Criteria and Methods for Evaluating Intelligent Transportation System Plans and Operational Tests

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An evaluation process for the preparation of intelligent transportation system (ITS) plans that is sensitive to the differences between ITS and conventional transportation improvements is described. [The term "intelligent transportation system" replaces "intelligent vehicle-highway system (IVHS)."] A relatively complete set of evaluation criteria for ITS improvements is presented that is structured to clarify the confusion between the supply and demand impacts of ITS. This separation between "efficiency" and "output" measures means that it is possible to distinguish between ITS technology efficiency benefits and the individual and corporate demand responses to ITS that actually increase output (benefits) over those produced by the technology alone. The proposed criteria structure also incorporates the time scale of the impacts. This highlights certain fundamental correlations between the criteria that can lead to double counting of benefits and to highly correlated outcomes, which are not helpful in choosing between alternatives. The criteria structure facilitates selection by decision makers of greatly reduced criteria sets to simplify ITS evaluations. By recognizing the separate supply (efficiency) and demand (increased output) impacts of ITS, it is also possible to avoid dramatically underestimating the benefits of the new technology and to avoid serious mistakes in assessing the safety, environmental, and energy impacts of ITS alternatives. Default values to evaluate ITS improvements for inclusion in transportation system plans are provided. The criteria and default values highlight where research and operational tests can provide improved values and information that will most quickly advance the state of the art of ITS evaluation.

Developing and evaluating intelligent transportation system (ITS)—formerly intelligent vehicle-highway system (IVHS)—plans require a methodology that meets the following requirements:

1. Is fully sensitive to differences between ITS and conventional transportation improvements;
2. Recognizes that many criteria are measures of the same benefits and therefore aggregates these evaluation criteria to minimize double counting and misplaced higher implied weights given to the same consequences under different names;
3. Is sensitive to the needs of various groups in society and areas within a region or state to benefit from the program;
4. Provides strategic direction (where should we head and is it really worthwhile to undertake ITS projects to get there?);
5. Emphasizes accurate and sensible results (subject to face validity checks) rather than (false) precision;
6. Avoids criteria specific to individual actions that promote their adoption in a "self-fulfilling" evaluation; and
7. Focuses as much as possible on site-specific results (rather than hoped-for achievement of benefits in a generic type of setting).

To satisfy Requirements 1 and 2 it is necessary to do the following:

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- Avoid underestimating the mobility and other personal and corporate economic benefits from ITS; and
- Recognize the occurrence over varying periods of time of the same impacts under different names.

Requirements 3 and 4 lead to a three-stage evaluation process:

1. Stratification of projects by location (e.g., by geographic area within a region or a state);
2. Grouping of projects by their relative merit within strata; and
3. Evaluating the absolute worth of candidate ITS projects for inclusion in a system plan or reporting the results of an operational test.

ITS EVALUATION PROCESS

Figure 1 is a flowchart of the ITS plan development and evaluation process. The process starts with development of program goals and a set of candidate projects responsive to these goals. As shown in the flowchart, the projects can be stratified by geographic area (location) within the region or state for which the ITS plan is being developed. Project impacts and costs are then assessed relative to a set of evaluation criteria developed as described below, and the projects are grouped by their relative merit within strata. A budget constraint can be developed for each stratum, and projects from the groups having the most merit can be included in programs of projects up to the budget limits for each stratum.

Finally, for them to be included in an ITS system plan, the projects must meet not only the budget test but also an absolute-worth test. Therefore, the last stage of the evaluation process involves carrying out program-level benefit-cost analyses. If the programs of projects have benefits that exceed their costs, the program can be recommended for implementation. If a program fails the benefit-cost test, the process can be repeated, at least to the step of revising the allocated program budget for the relevant project stratum. The process may also require redefinition of the evaluation criteria or program goals, or both.

In summary, this evaluation process implies that there will be a cutoff of projects in the plan on the basis of adhering to known or assumed budget limits, as well as meeting certain benefit-cost thresholds. In addition, this evaluation process breaks considerable new ground. A comprehensive screening and evaluation of a very widely cast net of candidate ITS projects based on their site-specific benefits and costs had not been carried out earlier before the application of this methodology in the preparation of the Washington State and metropolitan Boston ITS strategic plans (*1*). In the past,

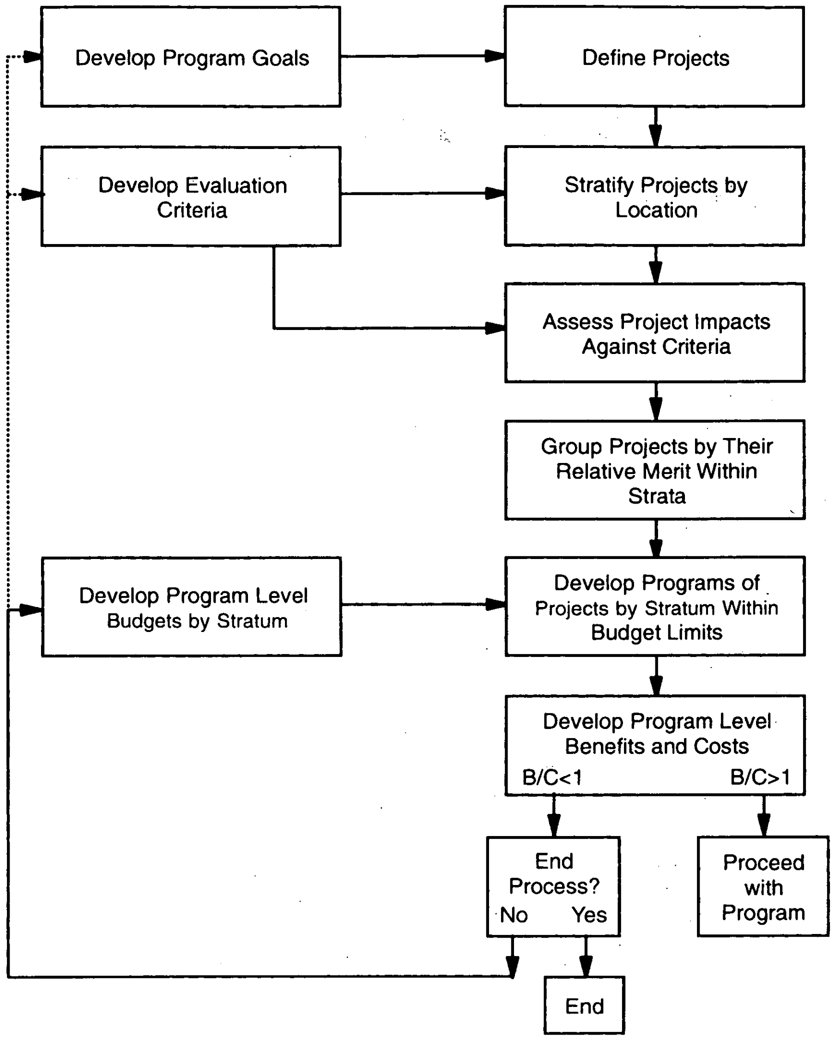

FIGURE 1 ITS evaluation methodology.

