a function of the activity systems at the origins and destinations, and the price and level-of-service conditions by the travel mode and all its substitutes *(7)*. These direct demand models are themselves simplifications of general equilibrium models that explain how land use and travel vary simultaneously with transportation improvements (8). They are partial equilibrium models that describe how part of the system behaves so it will be in equilibrium with the rest of the system. Thus, there is modeling of the behavior of the tripmaker, who considers all trip end opportunities to be fixed. This may or may not be appropriate for IVHS evaluation, depending on how the models' relationships between travel and its determinants are structured. The paradigm in Figure 5 suggests that the evaluating IVHS systems, developing models that incorporate real-time information on dynamically changing travel opportunities and costs may be at least as important as developing general equilibrium models.

Dynamic Travel Models

The IVHS benefits assessment framework in Figure 4 shows that traffic simulation models are used to input initial "supply" conditions into the behavioral travel demand model. For example, it is relatively straightforward to model the effects of improved traffic signal settings from IVHS (ATMS) on a fixed set of link-traffic volumes, using currently available tools such as NETSIM and TRAF-NETSIM. However, because queuing is so characteristic of congested highways, assuming link flows and travel times to be time invariant does not accurately describe the stochastic nature of congested traffic. For this reason, the framework in Figure 4 separates the initial simulation models from the later dynamic travel models.

Dynamic travel models are intended to analyze the effects of IVHS information on travel volumes and congestion levels in high-volume networks. The state of the art in dynamic assignment and simulation for IVHS is summarized by Mahmasani et al. *(9)*. At present, most dynamic travel models are highway path-choice models, which provide the ability to

- Model the route-choice behavior of drivers with and without access to IVHS information;
- Predict travel times on the basis of the assignment results and provide feedback to the control center that may be used in the assignment of vehicles; and
- Track the location of the drivers who receive guidance information from the control center.

Work on dynamic traffic assignment is moving rapidly for descriptive user equilibrium and normative system optimizing problems. Key research areas are modeling and incorporating the appropriate travel behavior decisions and representing the dynamic (transient) traffic phenomena of congested networks.

Ultimately, dynamic traffic assignment (path choice) models will be fully integrated into the behavioral demand model, as shown in Figure 4. For an example of a model system that combines mode, departure time, and route choice in a dynamic model, with interdependent travel costs, see Boyce et al. *(10)*. The interaction of these models with the models of the other travel choices will be complex because the objective is to model (explain) not only path choice but also, as discussed earlier, the behavior of individuals making, for example, high-value trips to destinations farther away, or trips made more frequently with the information from IVHS that the traveler will not be caught in heavy congestion. The behavioral response to this information is anything but fixed. To be able to model (or simulate) it in a time-varying (dynamic) context, it is necessary to understand the cause-and-effect mechanisms that govern travel behavior. Unfortunately, empirical data on these behaviors are as yet extremely limited.

Regardless of whether they describe time variant or invariant travel and flow conditions, the behavioral travel models used for IVHS evaluation must contain appropriate supply and demand equilibration mechanisms that ensure that the information given to travelers (and input to the travel model) is the same as that produced by the model. This is the only way to assess whether IVHS can permit travel at more efficient speeds and thereby reduce air pollution, and so on. The linkages between all of the travel choice models, however dynamic, must converge on a steady-state output, albeit with the required stochastic distributions of traffic characteristics. This does not preclude modeling the response of travelers over time in all of the travel choice models (including dynamic traffic assignment), as they receive information on time variant travel and trip-end activity conditions.

FLOW-PRODUCED PHYSICAL IMPACT MODELS

The final set of models in the evaluation framework in Figure 4 are the models linking the emissions, safety, fuel use, noise, and other flow-produced physical impacts with the travel volumes and flow characteristics resulting from the IVHS improvement. For example, to evaluate whether candidate IVHS strategies are compatible with CAAA requirements, the framework links the travel demand model with the mobile source emissions models to assess air quality impacts. Currently available emissions and other impact models that use flow volumes and travel conditions as inputs are relatively easy to adapt to an IVHS evaluation.

Measuring the mobility improvements from IVHS on the basis of the behavioral unit of travel—namely the trip—has advantages not only for evaluating user benefits but also for measuring air quality impacts. For example, well over half of vehicle emissions from even a long (20-mi) summer automobile commute are caused by the trip being made in the first place—the combination of trip start emissions and hot soak emissions at the trip end—not by the VMT on the links of the network.

Ultimately, it is important to recognize that estimation of carbon monoxide and hydrocarbon emissions (for example) from motor vehicles is a complex process that requires a substantial amount of information on the amount and type of travel, vehicle activity (start, cruise, idle, acceleration, deceleration, time between starts and trips), vehicle characteristics (type of vehicle, age, size, engine type, transmission system, antipollution devices, type of gasoline used), vehicle operating conditions (hot versus cold starts, engine temperature, vehicle load, speed of vehicle), environmental conditions (altitude, ambient temperature), and roadway conditions (horizontal and vertical alignments). An accurate estimation of the pollutants from vehicle emissions may necessitate analysis at a very detailed level, beyond the resources and data available for typical transportation planning studies.

