Overview of Evaluation Methods with Applications to Transportation Demand Management

ERIK T. FERGUSON

Transportation demand management (TDM) is increasingly popular as a response to traffic congestion, air pollution, and related problems. Innovative institutional arrangements have been conceived to implement TDM in a more efficient and effective manner. Careful evaluation is necessary to determine whether TDM has been successful, however. TDM evaluation efforts have tended to lag behind TDM implementation efforts. Results of few TDM evaluation studies have been published. TDM evaluation may be based on direct observation, revealed preference, stated preference, or organizational survey sampling methods of data collection. TDM programs generally are complex policy instruments with modest goals and objectives, providing marginal impacts on travel behavior that are difficult to discern. This description suggests that TDM evaluation methods should be complex in order to be accurate. Yet, effects of TDM programs may not be sufficient to justify costly TDM evaluation efforts. The challenge to the TDM evaluator is to develop tools appropriate to the task in terms of both cost and accuracy. This challenge could be accomplished by integrating TDM evaluation into the general framework of transportation system performance monitoring at the regional level. The urban transportation planning system is in use in most urban areas where TDM is likely to be implemented. Additional data are needed to assess TDM impacts in such areas. The art of TDM evaluation has a long way to go before it reaches maturity as a practical transportation planning and evaluation tool. The time for greater action on TDM evaluation, as in TDM implementation, is now.

Transportation demand management (TDM) is the art of slightly and gradually modifying individual travel behavior, rather than always expanding transportation capacity in response to observed or anticipated traffic congestion at the local and regional levels. TDM has most often been used in dealing with problems related to surface transportation, though examples exist of applications to reducing congestion during peak periods at airports, managing general aviation, operating ferry services, and the like. Recent examples from fields beyond transportation include least-cost energy sector planning, drug interdiction on the demand side (reorientation of drug control programs toward preventive strategies and drug treatment programs), and many similar examples.

Evaluation is the art of determining whether policies, programs, or projects are effective in accomplishing goals and objectives related to an organization's mission. TDM evaluation is the art of determining how, when, and where individual travel behavior actually is modified in response to specific types of TDM strategies. This is often a surprisingly difficult mission to accomplish, given the mobility of TDM subjects, and the typically modest (marginal) impact of TDM strategies on the travel decisions made by individual travelers on a daily basis.

College of Architecture, Georgia Institute of Technology, Atlanta, Ga. 30332-0155.

TDM EVALUATION METHODS

TDM evaluation methods may be grouped into four major classes of activity, on the basis of their underlying data requirements. These include direct observation (DO), revealed preference (RP), stated preference (SP), and organizational sampling (OS) methods. Each of these methods is discussed in turn. RP and SP methods may be implemented through random, stratified, or clustered survey samples, administered over the telephone, through the mail, or, most recently, interactively on the video display screen of a personal or mainframe computer. DO methods require no direct participation on the part of individual travelers thus observed. OS methods are perhaps the most recent of the four methods in terms of application. OS methods are a direct outgrowth of researchers' attempts to understand the nature of employer-employee interactions, primarily in terms of carpool and vanpool formation, in response to employer TDM program implementation efforts.

DO Methods

DO methods are the oldest though no longer the most common methods used in obtaining travel behavior information related to transportation system use. DO methods have the advantage of being simple, direct, and subject to few biases in sampling or estimation (other than systematic observer error), most of which are relatively easy to identify and correct.

DO methods are implemented at the site level by stationing observers at a single point, if only one entrance or exit point exists, or at multiple points, to cover all possible entry and exit points to the site selected for analysis. DO methods are implemented at the corridor level by selecting a point or points along a specific travel corridor, such as a major arterial or highway, and placing observers at all critical points thus selected. DO methods are implemented at the areal or regional level by drawing a cordon line around the area selected for

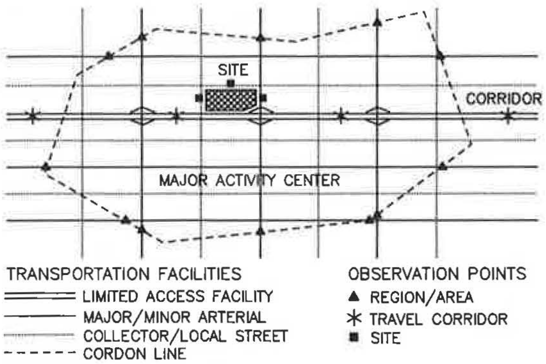

FIGURE 1 Direct observation of travel behavior.

study, and placing observers at all major entry and exit points to the cordoned area (Figure 1).