ITS plans have consisted of lists of projects deemed worthwhile on the basis of hoped-for results. Although this method is entirely acceptable for planning a research program whose payoff cannot be known in advance, ITS is now advancing, as it should, into its production mode. This puts severe demands on the current status of knowledge of ITS impacts.

Similarly, the evaluation of ITS operational field tests requires identifying and anticipating the impacts of ITS to be able to measure them as part of the operational test evaluation. Since only now is it becoming possible to recognize the existence of very important differences between the impacts of ITS and those of conventional transportation improvements, there is considerable uncertainty in quantifying many, if not most, ITS benefits. These limitations point up the urgent need for systematic evaluations of ITS operational tests to be able to quantify the impacts of ITS projects and develop ITS system plans that provide net benefits to society. The first step in this process is to develop an appropriate set of evaluation criteria that allows one to anticipate and evaluate the important impacts of ITS projects.

PROPOSED EVALUATION CRITERIA

A comprehensive list of appropriate ITS evaluation criteria is presented in Table 1. Except for the costs of ITS, most of the criteria in Table 1 are positively worded, which is not intended to imply that ITS projects have only positive impacts. Certainly there will be projects that score negatively with respect to various criteria.

The major structure of the criteria in Table 1 is along the following two dimensions:

	Time Scale		
Criterion Type	*Short Term*	*Medium Term*	*Long Term*
Increased operational efficiency (supply)			
Demand adjustments that further increase output			

This structure deals head-on with the great confusion between supply and demand impacts in ITS evaluation. The separation between efficiency (Criterion 1.0 in Table 1) and output (Criterion

TABLE 1 Comprehensive List of ITS Evaluation Criteria

1. Increased Operational Efficiency (supply-side efficiency, meaning more output per unit of input)

 1.1 Short Term: Transportation System Operation

  1.1.1 Infrastructure Efficiency
  - Increased throughput or effective capacity
  - Increased speeds
  - Reduced stops
  - Reduced delay at intermodal transfer points
  - Reduced operating costs (e.g., from ETTM or information for incident response, etc.)
  - ITS O&M cost

  1.1.2 Vehicle Efficiency

   1.1.2.1 Private Autos
   - Increased vehicle occupancy
   - Reduced operating costs (including wear and tear)
   - ITS O&M cost

   1.1.2.2 Transit
   - Reduced operating costs
   - Increased usage (i.e., volume of people moved)
   - Facilitate fare collection and fare reduction/equity strategies
   - APTS O&M cost

   1.1.2.3 Freight
   - Reduced operating costs
   - Increased throughput (i.e., volume of goods moved by the existing fleet)
   - CVO O&M cost

 1.2 Medium Term: ITS Costs
 - Capital costs of ITS
 - Liability costs of ITS

 1.3 Long Term: Investment Costs
 - Reduced capital costs of new infrastructure
 - Improved data for more cost-effective transportation investment planning
 - Improved data for concurrency planning

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2.0) measures means that it is possible to separate the ITS technology benefits from the individual and corporate demand responses to ITS that actually increase output (benefits) over those produced by the technology alone. This separation also makes it possible to evaluate induced travel. Induced travel has its negative physical (travel volume, congestion, and flow-related environmental) impacts and positive mobility and economic benefits; each one is dealt with separately (if imperfectly, given today's demand models).

The structure also deals explicitly with the time frame of the impacts. Some impacts occur quickly, typified by travel behavior responses to ITS changes (Criterion 2.1). Some take more time to occur, as exemplified by ITS technology investments (Criterion 1.3) and investments in other plants and equipment (Criterion 2.2) to increase the productivity of the economy. Finally, there are the long-term impacts such as infrastructure cost savings and changes in long-run demand (Criteria 1.3 and 2.3, respectively). In most cases, the impacts that occur over various lengths of time are responses to the same underlying benefits of ITS. Therefore, the same benefits may be considered (double counted) a number of times. Organizing the impacts according to their time scale highlights certain fundamental correlations between the criteria and helps simplify the evaluation process. This is discussed further.

More generally, the evaluation criteria in Table 1 are not ITS strategy or technology specific. For example, "reduced delay at border crossings" is not included as a separate criterion because it suggests a certain set of actions; rather, "reduced delay" and reductions in the various personal, shipper, and corporate user costs should suffice. Similarly, the following are not included on the list:

- Reduced delay from improved incident detection,
- Reduced incident response times,
- Reduced accidents from improved . . . ,
- Benefits from 911 emergency services,
- Improved air quality by smoothing traffic flow, or
- Information to agencies to improve system operation.

These criteria are all specific to individual ITS options or strategies. They are not included in Table 1 because they are biased to the options and would lead to "self-fulfilling" evaluations.

TABLE 1 (*continued*)

2. Increased Output (demand adjustments that further increase output or benefits from ITS improvements)

   2.1 Short Run: Mobility

   2.1.1 Personal (passenger)
   - Increased travel opportunities (trip end benefits)
   - Decreased costs (disutility) of travel (including travel and delays to unfamiliar drivers/travelers). Includes:
     - Increased awareness, and ease of use of transit and ridesharing
     - Travel time (and its various components)
     - Travel time reliability
     - Travel cost (and its various components)
     - Comfort, stress, fatigue, confusion, etc.
     - Safety and personal security
   - Increased sense of control over one's own life from predictable system operation (including toll and transit fare charges)

   2.1.2 Freight
   - Decreased cost of freight (goods) movement to shippers, including:
     - More reliable "just in time" delivery
     - Travel time
     - Travel cost
     - Driver fatigue, stress, etc.
     - Cargo security
     - Safety (e.g., from tracking hazardous material)
     - Transaction costs

   2.2 Medium Run: Economic Development
   - Increased access to
     - Labor
     - Materials
     - Markets
   - Increased industrial output
   - Reduced costs
   - Increased investment in plant and equipment
   - Opportunities for new services/product innovation
   - Opportunities for public/private partnerships
   - Increased international competitiveness

   2.3 Long Run: Personal Adaptations
   - Lifestyle changes
   - Land use (settlement) pattern changes (to internalize or otherwise be "informed by" congestion and other social costs of private travel and location decisions)

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WHY SEPARATE DEMAND SIDE FROM SUPPLY SIDE?