Institutional factors will also dictate the inclusion of certain variables and relationships in the framework. These range from required output variables (e.g., specifically mandated air quality measures) to restrictions on the way the system can operate (e.g., liability governing when and how IVHS information can be presented) to whether IVHS develops as a stand-alone system or becomes part of a metropolitan information utility with consumers trading off many activities that compete for their time and money (potentially involving new layers of variables and relationships).

IMPLEMENTING IVHS EVALUATIONS

The evaluation modeling framework presented in this paper is designed explicitly to quantify the benefits of IVHS, including additional benefit measures to those from conventional transportation improvements, to avoid seriously underestimating the benefits from these improvements. Figure 6 presents a list of evaluation measures relevant for evaluating IVHS improvements that are in addition to those normally used to evaluate conventional transportation improvements. The additional user benefit measures in Figure 6 are the primary focus of this paper.

Ultimately, what is included in IVHS evaluations is linked to the goals set for IVHS: what travelers want and expect IVHS to accomplish. For example, some proponents of IVHS see the potential of IVHS strategies for internalizing some of the current external (social) costs of congested highway travel.

For Conventional Transportation Improvements:

- User Benefits
  - Travel time
  - Travel cost
  - Safety
- Costs
  - Construction (capital)
  - O&M
- Externalities
  - Air quality
  - Fuel/energy consumption
  - Noise
  - Land use patterns
  - Neighborhood impacts
  - Productivity/economic development

For IVHS Add:

- User Benefits
  - Benefits from trip end opportunities
  - Travel time reliability
  - Control
  - Privacy
  - Legal
- Implementation Risk
  - Feasibility
  - Technology flexibility
  - Ease of implementation and use (staffing/skills)
  - Community acceptance
  - Agency Coop./Coord.
- Other Benefits
  - Improved data collection

FIGURE 6 Additional measures needed to evaluate IVHS improvements.

Individuals currently perceive only a fraction of the total congestion they cause. Every time a driver enters a heavily congested roadway, far more aggregate delay is imposed on others—on the system—than on that driver. In turn, this aggregate delay results in far more air pollution and energy consumption by others than by the individual causing the delay and pollution in the first place. In fact, the more congested the highway, the greater the difference between the social and private costs of making an additional or longer trip by automobile *(12)*.

Congestion is also the price that the current transportation system imposes on everyone as a result of individual life-style decisions to locate in sprawling regions and on larger plots of land, farther away from work and shopping. And because increasing amounts of money are spent on housing, the transportation price that individual life-style decisions impose on everyone else is not known by the individual making those decisions. Individuals make investments in expensive housing without considering the total cost of their location decisions *(4)*. IVHS is likely to play a role in promoting more informed activity location decisions in the long run, just as it informs such decisions in the short run.

The evaluation framework presented in this paper is intended to help guide the evaluation and selection of IVHS projects on the basis of their site-specific benefits and costs, rather than their desired results. Although the latter is entirely acceptable for planning a research program whose payoff cannot be known in advance, it is necessary to proceed to the next step of carefully evaluating operational field tests and advancing IVHS into its production mode. The causal framework described in this paper allows one to anticipate the important consequences of IVHS and therefore carry out benefit-cost analyses of new investments as well as collect the appropriate data for planning and evaluating operational field tests.

REFERENCES

1. *Special Report 232: Advanced Vehicle and Highway Technologies*. TRB, National Research Council, Washington, D.C., 1991.
2. D. Brand. Conference Summary. In *Special Report 237: Moving Urban America*, TRB, National Research Council, Washington, D.C. 1993.
3. J. D. Kasarda. Population and Employment Change in the United States: Past, Present and Future. In *Special Report 220: A Look Ahead: Year 2020*, TRB, National Research Council, Washington, D.C., 1988, pp. 83–148.
4. D. Brand. Research Needs for Analyzing the Impacts of Transportation Options on Urban Form and the Environment. In *Special Report 231: Transportation, Urban Form, and the Environment*, TRB, National Research Council, Washington, D.C., 1991, pp. 103–107.
5. E. A. Deakin. Jobs, Housing and Transportation: Theory and Evidence on Interactions Between Land Use and Transportation. In *Special Report 231: Transportation, Urban Form, and the Environment*, TRB, National Research Council, Washington, D.C., 1991, pp. 25–42.
6. D. Brand. Use of Travel Forecasting Models To Evaluate the Travel and Environmental Effects of Added Transportation Capacity. Presented at DOT/EPA Conference on the Travel and Environmental Effects of Added Transportation Capacity, Bethesda, Md., 1991.
7. T. A. Domencich, G. Kraft, and J.-P. Valette. Estimation of Urban Passenger Travel Behavior: An Economic Demand Model. In *Highway Research Record 238*, HRB, National Research Council, Washington, D.C., 1968.
8. D. Brand. Theory and Method in Land Use and Travel Forecasting. In *Transportation Research Record 422*, TRB, National Research Council, Washington, D.C., 1973.
9. H. Mahmasani et al. *A Review of Dynamic Assignment and Traffic Simulation Models for ATIS/ATMS Application*, The University of Texas at Austin, 1992.
10. D. Boyce, B. Ran, and L. LeBlanc. *A Combined Dynamic Model Departure/Route Choice Model with Multiple Groups of Travelers*. Presented at 72nd Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 1993.
11. P. De Corla-Souza. *Surburban/Urban Transportation Investment—What Will It Cost and Who Will Pay*. FHWA, U.S. Department of Transportation, 1990.

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