DO methods are often used to collect data for highway capacity analysis, and can be useful in calibrating regional travel demand forecasting models. DO methods are not often used solely for TDM evaluation, but may be useful in checking the validity of more detailed travel demand information obtained from other sources. Recently, photographic equipment occasionally has been used to obtain license plate numbers for vehicles directly observed along major travel corridors with newly installed high-occupancy-vehicle (HOV) lanes. License plate information was used to obtain mailing addresses for observed facility users through state motor vehicle departments, allowing RP and SP surveys to be distributed through the mail to all users thus identified.

DO methods have virtually unlimited potential for increasing the accuracy and precision of certain travel behavior parameter measurements, such as the number of vehicle trips and the number of vehicle-miles of travel along specific corridors. DO methods are extremely limited in terms of the variety of data that can be observed, without invading the privacy of individuals in fundamentally obtrusive ways. DO methods are not suitable for identifying the intentions as opposed to the actions of individual travelers. Neither can DO methods be used to identify travel origins and destinations in a broader regional context. This argues against relying on DO as the sole method for collecting data relevant to TDM evaluation.

RP Methods

DO methods can be used to obtain behavioral characteristics of users, but they are highly problematic in determining economic and demographic factors that may be important factors in individual and household travel behavior decision making. RP survey methods were developed to capture more information relevant to individual decison making in transportation and other fields. RP surveys ask respondents to identify their current travel behavior, often in much greater detail than is possible through the use of DO methods alone. RP surveys may ask questions about past travel behavior as well. RP surveys usually make some attempt to identify ambient working conditions, household characteristics, and individual attributes such as income or automobile availability, which have been found to influence travel behavior decisions previously.

A particularly useful type of RP method is choice-based survey sampling. For example, on-board transit surveys are choice-based, in that only transit users are asked to reveal their preferences through the implementation of on-board transit surveys. Choice-based sampling generally is more efficient than random sampling for rare or elusive populations. An on-board transit survey would not be necessary in New York City. Random telephone or mail surveys would elicit adequate information on transit use and competitive modes in New York City, at a lower cost per survey completed. In typical suburban transit markets, the use of on-board surveys is often critical for keeping data collection costs low, while providing adequate information on the characteristics of transit users in these areas.

RP methods generally are subject to greater variation and error in measurement than are DO methods. Survey participation frequently is far less than 100 percent, introducing the potential for unknown sampling biases. Participants may make mistakes in completing RP surveys because of misunderstanding of technical terms, lack of knowledge, transcription error, faulty memory, plain old mistakes, and other factors. Most people estimate travel distance only to the nearest mile, and travel time only to the nearest 5-min increment. If greater precision in measurement than this is required for adequate modeling of behavior, it can generally be had only through the use of DO methods. Despite these caveats, RP methods are inherently more useful than DO methods in TDM evaluation, because RP methods provide far more information on observed travel behavior and factors only indirectly observable that may influence such travel behavior.

SP Methods

RP methods are in turn limited to collecting information on what has already transpired, i.e., preferences revealed in the form of actual, at least theoretically observable, travel behavior choices. In some cases, this information may be insufficient or even entirely irrelevant. When a new type of service, such as a new transportation technology, is contemplated for implementation, forecasts of the eventual usage this new technology may achieve usually are required to gain critical project funding. Asking members of the local population if they had ever used the new technology, for example in a different city, might be interesting. Yet, basing forecasts of future local new technology usage on such prior experience in a different regional setting would be absurd. Similarly, asking them whether they would use a mode of transportation of which they were not aware, and might only dimly understand in the context of prior experience, would be equally problematic for forecasting purposes.