ITS differs from conventional transportation improvements in the way information is communicated and used to increase the benefits from travel and transportation 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 operational control capabilities and its ability to provide the most helpful information to the traveler.

When the pre-ITS concern was to improve the physical transportation infrastructure, improvements were evaluated on the basis of the use of the network. Aggregate observable 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; how individual travelers use the information to make their personal travel decisions and how firms use the information to ship their product. Mobility, which is what is being sought, is measured by the opportunities for, and the benefits from, travel. One can anticipate that there will be significant individual and corporate demand responses (Criterion 2.0 in Table 1) to the ITS information that will increase the benefits of ITS systems over and above their improved system operational efficiency (Criterion 1.0). These mobility benefits of ITS must be measured at the level of the individual tripmaker or firm instead of being based on aggregate flow volumes or travel times on the network (*2*).

For example, by providing reliable attraction location information and travel directions to unfamiliar drivers, the 1992–1993

TABLE 1 *(continued)*

3. Safety

- Increased personal security
- Reduced number and severity (cost) of:
  - P.D. accidents
  - P.I. accidents
  - Vehicle thefts
- Reduced fatalities

4. Environment and Energy (physical impacts)

4.1 Environment
- Reduced vehicle emissions
- Reduced noise pollution
- Reduced right-of-way requirements
- Neighborhood traffic intrusiveness (affecting community acceptance)

4.2 Energy
- Reduced fuel consumption

5. Implementation

5.1 Ease of Implementation/Deployment
- Technical feasibility (including standards issues)
- Regulatory support
- Revenue and financial feasibility
- Equity impacts
- Privacy impacts
- Availability of staffing/skills
- O&M requirements

5.2 Agency Cooperation/Coordination
- Increased sharing of incident/congestion information
- Reduced information-gathering costs
- Increased coordination/integration of network operation, management and investment
- Agency commitment to ITS system

5.3 Technology Flexibility
- Ability to evolve with changes in system performance requirements and technology

Travtek demonstration in Orlando was intended to minimize the time spent lost in a strange city. In addition, the information the system provided was likely to encourage tourists to visit more attractions and increase the entertainment value of their vacations. Aggregate VMT and time spent traveling might increase, but mobility and user benefits would increase even more. It is reasonable to conclude that the user benefits of ITS will be much greater than those resulting from reductions (if any) in aggregate travel time and delay.

In the more general case, travel decisions involve a series of tradeoffs 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 ITS will increase the informed nature of these tradeoffs and all of the adjustments people make to minimize their cost of travel (e.g., to avoid congestion) and maximize their benefits from travel. For example, with reliable travel time information, travelers for whom the benefits of certain trips are small may choose to travel shorter distances, change modes, or forgo or defer trips when congestion is heavy. Others may choose to travel to higher-value destinations that are farther away or make more frequent trips with the confidence that they will not be caught in heavy congestion. Trip end information on the availability (in real time) of goods and services at specific prices and locations (e.g., stores) would eliminate searches involving travel to obtain the same information. ITS systems likely 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. The net increase in user travel benefits may be substantial, yet aggregate observable reductions in VMT and travel time are not likely to reflect these benefits. In fact, the aggregate reductions in VMT and travel time are likely to be small.

This means that estimates of the mobility and other personal and corporate economic benefits of ITS that are based on aggregate observable flow volumes and travel times on the network are likely to seriously underestimate these benefits. Instead, it is necessary to measure the demand-side benefits of ITS at the individual tripmaker and firm level, rather than base them on aggregate measures of flow volumes and travel times on the network. This is the reason it is necessary to separate the demand-side criteria, measurable at the individual (disaggregate) level (Criterion 2.0 in Table 1), from the more familiar aggregate observable supply-side efficiency criteria (Criterion 1.0) in evaluating ITS plans and operational field tests.

WHY SEPARATE ITS IMPACTS BY TIME FRAME OF OCCURRENCE?

As noted earlier, the proposed evaluation structure deals explicitly with the time frame of the impacts. On the supply side (Criterion 1.0), certain impacts occur quickly, such as increased vehicular speeds and throughput, reduced commercial vehicle operating and maintenance costs, and improved transit operating characteristics (travel times and delays). On the other hand, possible cost savings from reduced infrastructure construction can take a long time to occur. It is also not proper to count these construction cost savings as benefits, because if the money actually were spent and new facilities were constructed, the new capacity would provide additional benefits over and above what the original ITS investment provided. Therefore, the original operational benefits of ITS that led to the long-run infrastructure cost savings are really the relevant benefits to use in the evaluation. Counting the infrastructure cost savings double counts the benefits that give rise to the cost savings (and also ignores other benefits of the additional expenditure).

The most important reason for organizing the criteria by the time frame of their occurrence is to highlight certain fundamental correlations between the criteria and to simplify the evaluation process. In most cases, the impacts that occur over various lengths of time are responses or adjustments to the same underlying benefits of ITS. For example, with regard to the demand impacts (Criterion 2.0), there is a well-known hierarchy of short-run (travel) to long-run (land use) behavioral responses to transportation system changes for which separate forecasting models and relationships are (mistakenly) used to evaluate impacts (*3*). (Also, these models have been developed only to forecast the short- and long-run demand consequences of transportation capacity increases, not the information infrastructure that sets ITS apart from conventional transportation improvements.) In any event, it is important to understand that the longer-run behavioral responses to transportation system changes, namely the land use and productivity/economic development (Criteria 2.3 and 2.2, respectively) impacts, usually involve double-counted short-run mobility (Criterion 2.1) benefits to both passengers and shippers. Why this is so is discussed in the following paragraphs.

The common origin of both the short-run (travel) and long-run (land use) behavioral responses to ITS improvements is shown in Figure 2 (*4*), the chain of causality in a model of individual behavior that incorporates ITS information on activity and travel opportunities. The individual utilizes information on opportunities to engage in activities at various locations, some or all of which may involve travel. The individual also has needs: to work, shop, play, be safe, and have a home. These determine how the individual chooses from among the various activity opportunities. 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.

