Abridgment

Evaluation of Transportation System Management Strategies

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The construction of a transportation system management evaluation framework that can be easily integrated into the current urban transportation planning process and that can be adapted to previously established institutional arrangements within medium-sized metropolitan areas is discussed. The scope of this project was two-fold. On the one hand, the study involved the development of a general evaluation framework that could be adapted to specific metropolitan areas. On the other hand, the project encompassed the testing of a framework that could be adapted to specific metropolitan areas. For this testing, the evaluation framework was partially applied within one case-study area: the Omaha-Council Bluffs metropolitan area, which encompasses portions of Nebraska and Iowa. Based on the general investigation and the specific case study, a program was then developed to implement the evaluation framework within a metropolitan planning organization.

This study sought to improve the evaluation phase of transportation system management (TSM) planning by applying a systems-analytic approach to the construction of a TSM evaluation framework (1). Other researchers have also applied this concept to TSM strategies (2-4).

FRAMEWORK

The basic components of this framework are (a) goals and objectives, (b) measures of effectiveness, (c) strategies, (d) a decision model to evaluate strategy performance, and (e) techniques to monitor strategy performance. Since each metropolitan area is unique in character and institutional arrangements, the individual agencies responsible for strategy implementation and regional transportation planning must identify the specific components for that metropolitan area. The following conclusions were drawn from this study with respect to how these agencies should identify the basic components:

1. Statements of TSM objectives should be constructed that clearly identify the objectives and the measures of effectiveness that will be used to measure the degree of attainment of an objective by a given strategy.
2. Initially all the identified TSM strategies should be screened against the objectives to develop a set of potential strategies for that metropolitan area.
3. The potential strategies should then be grouped into alternative TSM packages. For example, the single strategies of a carpool program, transit management program, and a staggered work-hours program might constitute one TSM package.
4. The set of alternative TSM packages should be evaluated and monitored according to a geographical stratification of the transportation system, i.e., corridor, subarea, or link.

Once these basic components are identified for a given metropolitan area, the next step is to compare each TSM package with the other packages. Three techniques (5-7) that have been applied to evaluate various types of transportation facilities (the traditional cost-benefit analysis, cost-effectiveness analysis, and utility-based analysis) were analyzed. This analysis led to the recommendation that an additive-utilities model be used as a TSM decision model for several reasons: (a) The model is based on expected consumer-behavior theory, (b) the model can incorporate TSM measures of effectiveness that are both economic and noneconomic in nature, and (c) in general, the model is relatively easy to apply. The mathematical form of the model is

$$U(x_1, \ldots, x_n) = \sum_{i=1}^{n} w(x_i)\, u(x_i) \tag{1}$$

where

$U(x_1,\ldots,x_n)$ = the total utility of a TSM package with regard to all the TSM attributes x_n,
$w(x_i)$ = the weight or utility of attribute x_i,
$u(x_i)$ = the utility function defined at the attribute value of x_i, and
n = the total number of attributes.

The recommended steps to apply this technique are (a) determine the TSM objectives and measures of effectiveness; (b) assign weights, $w(x_i)$, to the TSM attributes; (c) develop alternative TSM packages; (d) estimate the values of each measure of effectiveness for each package; (e) determine the shape of the utility functions, $u(x_i)$, for each measure; (f) compute the utility of each package from the above equation, subject to any predetermined constraints; and (g) select the package that yields the highest total utility, subject to a budget constraint.

Since the specification of the weights and the utility functions are based on subjective judgments, it is recommended that the model be used only as a tool to narrow the range of the TSM packages. Ultimately the final selection of a "best" TSM package will be accomplished through negotiation among implementing agencies, planning agencies, and citizens.

Of course, the adequacy of the overall evaluation process clearly depends on the detail of available information on the measures of effectiveness. Thus, it is important that each implementing agency, or any other agency concerned with a particular measure of effectiveness, monitor the transportation system with respect to the stated TSM measures of effectiveness. Examples of monitoring techniques are (a) machine and manual traffic counts, (b) travel time and delay studies, (c) accident studies, (d) noise and air quality monitoring, and (e) energy monitoring. The following conclusions were made about monitoring:

1. A monitoring technique must be tied to a particular TSM objective and measure of effectiveness.
2. The monitoring of TSM strategies should be carried out according to geographical component, i.e., corridor or link.
3. The monitoring of TSM strategies should be conducted on a periodic basis. In general, it will be necessary to establish a base condition and time period for each measure of effectiveness.
4. The monitoring of the various types of strategies must be coordinated on a regional level to ensure consistency in measurement.