SP methods were developed to model consumer attitudes in relation to observed behavior, usually for marketing purposes. In the latter regard, it was determined that perceptions did not always reflect reality in the minds of consumers, and that actual choices might modify perceived differences in the usefulness of available choice sets. Focus groups were invented to bring groups of people together to informally discuss hypothetical or future choice sets, as opposed to actual or current choice sets, in a constructive manner, with a little bit of organizational purpose injected into the proceedings for good measure, to keep the general tone of the group discussion on the right track. Focus groups were found to be useful in constructing more realistic hypothetical choice sets, which could then be tested more rigorously (in statistical terms) through surveys aimed at asking what people might do under certain situations, modeled on the present, but with structural changes such as new or improved transit service, parking pricing and supply control measures, and the like, included in detailed descriptions of highly realistic and probable future scenarios.

SP methods are subject to even greater variability and error in measurement than are RP methods. How people react on an individual basis to the description of hypothetical choice sets, and how well they can gauge their sensitivity to changes in transportation system design, are still poorly understood as research issues. Nonetheless, SP methods are critical for evaluating scenarios that differ from the present in significant ways, and are therefore important in long-range planning (not so relevant to TDM) and in understanding whether or not transportation service or product innovations are adopted by significant numbers of individual travelers within specific travel markets (very relevant to TDM).

OS Methods

The most recent innovation in transportation evaluation methodology has come in the form of OS methods, used in what might be called quantitative (comparative) institutional analysis. OS methods require only that an organization exists in some form (firm, household, carpool, etc.), and that at least two levels of organizational structure be included explicitly in survey sampling for later statistical analysis purposes.

DO methods fail to reveal all objective aspects of behavior, unless the object of study is followed around for a rather extended period of time. RP methods fail to consider changes in transportation systems that may require structured speculation on the part of study participants concerning hypothetical choice sets or future travel behavioral modifications. SP methods allow the study participant to speculate more freely, but cannot capture information that the participants do not have at their personal disposal on indirect causal factors influencing the relative usefulness of various travel options, or the travel behavior choice set itself. Examples of such information might include the total supply of parking spaces available to all employees at a particular work site for a particular price or at different prices, whether or not a potential carpool partner has been offered flexible work hours, which may be preferred to carpooling by some employees as a congestion avoidance technique, and so on.

OS methods allow the TDM evaluator to link directly observed, revealed, or stated preferences of study participants to the organizational environment in which travel behavior decisions are made. Travel behavior decisions are not made under antiseptic laboratory conditions, far removed from the concerns of family, work, and social activities, but rather are integrated in complex ways into multilayered patterns of living, lifestyles, or lifecycles. These complex organizational ties can be modeled explicitly in terms of the context of travel demand forecasting and TDM evaluation only through the application of OS methods. Activity analysis usually focuses solely on household activities because these may relate to individual travel behavior, but otherwise it is similar in principle to OS methods for most practical purposes.

OS methods may be at one and the same time both more and less subject to variability and error than the methods previously discussed. Defining what organizations are and how they operate is more difficult and complex than simply observing the behavior of a single individual at a single point in time and space. Thus, OS methods are only as good or as relevant as the strength of the organizational linkage between an individual under observation and the organizational principle suggested as one determinant of behavior may be.

Perhaps some of the organizational ties to travel behavior are influenced by yet other organizational ties, further complicating this already rather messy picture. The policies and procedures of individual organizations may exert different qualitative influences and certainly have different quantitative impacts on different individuals within the organization. Some organizations may even have entirely different sets of policies and procedures for different individuals or classes of individuals within the organization. All of these separate policy analytic activities may exert weak influences on some individuals, and strong influences on yet other individuals. The possible relationship between these institutional factors and TDM have only recently come under study in a quantitative and objective fashion, through the use of rigorous statistical analysis techniques for examination and evaluation purposes.

OS methods may be less variable than some other methods, to the extent that OS techniques build on the others to provide measures of effectiveness for specific policies and procedures across many rather than just one or a few independent organizational observations in analysis. Reducing variability in measurement of such key organizational influences as parking pricing and supply control policies from one firm to another is a major potential benefit of OS methods. This is important, because OS methods do impose significantly higher costs in terms of both data collection and data analysis. The use of OS methods is not justified without the provision of additional benefits. Such benefits do seem to exist, and are not available in the same guise through application of DO, RP, or SP methods, either together or in isolation.

OS methods may be of particular importance in evaluating TDM, because of the highly dispersed nature of TDM program implementation, and the close relationship between successful TDM implementation and the creation of entirely new kinds of organizations, such as transportation management associations, trip reduction ordinances, and the like.