Figure 2 highlights the lack of a direct causal relationship between land use and travel. Both impacts stem from a third variable, namely individuals responding to information on opportunities, needs, and resources to "consume" both land and travel. Empirically, the presence of third variables driving both land use and travel has been amply demonstrated; individuals consume both more land and more travel as their income increases (*5*). Understanding that ITS information has the potential to affect both allows one to better assess these impacts in this evaluation.

In general, land value increases from increased transportation accessibility are considered to be the capitalized stream of short-run user travel benefits from the improvement. Even if ITS leads to longer trip lengths and "sprawl," one can assume that the benefits from trip length increases resulting from higher-value residential locations and other activities at the trip ends are equal ("at the margin") to the added travel time/cost of these longer trips. Therefore, it is possible to avoid making value judgments on the worth of various land use distributions and use the results of individual choice behavior first to determine the numbers of trips made with each length and mode and second to value these trips at the values used by the individuals in making their travel decisions. This means that the travel time and cost impacts can be valued at the travel time versus out-of-pocket travel cost "utility" values of travelers. These utility function values of time are fairly well researched in urban travel demand forecasting. For example, for daily trips to work,

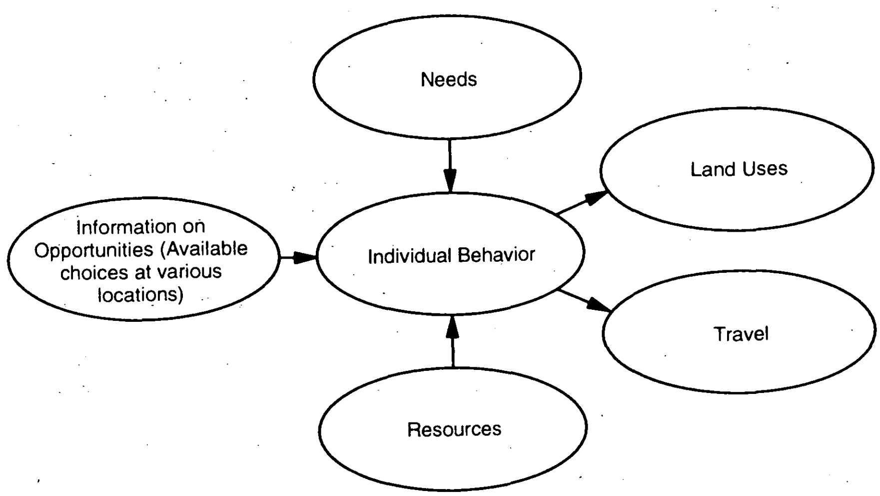


FIGURE 2 Paradigm of individual behavior incorporating ITS information.

travel time is valued on average at approximately 40 percent of the wage rate. One can use this short-run travel time value to value both the short-run travel and the long-run land use distribution impacts of ITS investments.

In the long run, the behavioral response of travelers and shippers to ITS should substantially benefit the "efficiency" of the land use or settlement patterns. Without ITS, the automobile-highway system is a classic example of a system governed by individual choice that puts private interests over the public interest. Every time a person drives his or her car onto a congested roadway, far more aggregate delay is imposed on others—on the system—than on the driver. In economic terms, the marginal private cost of highway travel is much lower than the marginal social cost of travel on an already congested highway system. In fact, the more congested the highway corridor, the greater the difference between the marginal social and private costs of making a trip by automobile (*6*).

Congestion is also the price the current transportation system imposes on its users as a result of individual private decisions to locate on larger plots of land, farther away from work and shopping. And as increasing amounts of money are spent on housing, the transportation price that individual lifestyle decisions impose on everyone else is not known by the individual when he or she makes those decisions. Investments are made by individuals in expensive housing without consideration of the total cost of their location decisions on society. These decisions lead to real inefficiencies: the system has lost its ability to confront consumers with the real costs of their decisions. This is as true in the long run for land use location decisions that generate congestion as it is in the short run for the individual travel decisions described in the previous paragraph.

ITS systems can lead to more efficient lifestyles in the sense that it should be possible to provide more accurate information on the real costs of travel and land use location decisions with than without ITS systems. More accurate information will lead to a more predictable travel environment in which travel costs are internalized before the fact to influence travel decisions, rather than after the fact when the traveler who is stuck in traffic cannot do anything about it. Once again, however, to the extent these impacts are internalized to the travelers, they can be calculated as lower travel (user) costs, rather than higher-value land use location impacts of ITS that are separate from the travel costs.

These examples are intended to show the prevalence of double counting between the short-run and long(er)-run criteria under the first two categories of impacts (criteria 1.0 and 2.0) in Table 1. Criteria that are highly correlated in their outcomes are not helpful in choosing between alternatives. However, although double counting should be avoided, different decision makers may value (weight) differently different manifestations of the same impacts. Ultimately these decision makers also must decide which manifestations of the same benefits represent real value added to society and which can be combined or eliminated in the evaluation. Therefore, all criteria are included in Table 1, subject to their being grouped together to facilitate the evaluation process as described below.

SAFETY, ENVIRONMENTAL, AND ENERGY CRITERIA

The safety and environmental and energy criteria (criteria 3.0 and 4.0 in Table 1) are related to the aggregate flow volumes and conditions on the network. Normally, in the evaluation of conventional transportation improvements, these "flow-produced physical impacts" are directly related to user benefits because increased user benefits from a transportation improvement lead to more travel, which then gives rise to more physical impacts of this travel. This direct relationship for conventional transportation improvements does not hold for ITS improvements, as explained earlier.

Therefore, the flow-produced physical impacts (Criteria 3.0 and 4.0) of ITS should be related to the flow volumes and operating characteristics included in the efficiency group (Criterion 1.0) rather than the measures included in the demand group (Criterion 2.0). These events produce the chain of causality for forecasting these ITS impacts, which is shown in Figure 3 (*2*).

IMPLEMENTATION IMPACTS

Implementation impacts (Criterion 5.0) include the following:

- 5.1 Ease of implementation;
- 5.2 Agency cooperation/coordination; and
- 5.3 Technology flexibility.

These implementation impacts are most readily described by the detailed bulleted criteria under each of these headings in Table 1.