CASE STUDY IN EVALUATION

The above framework was used to evaluate TSM strategies within the Omaha-Council Bluffs metropolitan area, a major midwestern region centrally located within the United States. Although the downtown business districts of Omaha and Council Bluffs constitute the traditional urban core, the metropolitan region has undergone intensive decentralization over the last decade. In general, urban development has sprawled outward, resulting in a low-density pattern serviced by lineal commercial development. This fairly rapid suburbanization resulted in the following transport inefficiencies: (a) Highway capacity is unevenly distributed throughout the region, (b) automobile occupancy rates are low, (c) alternative modes to the automobile are severely limited, and (d) noise pollution, air pollution, and energy waste are by-products of sprawling development (8). As this study determined, these inefficiencies can be linked to the way in which transportation projects are evaluated. If TSM strategies are to be successful in coping with these inefficiencies, then the proposed evaluation framework must be carried out within metropolitan areas.

After an extensive literature search was conducted in order to identify objectives and measures of effectiveness that might be appropriate for the Omaha-Council Bluffs metropolitan area, 13 TSM-objective statements were constructed. Two examples are (a) to improve the quality of transportation service within the metropolitan area by reducing the average point-to-point travel time during the peak hour and (b) to improve the safety of traveling on the transportation system by reducing the total number of accidents per year.

Since the state of the art of forecasting the outcomes of TSM strategies is in a relatively early stage, the study team simulated the values for the 13 TSM measures of effectiveness. Five abstract TSM packages were simulated for testing the additive-utilities model. To illustrate, consider the following example. The simulated values of travel time for packages 1 and 5 are, respectively, 3.4 and 2.6 min/mile. Here, 3.4 represents the worst travel time and 2.6 represents the best travel time among the five packages. Similarly, the simulated value of the total number of accidents was 15 732 and 16 073 for packages 1 and 5, respectively. Thus, values were simulated for each of the 13 TSM measures of effectiveness in order to define the five abstract TSM packages.

The TSM objectives, measures of effectiveness, and five abstract packages were given to five "judges" (four transportation planners on the Omaha-Council Bluffs Metropolitan Area Planning Agency staff and one study-team member), who were asked to assign ratings to the 13 TSM measures on a scale of 0 to 10 on which 0 indicates that the attribute is of no value and 10 indicates that the attribute is of extreme importance. After the judges had rated each attribute, the means and standard deviations of the ratings were computed, and then each judge was asked to reconsider his or her response for an attribute if his or her rating varied ± 2 points from the mean rating. Once this second round was completed, a set of normalized weights, $w(x_i)$, was computed so that the sum of the weights is equal to 1. In general, such quality and efficiency attributes as travel time and travel costs were rated as highly important by all the judges. The weights placed on travel time and costs were 0.111 and 0.127, respectively. In contrast, safety was rated as moderately important and was given a weight of 0.065.

The next step in the quantification of the additive-utilities model involved the specification by the five judges of each utility function, $u(x_i)$, for the 13 TSM measures of effectiveness. Given the range of values of the measures among the five packages, the boundary conditions for each utility function were determined as u(best x) = 1 and u(worst x) = 0, where best x is the most-preferred value for a measure x among the five packages and worst x is the least-preferred value. For example, $596.7 million/year (package 3) is the most-preferred value for cost, whereas $634.2 million/year (package 1) is the least-preferred value. Each judge was then asked to assign values to each measure at corresponding utilities of 0.25, 0.50, and 0.75. Subsequently, the mean value for each measure of effectiveness was computed, and one composite utility function was determined for each attribute.

The total utility of any given TSM package was then computed from the additive model. To illustrate the operation of this model, consider the TSM package 2 and the TSM attribute of travel time. The simulated value of travel time is 3.1 min/mile for package 2, and the weight, $w(x_1)$, placed on travel time is 0.111. The utility of 3.1 min/mile, u(3.1), determined by the judges is approximately 0.60. Thus the contribution of the weight and utility of travel time to the total utility of package 2 is

$$w(3.1)\ u(3.1) = (0.111)(0.60) = 0.067$$

The contributions of all the 13 attributes were computed in the same manner and summed to give a total utility for package 2 of 0.34. For packages 1 through 5, the total utilities were computed to be 0.23, 0.34, 0.57, 0.56, and 0.54, respectively. Thus, according to the highest-utility criterion, the packages are ordered according to decreasing utility as 3, 4, 5, 2, 1. The "best" package among the five packages is number 3.