ANALYTICAL FOCUS

Which data collection method or combination of methods to apply to TDM evaluation will vary, depending on the analytical framework or focus, the mission of the TDM program to be evaluated, and the measure or measures of effectiveness selected to indicate attainment or nonattainment of TDM program goals and objectives. The analytical focus of TDM evaluation may be spatial, temporal, or organizational in nature, or some combination of all three.

Spatial Focus

The scale of TDM implementation efforts will determine the geographic focus of evaluation efforts, which may be site-specific, corridor-oriented, or regional in scope. OS methods have been applied to activity centers in the form of site-specific surveys of employers and employees in Southern California and Brentwood, Tennessee. OS methods have been applied on a corridor basis to vanpool coordinators and vanpool members in the Ventura Improvement District (Ventura Freeway Corridor) in the San Fernando Valley.

OS methods have been applied on a supraregional basis in the form of the Nationwide Personal Transportation Studies (NPTS) of 1969, 1977, 1983, and 1990. The NPTS surveys were all conducted in the form of a stratified, clustered, random sample of housing units within both metropolitan and nonmetropolitan areas of the United States taken as a whole. The latest NPTS was based on a telephone survey sample, whereas the previous three relied on personal interviews conducted in the home of each responding household. Most TDM programs are site-specific, but may include service areas ranging in size from a single employer to a single large building to an activity center covering hundreds of acres, with thousands of employees potentially involved.

Temporal Focus

Recently, researchers have begun to explore the use of longitudinal analysis based on panel surveys to gather discrete data on dynamic changes in location and travel behavior. A panel survey is composed of two or more waves, where a wave is defined as a repeated survey of a specific group of survey respondents, who are asked in advance to participate in the survey process over a number of days, weeks, months, or even years. Because of the time and expense involved in conducting longitudinal panel surveys, these are perhaps best suited in the context of TDM to the evaluation of TDM measures associated with large capital investments, such as ridesharing promotions in support of the operation of new HOV capital facilities on major surface arterials or highways.

Organizational Focus

Potential organizational scales of analysis include national, state, regional, or local, in terms of unitary public policy, and activity centers, office buildings, and firms, in terms of typically more competitive and thus more fractionated private TDM policies. Public policy is often viewed as a single holistic determinant of travel and other forms of behavior, with equally weighted impacts across all potentially affected parties. This is often a questionable assumption. In practice, it is more likely that unequal effects may be observed, depending on prior knowledge and experience of individual travelers, the distribution of information and transaction costs across time, space, and organizational operating environments, the specific form of TDM implementation practices used, performance monitoring considerations, and enforcement provisions, if any. Private policies are probably more often subject to major differences among firms in terms of impacts than are public policies, but even this simplifying assumption will not always hold.

OS methods most clearly are useful where many actors are involved in different types and levels of policy making. Given that TDM is often implemented as a result of public-private partnerships, with many firms and public agencies involved at varying levels of decision making and in varying degrees of interest or compliance, OS methods seem particularly suitable for evaluating TDM programs across firms, activity centers, and the like.

Combined Foci

Even more complex are analytical foci that combine spatial, temporal, and organizational measures of variability. At the national level, the NPTS provides an organizational data base composed of four separate files, including household characteristics, individual characteristics and intraurban travel, individual characteristics and interurban travel, and vehicle characteristics.

These NPTS data are available for 1969, 1977, and 1983, and soon will be available for 1990 as well. The four files can be and often are treated independently for analysis purposes. These files also can be combined. The household file is the highest level of organization, with the vehicle file perhaps the lowest, in organizational terms. An analysis of mode choice for the work trip under the assumption of household influences or constraints on travel might require data from the first, second, and fourth NPTS files. Automobile ownership is often posited to influence various aspects of urban travel, such as vehicle-miles of travel and mode choice decision making. The level of inter- (and perhaps intra-) urban travel may influence automobile ownership simultaneously, or with a lagged temporal effect (Figure 2).