COMPARISON OF CRITERIA WITH GOALS IN 1992 U.S. DEPARTMENT OF TRANSPORTATION ITS STRATEGIC PLAN

The six national goals in the 1992 U.S. Department of Transportation ITS Strategic Plan (*7*) map very well on the criteria structure in Table 1. The six national goals (with their corresponding criterion numbers from Table 1) are as follows:

1. "Improve the safety of surface transportation" (Criterion 3.0);
2. "Increase the capacity and operational efficiency of the surface transportation system" (Criterion 1.0);
3. "Enhance personal mobility and the convenience and comfort of the surface transportation system" (Criterion 2.0);
4. "Reduce the environmental and energy impacts of surface transportation" (Criterion 4.0);
5. "Enhance the present and future productivity of individuals, organizations, and the economy as a whole" (Criterion 2.2); and

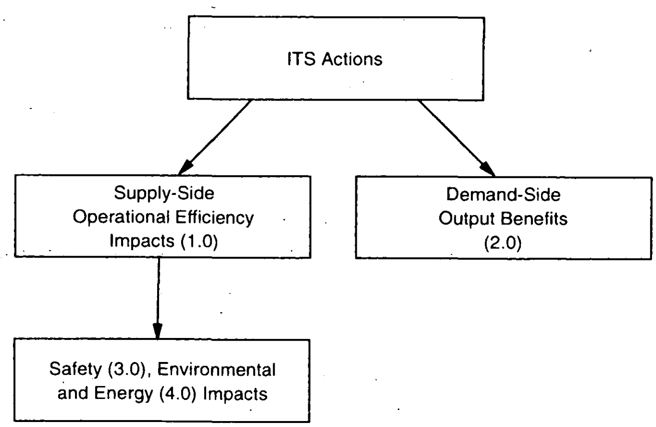


FIGURE 3 Relationship between ITS impacts.

6. "Create an environment in which the development and deployment of ITS can flourish."

The first four national goals are the slightly reordered 1.0 through 4.0 in Table 1. The reordering in this paper is methodologically based on the need to evaluate first the aggregate flow and efficiency impacts (1.0) of ITS options, which are then used to assess the safety consequences (Criterion 3.0) of ITS options (see Figure 3).

The fifth national goal (enhance productivity) is the medium-run (Criterion 2.2) set of demand adjustments to increase output in Table 1. The criteria organization facilitates producing information and helps avoid double counting during the evaluation process. Understanding the differences between the national goals and the structure in Table 1 can advance the state of the art of ITS evaluation.

Finally, the last national goal (create a U.S. ITS industry) is legitimate at the national level but not at the local level, except as it is included in the economic development/productivity criterion (2.2). Creating a technology for its own sake should not be relevant at the local level in developing an ITS plan.

TREATMENT OF AFFECTED GROUPS

The criteria in Table 1 generally are applicable at the urban, rural, and intercity levels, as well as to many groups in society. Table 2 shows the headings from the benefits "taxonomy" in the Mobility 2000 Benefits Report (*8*). In the example evaluations shown in this paper, the impacts on particular groups can be considered in the grouping of criteria for evaluation discussed in the next section or in the weighting of the criteria, which can vary by location. The location strata used in the evaluation process highlight the varying importance of various groups in the different locations. Projects can be included in an ITS plan that provide benefits to rural and intercity travelers as well as to various affected groups in large, midsized, and smaller urban areas. It is important in any evaluation to highlight the tradeoffs that decision makers need to make with the information provided in an ITS evaluation process (*9*).

GROUPING CRITERIA FOR EVALUATION

The considerable uncertainty in forecasting the impacts of ITS projects requires sensible impact assessments (forecasts), subject to strong face validity checks, rather than false precision. The full set of criteria in Table 1 is structured to highlight the inherent correlations of the criteria. This allows grouping the criteria to assess candidate ITS projects using greatly simplified evaluation matrices that can be developed and used by decision makers.

It is strongly recommended that grouping the evaluation criteria and carrying out the evaluation of relative project merit (described in the next section) be done by a diverse group of the highest-level decision makers who can be assembled for at least a half-day process. Ideally, agency heads from all the modal transportation agencies in the study area should be involved, in addition to planning agency and citizen and environmental group representatives. A facilitator who is familiar with the entire process keeps the entire group as focused and productive as possible in a high-energy process, limited only by the time and attention span of the often-nontechnical attendees.

Table 3 shows an example list of grouped benefit-related evaluation criteria. The grouped criteria reflect the transportation program goals developed for a particular region. By using the same numbering system as that in Table 1, Table 3 shows which Table 1 criteria were used, either singly or grouped. Table 4 provides an easier-to-use list of the grouped evaluation criteria shown in Table 3.

The grouped evaluation criteria shown in Tables 3 and 4 are not meant to be all inclusive but rather to reflect an example set of objectives and understandings of decision makers. For example, "land use" (Criterion 2.3 in Table 1) as an evaluation criterion is missing from the example list. One reason this may happen is that it is not clear what the land use impacts of most ITS projects will be in the next decade or so. Another important reason is that many (but not all) decision makers are reluctant to take a position on which parts of a region should grow "at the expense" of land values in other parts of a region. Rather, the principal objective of many decision makers is to promote the mobility of the population by the information or travel options that ITS can provide to residents and firms. Any land use impacts will be highly correlated with the ITS mobility impacts and will likely be independent of VMT changes caused by ITS. To the extent that decision makers want to single out particular groups living in specific locations for special consideration in the evaluation, this can be done by defining separate criteria for those groups or even separate locational strata (see Figure 1). For example, in Table 3 the personal mobility (Criterion 2.1.1) of residents and nonresidents is selected as separate criteria in the evaluation.

Table 5 shows that there are important relationships between the criteria in Tables 3 and 4. Consistent with Figure 3, environment and safety are related to the primary supply-side operational efficiency impacts [congestion and Single-occupancy-vehicle (SOV) reduction], whereas the demand-side mobility affects drive economic development, which is a longer-run consequence of the same ITS user benefit. Conversely, as shown in Table 5, an improvement that is primarily safety oriented can reduce incidents, which in turn can reduce congestion as a secondary impact.