The following observations were made with regard to the application of the evaluation framework:

1. The overall procedure is relatively straightforward and simple to apply to evaluate TSM strategies.
2. The process of assigning weights and specifying utility functions encouraged the participants to give a hard look at their preferences with regard to evaluation criteria.
3. The outcome of the additive model may be sensitive to the specific weights and utility functions. Therefore, it is desirable to use a diverse group of individuals to quantify the model. In general, the assignment of the weights should not pose any difficulties to the layperson. On the other hand, the specification of the utility functions probably will pose difficulties; thus, it will be necessary to carefully guide the individual through this specification.
4. The additive-utilities model was successful in distinguishing between different packages and indicating similar packages.
5. Grouping the TSM strategies into packages appears to be the best way of analyzing the strategies. When strategies are grouped into packages, the synergistic effects of one strategy on another can be accounted for in both modeling and monitoring.
6. As noted earlier, since the outcome of the additive model is based on the subjective attitudes of various individuals, the models should be used only as a tool to guide the decision makers in their negotiation process for developing the TSM element.

TSM INFORMATION SYSTEM

The successful implementation of an evaluation framework requires the interaction between the agencies involved in the TSM process and the specific evaluation components. This interaction can be accomplished by a TSM information system that provides a clear flow of information from the stating of objectives through all the evaluation functions. This study recommended an information system that includes specific functions, agency roles, and information products. This information system includes the following functions:

1. Setting objectives and measures of effectiveness,
2. Identifying potential TSM strategies,
3. Grouping the strategies into alternative TSM packages,
4. Forecasting the consequences of the TSM packages,
5. Developing a priority list for the packages based on the additive-utilities model,
6. Implementing the packages,
7. Monitoring the packages,
8. Processing the TSM data, and
9. Retrieving the data.

Six specific examples of functions (or roles) and products are given below.

1. a. Function: The metropolitan planning organization (MPO) takes the lead role in setting TSM objectives and in determining measures of effectiveness to ensure consistency among the various implementing agencies. In addition, the MPO divides the transportation system into geographical components to establish a consistent geographical basis for evaluation and monitoring. Furthermore, the MPO takes the lead role, assisted by the implementing agencies, in developing the format to be followed in data collection.

b. The products are a statement of TSM goals and objectives, a list of TSM measures of effectiveness, a geographical stratification of the transportation system, and a specific data format.

2. a. Function: Each implementing agency, supported by the MPO, identifies the potential TSM strategies within its jurisdiction. Each agency then groups these strategies into alternative TSM packages according to its area of responsibility (such as a traffic operations package or a transit management package).

b. The product is a set of TSM packages delineated according to implementing agency.

3. a. Function: The MPO groups the individual TSM packages into more comprehensive packages that include all types of TSM strategies and encompass all the implementing agencies. Moreover, the MPO constructs these packages according to geographical components previously defined.

b. The product is a set of alternative TSM packages that will be tested on a systemwide basis.

4. a. Function: The MPO predicts the consequences of the alternative TSM packages with respect to the TSM measures of effectiveness. The prediction of the consequences should be made according to geographical component.

b. The product is the estimated values for the TSM measures of effectiveness by geographical component for all the alternative TSM packages.

5. a. Function: Each implementing agency then develops a priority listing of the alternative TSM packages according to a utility-based decision rule. The weights and utility functions used in the model will reflect the preferences of the decision makers and constituency of that agency.

b. The product is a priority listing of TSM packages with regard to a regional perspective.

6. a. Function: The MPO negotiates with the implementing agencies in order to develop a final priority listing of packages. The "best" package is then selected according to a total budget constraint, and a schedule is set for the implementation of each strategy.

b. The product is a "best" TSM package to be implemented according to a proposed schedule.

All of the evaluation functions were detailed in a similar manner in order to construct a program that can be implemented within an MPO.

CONCLUSION

Clearly, in order to increase the effectiveness of TSM strategies to improve transport efficiency, MPOs and implementing agencies must evaluate potential strategies in a systematic manner. To improve this evaluation process, this paper recommended that these organizations apply a framework consisting of the following steps: (a) defining goals and objectives, (b) determining measures of effectiveness, (c) identifying potential strategies, (d) using a decision model to evaluate strategy performance, and (e) monitoring strategy performance. This paper also recommended a TSM information system to be used to collect and store TSM data, retrieve TSM information, and transmit the information to decision makers. The implementation of this system by MPOs will help to improve not only TSM evaluation but also the entire TSM planning process.