At the subregional or activity center level, the recent formation of transportation management associations as public-private partnerships to promote TDM is a phenomenon of apparently increasing importance. TMA evaluation potentially might require data at four levels of organization, including the TMA board of directors (executive decision makers), the TMA executive director (or line staff), participating private firms or public agencies (often formally recognized as association members), and the employees of any or all such participating organizations. Complex linkages between various levels of TMA organization might have to be taken into

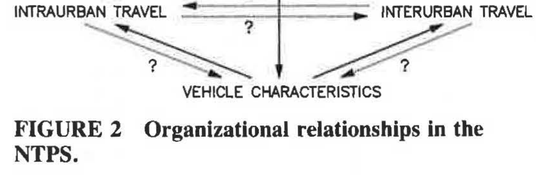

FIGURE 2 Organizational relationships in the NTPS.

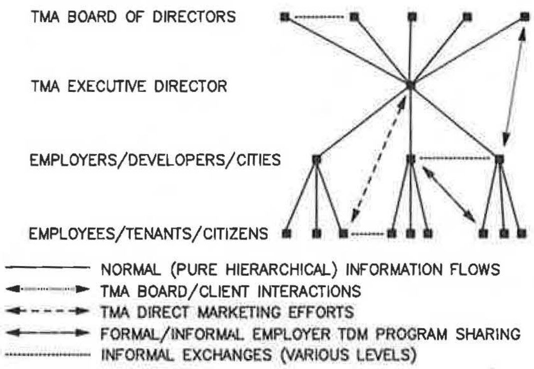

FIGURE 3 Organizational structure of TMAs.

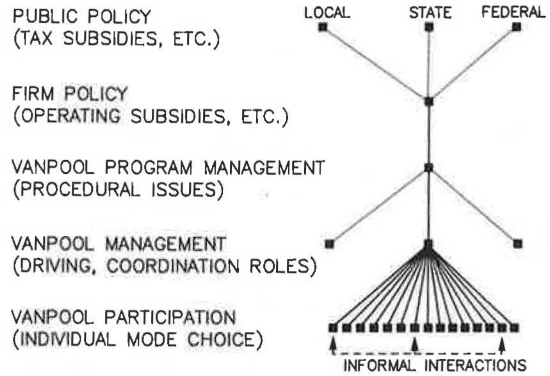

FIGURE 4 Organizational structure of vanpool programs.

account in evaluating TMA performance with precision and accuracy (Figure 3).

Most TMA evaluation efforts so far undertaken have been of relatively modest scope, often involving employee travel behavior surveys, employer ridesharing program surveys, and occasionally CEO surveys, but generally not all of these, simultaneously, before and after implementation. One exception is the South Coast Metro study conducted by the Orange County Transit District in Southern California. Few TMA studies have attempted to identify differences among participating firms in terms of incentives offered to employees. Fewer still have tried to identify the mix of supply and demand side measures used by TMAs to achieve their goals and objectives.

At the individual firm level, an organizational model of TDM implementation might include three levels of participation, including the CEO (policy), the TDM program manager (procedures), and the employees potentially or actually influenced by TDM program incentives and disincentives offered by the firm. At the individual TDM program level, an organizational mode of vanpool formation might include five major elements, as follows:

1. Public policy (federal, state, and local tax and regulatory policies);
2. Firm policy (private firm or public agency rules and regulations concerning issues such as vehicle type, vehicle ownership, operating subsidies, and driver perquisites);
3. Vanpool or ridesharing program management (procedural issues and orientation);
4. Vanpool management (vanpool coordinator and vanpool driver roles and responsibilities); and
5. Vanpool participation (formal and informal rules governing conduct within the vanpool, thereby influencing individual mode choice).

Although it might appear that vanpool formation is a relatively simple and straightforward process (Figure 4), it is in fact complex, and might be difficult to predict, in the absence of good information on both spatial and organizational factors influencing the relative size of potential vanpool markets. The author is studying vanpool formation on the basis of 2,400 vanpool members belonging to 400 vanpools serving 16 private firms and public agencies located in widely different parts of Southern California.

As these various examples illustrate, TDM implementation at all geographic levels of analysis may require an explicit organizational focus if relevant travel behavior parameters are to be identified in terms of comprehensive evaluation efforts. OS methods would be highly useful in most such efforts, if improved quantitative measures of TDM program impacts are desired as an outcome of the TDM evaluation process.