TABLE 2 Potentially Affected Groups

Categories of Benefit	Impacted Groups					
	Users (Groups)	General Population		Organizations		
	Urban, Rural, Elderly, Suburban, Commuter, etc.	Other Transportation System Users	Nonusers	Public Sector	Private Sector	
				Operators	Operators	Industry

TABLE 3 Example of Grouped Criteria Used to Evaluate ITS Projects

1. Increased Operational Efficiency (supply-side efficiency, meaning more output per unit of input)

    1.1 Short Term: Operational Efficiency

    1.1.1 Infrastructure
    - "Decreased Congestion"

    1.1.2 Vehicle Efficiency ("Increased alternate mode share")

    1.1.2.1 Private Autos
    1.1.2.2 Transit
    - Single Occupant Vehicle (SOV) Reduction

2. Increased Output (demand adjustments that further increase output or benefits from ITS improvements)

    2.1 Short Run: Mobility

    2.1.1 Personal
    - Mobility of Residents
    - Mobility of Nonresidents ("support tourism")

    2.1.2 Freight
    - Mobility of Commercial Vehicles ("facilitate efficient goods movement")

    2.2 Medium Run: Economic Development
    - Economic Development

3. Safety ("Improve Highway Safety")
    - Safety

4. Environment and Energy ("Improve Environment")
    - Environment

5. Implementation
    - Ease of implementation/agency commitment

Note: The table shows the grouping of criteria from Table 1; the example criteria are the bulleted items.

EVALUATION OF RELATIVE PROJECT MERIT

When transportation improvements are under evaluation, weights often are assigned to evaluation criteria. Multiplying the quantitative weights times the (interval) scaled measures of criteria "attainment" allows the evaluator to produce an overall weighted measure of merit of each project.

This stage of the evaluation process shown in Figure 1 can begin by having the decision makers assign weights to a larger number of the Table 1 criteria than those shown in Tables 3 through 5. This can help in deciding on the final criteria shown in the latter tables. The result of the criteria weighting process can be different relative weights of the criteria on a one-to-five scale for each of, say, five geographic areas (strata). Example weights are shown in Table 6, in which safety receives the highest weight (5) in every area, whereas ease of implementation receives a 1 in every area. Safety is always of great importance in transportation, but not all ITS projects affect safety to any great extent. Conversely, ease of implementation is weighted low, but ITS projects vary widely in their outcomes with respect to this criterion. The criterion probably should be weighted low both because it may be seen as a tiebreaker ("We want early successes") and because a project should not be implemented without benefits other than being "easy to do."

Other criteria will vary in their relative weights, depending on their local importance. As indicated in Table 6, reducing congestion is most important in the example major urban area, but congestion reduction, by itself, may not be of the greatest importance any-

TABLE 4 Grouped Criteria Used to Evaluate ITS Projects in Example Study: Simplified Numbering System

1. Congestion
2. SOV Reduction
3. Mobility — Residents
4. Mobility — Nonresidents
5. Mobility — Commercial
6. Economic Development
7. Safety
8. Environment
9. Implementation Ease

TABLE 5 Relationships Between Evaluation Criteria

Primary	Secondary
1. Congestion	7. Safety
2. SOV Reduction	8. Environment
3. Mobility -- Residents 4. Mobility -- Nonresidents 5. Mobility -- Commercial	6. Economic Development
7. Safety	1. Congestion
9. Implementation Ease	

where. SOV reduction may be more important in the major urban area as a measure of increased alternate mode share, which may be a major ITS program goal. Economic development may always be very important, but relatively speaking may be most important in the small urban areas and in rural areas.

Many ITS plans will be developed for only one region, in which case the added complication of different weights and separate impact assessments for different areas (or strata) will not be needed. This can greatly reduce the time and effort needed to be expended by the decision making group in the process.

The next step in the evaluation of *relative* project merit is the impact assessment step. *Consumer Reports*-type measures of impact assessment on a plus or minus five- or ten-point scale can be used for each criterion that is affected by an ITS project. (A 0 can be used for no impact.) The impact assessment portion of the evaluation should be a screening and informing process that allows the decision-making participants to become comfortable with the criteria, the assessment of project impacts in terms of these criteria, and the grouping of projects by relative merit on the basis of their impacts. The actual assignment of impact values for each project is done by the members of the decision-making group with strong input from the technical facilitator who is familiar with the likely impacts of the ITS options. The process has been shown to be an excellent way to educate and obtain the support of decision makers for the conclusions of the evaluation.

Table 7 summarizes example relative merits of a series of example candidate ITS projects applied to several locations, whereas Table 8 provides a more generic example of a project evaluation rating sheet for one area (or stratum). Note that the candidate projects (rows) differ between the two tables, and the criteria (columns) in Table 8 omit two of the criteria in Tables 3 through 6. Table 8 leaves blank spaces for three additional criteria and illustrates that there will be site-specific differences in the selected criteria, criteria weights, candidate ITS projects, and their relative impacts between any two locations (strata). The righthand "weighted-sum" column in Table 8 is filled out by the evaluators for each candidate ITS project. This column illustrates how the weighted measures of merit summarized in Table 7 are calculated (for a different set of ITS projects).

Project cost/effectiveness or cost/merit is not calculated at this stage because projects often can be subdivided into lower-cost projects that still have high relative merit. Also, many candidate projects are interdependent, relying on the same infrastructure (e.g., traffic speed monitoring for ATMS and ATIS). It is not always easy

TABLE 6 Example of Weighting of Evaluation Criteria by Geographic Area (Strata) Within State

Criteria	Geographic Area				
	Major Urban Region	Mid-sized Urban Regions		Small Urban	Intercity/ Rural
		A	B		
1. Congestion	3	2	2	1	1
2. SOV Reduction	4	2	3	1	1
3. Mobility — Residents	3	3	3	4	4
4. Mobility — Nonresidents	1	2	2	2	3
5. Mobility — Commercial	4	3	4	2	4
6. Economic Development	4	4	4	5	5
7. Safety	5	5	5	5	5
8. Environment	4	3	3	2	1
9. Implementation Ease	1	1	1	1	1

TABLE 7 Example of Relative Merit of Candidate Projects

User Service Project	Merit				
	Major Urban Region	Mid-sized Urban Regions		Small Urban	Intercity/ Rural
		A	B		
Public Transit/TDM	50	27	32	17	13
TDM Support	33	26	30	14	-
HOV Priority Support	19	-	-	-	-
Transit Vehicle Management	33	24	26	28	26
Congestion Pricing Support	57	-	-	-	-
Traveler Information					
Trip Planning — Pre-Trip	97	51	71	42	30
Trip Guidance — En-Route	77	53	59	32	43
Traffic Management					
Incident Detection & Management	77	47	51	42	46
Freeway Ramp Metering	73	36	48	26	-
Traffic Control	99	89	97	70	20
Freight and Fleet Management					
Intermodal Port Transfers	25	-	25	-	-
Regulatory Support/Borders	-	-	-	-	37
Hazardous Materials	12	11	11	10	9
Additional Services					
Emergency Service Management	15	16	15	17	14
Enforcement System	21	16	15	15	16
Mayday Test	-	-	-	-	28

to decide which project comes first and should be charged the common infrastructure cost in a calculation of cost per relative merit.