ACKNOWLEDGMENT

The study reported herein was funded by the Urban Mass Transportation Administration of the U.S. Department of Transportation. The opinions and recommendations expressed in this paper are mine and not necessarily those of the Urban Mass Transportation Administration.

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Publication of this paper sponsored by Committee on Urban System Operations.

Measuring the Effectiveness of Priority Schemes for High-Occupancy Vehicles

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In order to measure the effectiveness of high-occupancy-vehicle priority measures or any similar plan to improve transport systems, it is necessary to provide operational definitions of the output of the system and the mobility of its users. Based on theoretical and empirical studies, it is suggested that a useful measurement of system output would be the total distance traveled on the system per day by all travelers (including pedestrians), and a useful measurement of mobility would be the product of daily distance traveled and speed per household and per traveler. These criteria combine the effect of interactions among many travel components such as trip rate, distance, time, and speed that are evaluated separately by the conventional procedures. They can, and often should, be applied to total travel in the area affected, and not only to the direct, local effects of the improvements. The suggested measurements were applied to assess the results of the Singapore Area Licensing Scheme, the first road-pricing measure to be introduced in a complete city center. Data obtained from tabulations prepared in the World Bank from the results of before-and-after household surveys carried out in Singapore in conjunction with the introduction of the Area Licensing Scheme in June 1975 are presented. The results indicate that the introduction of this plan was associated with a significant reduction in both the output of the road system and the mobility of car-owning households and with an insignificant change in the mobility of carless households.

Priority measures for high-occupancy vehicles (HOVs) generally have a number of objectives. The basic ones are likely to be

1. To increase the useful output of the road network and the mobility of the people who use it and
2. To reduce travel costs, with consideration of time, fuel and other vehicle operating costs, accidents, atmospheric pollution, and noise pollution.

It is rarely possible for all objectives to be achieved, and trade-offs have to be accepted; for example, savings in travel costs can be associated with the loss of mobility, and savings in time can be associated with increased accidents. However, many of the concepts routinely used by traffic engineers can be used to assess the achievement of each objective separately. The task of assessing all these effects on the basis of one measuring rod (for example, money) is beyond the scope of this paper, which is concerned with quantitative measurements of transport output and mobility.

LOCAL AND GENERAL EFFECTS

The introduction of HOV-priority measures may be expected to have immediate impacts on traffic along the routes directly affected. For example, the Shirley Highway Express-Bus-on-Freeway Demonstration Project had an immediate effect on bus users when it was introduced and on carpool users when carpools were allowed on the busway. These effects can be assessed with the aid of standard traffic-engineering measurements of vehicle counts, speed, and vehicle occupancy. But the immediate effects can result in significant secondary ones--the encouragement of carpools on the Shirley Highway route can result in a decline in vehicle ownership as travelers who switch to carpools find they need fewer cars in their households. Alternatively, the effect might be that automobiles not used for journeys to work are used by other members of the household, with important consequences to local activities such as shopping. To measure effects of this kind, it is often necessary to consider the total travel habits of a population affected by HOV-priority measures.

Many HOV-priority programs will result in gains to some travelers and in losses to others. It is important that losses as well as gains be considered. In some circumstances it may be desirable to split the travelers affected, e.g., by income group, by mode, by period of travel (peak or off-peak), or by residential zones. Thus, results might show that a program results in gains to bus users and losses to car users, or in gains to city-center dwellers and losses to suburbanites. The appropriate grouping of the affected users will vary from one situation to another. An example that shows gains and losses of mobility in Singapore is given in this paper. The fact that higher-income groups tend to travel more than lower-income groups suggests that mobility is valued at all income levels and that a reduction in mobility is regarded by most as a loss rather than a benefit.

MEASUREMENTS OF TRANSPORT OUTPUT AND MOBILITY

The output of a road network may be expressed in terms of vehicle kilometers (or miles) per unit of time, the vehicles varying in size and shape from the individual pedestrian to the truck or bus. Mobility is a measurement of the movement of the population using the road system. It can be measured in terms of average person trips per day, average person miles per day, or (for each traveler) daily travel distance times speed. More than 30 such definitions exist, ranging from single and simple measures of flow and speed to complex ratings of kinetic energy and various congestion and demand ratios (1).

However, it is suggested that a useful measurement of output, from the users' point of view, is the travelers' daily travel distance, measured in passenger kilometers. This measurement is based on theoretical and empirical considerations, conforms to conventional definitions, and can be derived directly from a home-interview survey without the need to calibrate a model. More specifically, the required data are the observed travel distance per household and per traveler, stratified by mode and by the households' socioeconomic characteristics.