THE TDM MISSION

The mission of a TDM program is critical in determining the purpose and scope of evaluation efforts eventually undertaken. TDM programs with specific, i.e., numerical, performance targets generally begin with a baseline survey to determine the level of effort needed to attain specific changes or levels of change in observed travel behavior. TDM programs with few specific performance targets may engage in no such preliminary studies and often do not conduct evaluations ex post facto either.

Goals

TDM goals may be as specific as (a) maintaining Level of Service C on all streets and highways within a particular community, (b) providing adequate financing for all necessary transportation system improvements within the community, and (c) reducing peak period travel to eliminate traffic congestion for as long as possible. TDM goals may also be as general as (a) mitigating traffic congestion without further definition, (b) improving air quality, (c) conserving energy, (d) making local or regional housing more affordable (e.g., through higher densities on smaller lots, with compensating transportation system changes), (e) maintaining regional mobility, (f) providing an adequate degree of redundancy in the transportation system, and (g) being prepared for emergencies and other contingencies that might crop up at some time in the future. Obviously, evaluation efforts should, in general, conform in outline to the goals that are being sought through TDM implementation.

Objectives

TDM objectives relate more specifically to how TDM goals are to be achieved. In most cases, the principal objective of TDM implementation is to enhance regional or suburban mobility. This general description is overly broad, and provides insufficient guidance in developing adequate TDM evaluation tools. TDM objectives may be further separated into four classes of programmatic intent, including (a) increased supply, (b) improved system management, (c) improved demand management, and (d) reduced demand. It might seem odd to include supply enhancement among TDM objectives, but it is unavoidable in practice, because of the interrelated themes of supply and demand that are affected by TDM policies and procedures.

MEASURES OF TDM EFFECTIVENESS

Measures of effectiveness in TDM evaluation also exhibit great variability, as might be expected from the broad range of goals and objectives that typically are meant to be served through the successful implementation of TDM programs in practice. Specific measures of TDM effectiveness often include changes in mode choice on an individual basis, changes in mode split on an organizational or geographic basis, and reductions in the number of (vehicle) trips generated by specific activities at specific activity centers. These specific measures of TDM effectiveness are usually directly measurable, at least theoretically speaking, but often not without great difficulty and cost, and always with uncertainty remaining *ex post*. Less specific performance measures may include (a) reduced traffic congestion (e.g., hours of traffic delay eliminated), (b) improved air quality (e.g., reduced automobile exhaust emissions), and (c) energy conservation (e.g., reduced gasoline consumption).

Indirect measures of TDM effectiveness often require sophisticated models in order to conduct adequate valuative efforts. More specific TDM performance measures often are necessary as direct input to more comprehensive regional travel demand, airshed, and energy consumption models. The cost of evaluating TDM effectiveness in these more general terms is considerably higher, but perhaps more useful, than simply counting the number of trips made (or not made), and the proportion of trips modified in some way (altered, diverted, restructured, etc.). Expanded TDM programs gradually may influence patterns of land use and development, at least indirectly and over longer periods of time. TDM may serve as one alternative to requiring developers to provide adequate transportation facilities as an explicit condition of development approval in urban areas experiencing rapid growth and increasing traffic congestion.

Mode Choice, Mode Split, and Trip Reduction

Changes in mode choice are the most common form of effectiveness measure used in TDM evaluation. Trip reduction ordinances often specify a target mode split, or change in mode split, to be achieved through mandatory or voluntary TDM programs, implemented by developers, employers, or both, at the local or regional level. A major problem with mode choice studies is variability in day-to-day travel, which often exceeds targeted goals for trip reduction, making measurement problems particularly acute. This measurement problem can be controlled to some extent through the adoption of dynamic, time-series analysis, with data collected in multiple time periods, at higher overall cost, of course.

Examples of longitudinal studies include weekly travel diaries, travel behavior surveys repeated on a periodic (e.g., monthly or annual) basis, etc. Intertemporal survey sampling imposes much higher data collection and analysis costs, not to mention significant time delays, particularly in the case of annual sampling. A lower-cost alternative is to ask questions explicitly related to temporal changes in travel behavior (weekly variability in mode choice, long-term loyalty to a particular mode, etc.) on a one-shot survey form. Dynamic changes in travel behavior are less cleanly specified in such one-shot cross-sectional survey designs, of course.