Once candidate projects are grouped by their relative merit within strata, programs of projects can be developed that exhaust the budget limits for each stratum (see Figure 1). Conversely, budget limits can be decided after the absolute worth of the programs of projects has been assessed in a benefit-cost analysis (see next section). In either event, the development of programs should avoid the scenario in which the most beneficial but expensive project uses up the entire program budget for the strata. This problem can be avoided by selecting projects from the highest ranked groups that provide significant benefits themselves and contribute to the infrastructure needed to implement other highly ranked projects (e.g., traffic speed monitoring for ATMS and ATIS).

ASSESS ABSOLUTE WORTH OF ITS PROGRAMS IN BENEFIT-COST ANALYSIS

The final stage of the evaluation process involves a more formal program-level benefit-cost analysis of the selected program of projects for each location or stratum that exhausts the funds available for that location. Costs already may be estimated for all projects reaching this stage of evaluation because of the budget constraint test. On the benefit side, the largest portion of the quantifiable benefits will likely be the combined user benefits from the time savings associated with the first criterion, congestion reduction (Criterion 1), and the mobility increases (Criteria 3 through 5 in Tables 4 through 6). Given the state of the art, it is difficult to quantify the proportion of these benefits that will be aggregate observable time savings on the (multimodal) network (that is, at the equilibrium levels of congestion and travel volume, including induced travel, that result from the ITS projects), and how much will be attributable to mobility increases that are measurable only with appropriate behavioral models at the individual traveler or firm level. Devoting considerable resources to attempting to quantify the value of one versus the other is certainly false precision, given the current state of the art.

Similarly, distinguishing between the longer-run economic development (Criterion 6, Tables 4 through 6) and short-run (travel) impacts of ITS improvements is beyond the current state of the art. The best current (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 (*10*). These direct demand models are partial equilibrium models that describe how travelers behave so that they will be in equilibrium with the rest of the system. They model the behavior of the tripmaker, who considers all trip end opportunities to be fixed. Direct demand models (estimated with cross-sectional data) are themselves simplifications of "general equilibrium" models that attempt to explain how land use and travel vary simultaneously with transportation improvements (*3*). The demand relationships embedded within them (e.g., the elasticities and values of time) reveal something about both long- and short-run behavior.

Also as noted earlier, even if ITS leads to longer trip lengths and "sprawl," one can conservatively assume that the benefits from trip length increases, resulting from higher-value residential locations and other activities at the trip ends, are equal ("at the margin") to the added travel time/cost of these longer trips. Therefore, the results of appropriate demand models can be used to value congestion reduction and mobility improvement at the values used by the individuals in making their travel decisions (i.e., 40 percent of the wage rate for daily trips to work). For example, an average hourly wage

TABLE 8 Example of IVHS Project Evaluation Rating Sheet

IVHS Function/Project	Decreased Congestion	SOV Reduction	Improved Mobility – Residents		Improved Mobility – Commercial	Economic Development		Safety		Implementation Ease (Institutional)	Weighted Sum
weight											
Traveler Information											
Incident, etc. Advisories – Enroute											
Incident, etc. Advisories – Pre–Trip											
Time/Cost Advisories – Enroute											
Time/Cost Advisories – Pre–Trip											
Route/Mode Guidance – Enroute											
Route/Mode Guidance – Pre–Trip											
Yellow Pages/Services Info.											
Traffic Management											
Incident Management											
Ramp Metering/Access Control											
Street Traffic Control											
Demand Management (Cong. Pricing)											
Construction Management											
Freight and Fleet Management											
HAZMAT Monitoring and Tracking											
Weigh–in–Motion (WIM)											
Regulatory Support											
Public Transport											
Transit Vehicle Monitoring											
Transit Vehicle Priority											
Smart Fare Payment											
Dynamic Ride Sharing											
Safety/Security Systems											
Electronic Toll Collection											
ETTM											

rate of $14.00/hr results in a value of time for work trips of $5.60/hr. The generally accepted figure for nonwork (offpeak) trips is half this value.

In summary, the quantifiable user benefits from ITS projects are bundled in an impossible-to-disentangle ball of short- and long-run measures under Criteria 1 and 3 and 4, through 6. However, until the results of new demand modeling research are available, it is possible to approximate their value without disentangling them. It is possible to value them using the observed aggregate time savings for similar ITS projects (if any) implemented elsewhere, times a multiplier on this lower bound estimate of user benefit to account for the mobility benefits individuals and firms experience from the tradeoffs they make to maximize their net benefits from travel (i.e., their tradeoffs between the times and costs of travel on all available alternatives they are informed about, and the benefits of travel from engaging in activities at their trip ends).

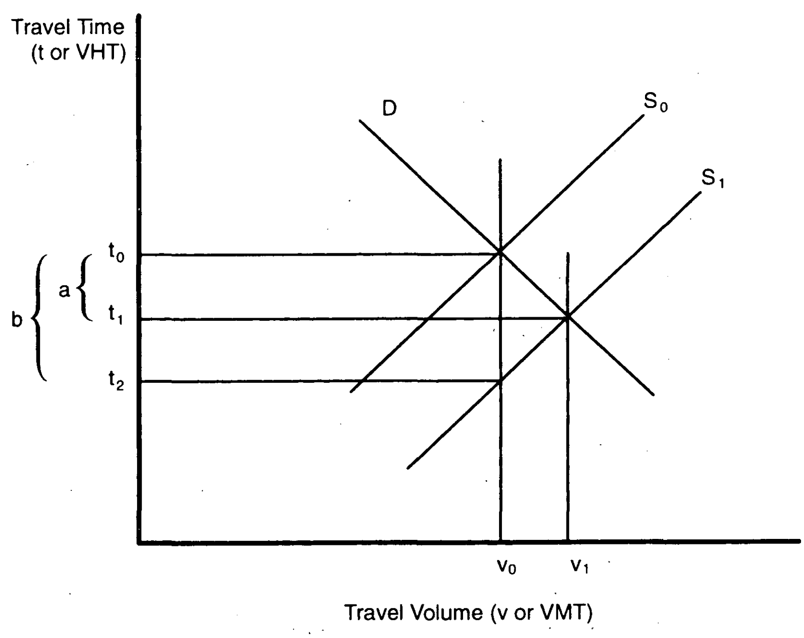
The following multipliers may be applied for projects involving both ATIS (information) and ATMS elements:

Travel Segment	*Multiplier*
Peak period person travel	2.0
Offpeak person travel (including tourists)	1.3
Commercial vehicle travel	1.5

These (default) multipliers should be applied only to projects that include an important element of information to travelers (real-time congestion information to residents and commercial vehicles; static destination and route information to nonresident tourists).

