Resource Paper

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How may the relations that exist between the amounts and distribution of travel and the social, economic, and environmental impacts of transportation facilities and systems be identified and evaluated?

How may the linkages that exist in current practice between travel demand forecasting and procedures for estimating the social, economic, and environmental impacts of transportation systems and facilities be strengthened and improved?

What specific changes can be recommended for the objectives and procedures of travel demand forecasting that would serve to improve the results of impact forecasting and analysis in transportation planning?

What research can be recommended that would serve to improve the results of impact forecasting and analysis in transportation planning?

Answers to these questions are of critical importance because an increasing proportion—perhaps a majority—of transportation decisions are being made in the political arena, and the critical factors in these decisions revolve around issues that are related to transportation-system impact rather than around issues that relate to the balance between the demand and supply of transportation service itself. On the other hand, advances in transportation demand modeling have centered on refinements in our understanding of the demand-supply relations. Unless the questions are satisfactorily answered, we risk widening the gap between the concerns of the professional-technical transportation planning hierarchy and the decision issues that are of most importance to our communities and, thus, to the future of transportation systems and their planning. Clearly, this gap is already sufficiently wide as to make many of our technical abilities irrelevant in the current processes of decision-making with regard to transportation systems and projects (1). Although it is not likely that we can satisfactorily answer these questions during one conference, we can help to chart the directions that will be followed during the next decade in mobilizing the transportation research and planning communities toward the objective of seeking their answers. Answers to these questions are of critical importance if the transportation planning community is to recoup some of its losses in public confidence during the past decade and if it is to produce plans that meet public expectations and hence pass the important test of validity that comes with implementation.

The first part of this paper presents a conceptual framework for classifying and identifying the impacts of transportation systems and facilities and for identifying impacts that can be addressed through demand modeling. We can make this framework a useful vehicle for answering the above questions by using it to analyze some specific issues and options for more effective integration of demand modeling and the analysis of impacts of transportation systems. Within this framework, later portions of the paper present specific opportunities for the establishment of linkages between impact analysis and demand modeling. Finally, the framework is used to arrive at recommendations for a series of research tasks aimed at operationalizing the linkages between demand analysis and concern for the environmental, social, and economic impacts of transportation systems.

CONCEPTUAL FRAMEWORK FOR THE STUDY OF TRANSPORTATION IMPACTS

A discussion of the relations between the impacts of transportation systems and projects and the knowledge about those systems and projects should begin by returning to some basic concepts introduced by Thomas and Schofer a few years ago. Using their terminology, we can describe a transportation project as a change in an existing system. The change consists of the addition of inputs into that system and produces certain outputs. Inputs are the things drawn from the environment in order to modify the existing transportation system, and they might be "in the form of material resources, such as raw materials, money, and labor, as well as nonmaterial things such as information, ideas, or skills" (2, p. 10).

Thomas and Schofer point out that the transportation planner is concerned with changing the uses of such inputs in order to affect changes in the outputs of the transportation system, and they divide these outputs into 2 categories that will prove useful in the structuring of transportation-system impacts. First, there is a class of outputs that may be called performance outputs. The performance outputs of a transportation system are those results of system changes that are directly related to the objectives of the system or the purposes for which it was built. Changes in travel times from one point to another and changes in travel volumes on particular links are good examples of performance outputs, for they represent the extent to which the planner succeeds in meeting the objectives that have been set for transportation-system performance.

A second class of outputs is termed concomitant outputs; they consist of the "material and nonmaterial things flowing out of the system and into its environment which are not direct contributions to the attainment of the objectives of the system. Concomitant outputs may be generated by the operation of the system or even the simple existence of the system" (2, p. 10). Examples of the concomitant outputs include the liberation of hydrocarbons into the atomosphere, the consumption of space for transportation rights-of-way, and the noise produced by the vehicles that are part of the system. Clearly, these are outputs of major transportation projects, although we certainly do not produce the systems with the intent of generating such by-products. They occur because we are constrained by existing technology; if it were possible to produce high-quality transportation service through the provision of performance outputs without concomitant outputs, planners would choose to do so. Currently, many concomitant outputs of transportation systems are treated as externalities in that the transportation-system planner does not control them and the user is not always called on to pay the costs that the concomitants impose on nonusers or to modify his behavior in order to control their production.