Traffic Congestion, Air Quality, and Energy Conservation

Indirect effects of successful TDM program implementation frequently are defined to include reduced traffic congestion, improved air quality, and energy conservation. If measuring (or still more problematic, forecasting) the direct effects of TDM program implementation is a difficult undertaking, anticipating indirect TDM benefits may seem virtually impossible to achieve with any degree of accuracy at a reasonable cost. Traffic congestion can be identified at the local (microscopic) level through intersection analysis. However, normal variability in day-to-day travel once again may make estimating even the direct effects of site-specific TDM programs on local traffic flows difficult to identify, unless the site happens to be the predominant source of local traffic, local traffic congestion, and perhaps local traffic variability.

More difficult is the estimation of changes in regional traffic delays or air quality impacts associated with local TDM program implementation. The measurement of these TDM impacts typically requires the use of highly sophisticated, large-scale regional travel demand forecasting models and air pollutant emissions inventory and dispersion models. In their current forms, these large-scale models often ignore both daily and individual variability in travel behavior, with much greater emphasis being placed on the differential effects of various transportation technologies for personal travel or air pollution emissions control. The Urban Transportation Planning System (UTPS) definitions of trip purpose (home-based work, etc.) were reasonably good in describing important attributes of travel behavior in the 1960s, but are much less adequate in today's urban and suburban travel markets. To date, travel behavior market segmentation studies have rarely been implemented on a wide enough scale to be used in regional travel demand forecasting models.

There are few behavioral links currently drawn between technologies for different types of vehicle (e.g., cars, vans, and trucks) that are important in determining marginal emission rates in air quality analysis, insofar as these relate to travel behavior. In fact, most regional emissions inventories rely on regional or state vehicle ownership data as the sole source of travel behavior inference, with the explicit assumption that newer vehicles are driven more miles per year than older vehicles, but with no other travel behavioral variability used in the analysis. This is a scattered approach to understanding the air quality implications of travel behavior decision making at the disaggregate level, where TDM programs presumably have their greatest marginal impacts.

Land Use, Development, and Affordable Housing

Recently, some attempts have been made to link TDM implementation to even broader societal goals, including more effective land use management, appropriate and sustainable development, maintaining jobs and housing balances, facilitating the provision of more affordable housing, and the like. Modeling the influence of short-term TDM strategies on these longer-term trends in urban growth and economic development at the regional level realistically is beyond current capabilities for accurate measurement, and will remain so for much of the current decade, at the least. This limitation does not imply that TDM programs cannot or will not contribute in some small measure to the attainment of such broader (and much longer term) societal goals. Identifying the strength of such relationships, should they exist, given current analytical capabilities is simply not feasible under reasonable cost constraints on data collection and analysis in 1991.

MODELING TDM EFFECTIVENESS

More specific issues related to modeling TDM effectiveness in real time include data availability, model compatibility, and multiple model interfaces. Some of these issues already have been alluded to in previous sections. A few more explicit references to the current state of the art in aggregate and disaggregate travel demand forecasting follow.

Aggregate Travel Demand Forecasting

Aggregate travel demand forecasting is currently undergoing a major transformation in response to declining computing costs and the advent of powerful PC-based computer operating environments. A plethora of new models have been developed for the PC, that are still usually based fairly close on the UTPS mainframe programs from the past. Both new and old models may be faulted for their failure to include nontechnological modes of travel such as walking and bicycling explicitly, for treating ridesharing as being entirely subsumed within the automobile mode of travel, and for treating regional travel demand as more or less permanently fixed, once the trip generation stage of modeling has been completed. Unless these limitations are lifted, aggregate models will serve TDM evaluation needs only poorly. Similarly, ways and means of incorporating variations in organizational policies and procedures explicitly within aggregate models probably also will be needed, if true measures of policy sensitivity are to be identified for locally implemented TDM strategies within such larger-scale aggregate models of location and travel behavior. Direct linkages between aggregate and disaggregate travel demand models and the analytical methods used in estimating such models may be required to achieve these objectives meaningfully.