These multipliers were derived using long-run automobile person trip demand elasticities of −0.8 and −1.0 for work and nonwork trips, respectively (*10*), and speed elasticities of −0.75 and −0.375 with respect to peak and offpeak volumes (*11*). Commercial vehicle demand elasticities were assumed (conservatively) to be lower than automobile work trip demand elasticities. The multipliers measure the relationship between the total change in consumer surplus (user benefit) from a transportation improvement and the aggregate observable benefit at the intersection between the supply and demand curves that defines equilibrium flow (including induced travel) after a transportation improvement. In economic terms, the multiplier is the amount by which the entire utility (γ-axis) difference of the consumer surplus rectangle (assuming a fixed-trip table) exceeds the smaller γ-axis utility difference of the consumer surplus triangle relating to induced travel. Figure 4 illustrates the multiplier for the (work trip) situation when the slopes of the supply and demand curves are equal.

It is probable that the multipliers on aggregate observed time savings given are underestimates of the actual total user benefits from ITS improvements. The reason for this is that although the −0.8 automobile person work trip elasticity given is a long-run elasticity incorporating "demand shifts," it was not estimated for transportation improvements involving ITS. The long-run demand



$t_0 v_0$ = Equilibrium aggregate observable VHT and VMT before ITS improvement

$t_1 v_1$ = Equilibrium aggregate observable VHT and VMT after ITS improvement

t_2 = Disutility of travel after ITS improvement measured at the individual traveler level (assuming no net change in travel volume)(2).

b = 2a when slopes of Demand and Supply curves are equal

FIGURE 4 Illustrative derivation of user benefit multiplier.

elasticity for transportation improvements involving ITS is likely to be larger than −0.8 because the number of known alternatives is larger and the possible substitutions are greater. This will result in a flatter demand curve, more induced travel, less aggregate observable congestion relief, and a larger multiplier. In Figure 4, these results may be diagrammed as a flatter demand curve, *D*, rotating counterclockwise around t_0v_0, causing the new observed aggregate equilibrium point t_1v_1 to be higher on the supply curve S_1 than before. The result is that *a* in Figure 4 is a smaller fraction of *b,* and the multiplier increases, possibly substantially. This is why, as stated earlier, aggregate observable reductions in congestion (travel time) from ITS improvements are so likely to be dramatic underestimates of ITS user benefits.

Whatever multipliers are used, the estimates of user benefits should be made separately for peak and offpeak (including tourist) passenger and all commercial (freight) movements and applied to the volumes of travel affected by the ITS improvements. For peak and offpeak passenger trips, the total user benefit can be valued at 40 and 20 percent of the real hourly wage rate, respectively, at the forecast year(s) for which the ITS improvements are being evaluated. In addition, because the observable changes in aggregate vehicle miles traveled (VMT) are only part of the user benefits, the separate calculation of passenger vehicle operating cost savings resulting from VMT changes will be small and can be ignored in most circumstances.

For large trucks, $60/vehicle-hr can be used as the value of time saved. This includes labor, vehicle operating and maintenance and depreciation for an 18-wheeler carrying 20 tons of cargo, plus an economic development impact (Criterion 6) of $10/hr. A fee of $10/hr is an inventory carrying charge calculated on the assumption that manufactured goods are worth an average of $5.00/lb, a 10 percent annual interest rate (i.e., 20 tons × 2,000 lb/ton × $5/lb × 0.10 ÷ 3,000 hr/year trucking time = $6.67/hr) and a 50 percent premium to account for the value of travel time reliability for "just-in-time" delivery.

The smaller portion of the quantifiable benefits for calculating the absolute worth of candidate ITS programs is composed of the savings in the social costs of travel attributable to the safety, environmental, and energy benefits that accompany the aggregate observable reductions in VMT on the network. As shown in Table 5, these "flow-produced physical impacts" are related to the aggregate observable flow volumes and operating characteristics included in the efficiency group of criteria (operating speed and SOV reduction), rather than to the measures included in the demand (mobility) group. To quantify them, the first portion of the user benefit estimate described above is used (i.e., without the multiplier), namely the VMT reduction observed for similar ITS projects (if any) implemented elsewhere. More specifically, only the portion of the VMT reduction caused by SOV reduction should be used for quantifying the environmental impacts. This is because the environmental impacts are caused primarily by SOV reductions, whereas the energy and safety improvements may be estimated on the basis of both impacts (see Table 5).

The safety, environmental, and energy benefits to society may be valued by using the following (default) values per unit VMT saved:

Measure (reference)	*Value per VMT ($)*
Safety (*12*)	0.022
Air pollution (*12*)	0.03
Noise pollution (*12*)	0.0035
Energy (*13*)	0.0025

As an approximation, these unit values per VMT should be applied only to the SOV volume reductions achieved as a result of the ITS improvement. These savings apply only to aggregate reductions in observed (or observable) trips caused by the ITS improvement. In the case of air pollution, this is because most air pollution is a result of vehicle trips rather than trip length. In the case of safety, this is because of the difficulty of relating accident rates to vehicle flow rates on a given type of roadway. In the case of energy consumption and noise pollution, the very low dollar values of these impacts makes the added precision of calculating these impacts as a function of vehicle speeds not worthwhile.

CONCLUSION

ITS plans and operational tests should be developed and evaluated in a way that is sensitive to the differences between ITS and conventional transportation improvements. By recognizing the separate supply (efficiency) and demand (increased output) impacts of ITS, it is possible to avoid dramatically underestimating the benefits of the new technology. The methodology and criteria presented in this paper provide the required structure and default values to evaluate ITS improvements for inclusion in transportation system plans. The criteria and default values provided in the paper also highlight where research and operational tests can provide improved values and information that will most quickly advance the state of the art of ITS evaluation.

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