Disaggregate Travel Demand Forecasting

Disaggregate methods are better suited to TDM evaluation, but are severely limited in scope when regional impacts are to be estimated. Disaggregate methods can be readily adjusted to include nontechnological modes of travel, and ridesharing can be separated from the drive-alone automobile mode through nested modeling techniques. Similarly, the effects of organizational variations in TDM program implementation can be tested directly through multiple-tier OS methods. Presumably, as the body of literature describing disaggregate responses to TDM programs in the public and private sectors continues to grow, a knowledge base will be created that eventually might inform important innovations in both aggregate and disaggregate travel demand forecasting techniques. Only when these changes occur will TDM alternatives be directly comparable with supply-side options, ensuring confidence in the resulting predictions.

Two of the critical data needs for linking aggregate and disaggregate methods in travel demand forecasting for TDM evaluation include the following:

1. Identifying explicit behavioral linkages between vehicle technologies used and factors influencing travel demand directly. NPTS data are available for partial comparisons at the national level of analysis. Region-specific data on interurban and intraurban trip making also are needed. These data obviously would help in air quality analysis, but might also provide new insights into travel behavior analysis for its own sake.
2. Identifying new sets of trip purposes and trip patterns, which are internally more homogeneous and externally more heterogenous with respect to TDM influences and travel behavior determinants in the current decade. Ideally, this procedure might be considered for inclusion in the 1990 Census data used to create dual independent map encoding (DIME) files for use in UTPS and its derivative travel demand forecasting models. Alternatively, setting the groundwork now for such a development as part of the 2000 Census at minimum should be considered.

Modeling TDM Dynamics

A key problem in TDM implementation is maintaining the effects of short-term stimuli over the longer term. Programs that are successful one year may suffer losses the next, depending on changes in the level of resources allocated, TDM staff turnover, other staff turnover, and the like. Similarly, people rarely respond instantaneously to changes in ambient operating conditions, such as parking price increases, transit fare reductions, or the provision of personalized matching assistance through a trained professional employee transportation coordinator. In fact, it is more often true that travel behavior changes reflect a stochastic process, in which 4 or 5 years may be required before a new equilibrium point actually is achieved. This is, no doubt, particularly the case when significant changes in TDM program incentives are involved.

Given the marginal impacts of 5 to 15 percent in aggregate travel reduction often attributed to TDM programs a priori, adding long lead times to equilibrium adjustment exacerbates measurement problems in TDM evaluation. During the time that TDM programs gradually modify travel behavior, external changes in local employment conditions, regional economic growth, or national transportation policy may occur, with travel behavior implications that could easily dwarf the expected changes from even a highly successful and very ambitious TDM program. This process can only make TDM evaluation more difficult to perform well, if at all. Finding cost-effective methods to deal with intertemporal changes in geographic and organizational operating environments for TDM implementation should be a high priority in improving the accuracy and precision of TDM evaluation efforts in the future.

CONCLUSIONS

Innovative TDM evaluation efforts are currently underway in several parts of the country. Studies are underway or have been completed in Seattle, Southern California, Washington, D.C., Brentwood, Tennessee, and several other locations. Much more work needs to be done to encourage sound TDM evaluation practices in all those areas of the country where TDM implementation is proceeding at full speed, often without proper consideration being given to the need for generating more accurate and reliable information on TDM effectiveness, prospectively or retrospectively. Federal, state, and local governments, and particularly state, regional, and local transportation agencies, can and should assist the often much newer private sector participants in TDM program implementation efforts to identify more appropriate TDM evaluation methods.

ACKNOWLEDGMENTS

Many people provided direct or indirect guidance in developing this paper, including, but not limited to, Babuji Ambikapathi, Darin Atteberry, Wayne Berman, Mark Bryant, Bob Cervero, Bob Dunphy, Gary Edson, Gen Giuliano, Jesse Glazer, Tony Gomez-Ibanez, Peter Gordon, David Hartgen, Judy van Hein, Alex Hekimian, David Hensher, Thomas Higgins, Tom Horan, Ryuichi Kitamura, Richard Kuzmyak, Douglass Lee, David Levinson, Ben Lin, Maria Mehranian, Michael Meyer, Tom Nissalke, Ken Orski, Adele Pearlstein, Don Pickrell, Catherine Ross, Elizabeth Sanford, Eric Schreffler, Don Shoup, Don Torluemke, Roberta Valdez, Martin Wachs, Frederick Wegmann, and Mark Wright. The author is responsible for any errors that remain.

Publication of this paper sponsored by Task Force on Transportation Demand Management.