One last borrowed term from Thomas and Schofer is the consequences that flow from the inputs, from the performance outputs, and from the concomitant outputs of transportation-system investments. These consequences are the results of the interaction between the inputs or outputs of the system and the environment within which the system is built. Clearly, the consequences of transportation-system inputs, performance outputs, and concomitant outputs are of great concern in the study of impacts (2, p. 11). For example, one consequence of the input of land might be a reduction in the tax collections of a municipality through which a transportation facility has been built because this land has been transferred from private to public ownership. Another consequence, this time the result of performance outputs, might be the increased use of a particular public park that was previously relatively inaccessible to the population of an urban area but to which travel times were significantly reduced by the opening of a new facility. Finally, an example of a consequence of a concomitant output might be an increase in the number of cases of emphysema that occur in a community because of increased exposure to the concomitant output of hydrocarbons in the air as a result of the construction of a freeway through the community. Clearly, these consequences depend on both transportation-system characteristics and the environment of that system. Thus, the changes in tax revenues depend on the preexisting tax base as well as the amount of land consumed for the construction of the facility; the changes in travel to the public park depend on the locational relations between the population and the park as well as the changes in the travel times; and the changes in the incidence of emphysema will depend on population density, preexisting health conditions, and presence of other sources of pollution as well as the presence of the new freeway.

Transportation-system impacts may be viewed in terms of a spiral of changes that take place in communities as a result of investments in changes in the transportation system serving them. In the analysis of these changes, the terms introduced by Thomas and Schofer provide a convenient way of labeling the different types of effects to which system changes give rise. I will, therefore, now turn more directly to considerations of transportation-system impact and will call on the terminology already introduced in order to build a framework for distinguishing among types of impacts and for relating each type to the concerns of transportation demand forecasting.

The most immediate and direct effects of transportation-system investments might be termed first-order impacts. These are the most measurable and probably the most predictable changes produced by investments in the network, and they include what have previously been characterized as changes in inputs, performance outputs, and concomitant outputs. First-order impacts, therefore, include the changes in the systems consumption of inputs, such as space and capital; changes in the production of performance outputs, such as point-to-point travel times and travel volumes on particular links in the network; and changes in the production of concomitant outputs, including shifts in the production of airborne pollutants and noise and the creation of linear "barriers" to movement at the local level.

When these first-order impacts are viewed in concert with the environments within which they take place, they give rise to second-order impacts. These include the important effects that Thomas and Schofer have labeled as consequences of transportation investments. Thus, in response to the first-order effects of travel time and traffic volume changes, urban activity patterns change and travel habits are adjusted to take advantage of the performance outputs of the transportation system. Similarly, the changes in concomitant outputs might give rise to second-order impacts such as increases in incidence of respiratory disease or decreases in property values if homes are exposed to high levels of noise or to visual impacts of transportation facilities.

The second-order impacts of changes in transportation systems may give rise to further repercussions that are entirely within the physical and institutional environments of those systems and that result from but do not directly involve the performance or concomitant outputs of the system or its inputs. Thus, a third-order impact might be a change in the levels of citizen organization within a community through the creation of antifreeway action groups or through letter-writing campaigns. Such a third-order impact might be a change of response resulting from a second-order impact that occurred as an intended or concomitant result of first-order impacts. Table 1 gives the relation between transportation system inputs and outputs and the 3 orders of impact. Table 2 gives examples of how this framework might be used to categorize particular transportation impacts at each of the 3 proposed levels.

Such a division of transportation-system impacts into 3 levels is valuable in studying the relations between these impacts and the concerns and capabilities of demand modeling. The numbers given in Table 3 indicate the relative strength of interrelations that exist between impact analysis and travel demand modeling and are defined as follows:

Linkages Between Demand Models and Impact Analysis	Relative Strength
Current focus of travel demand forecasting	1
Areas of potential linkage in short-to-intermediate time span	2
Areas of potential linkage in intermediate-to-long time span	3
Areas of little direct linkage, but from which important insights on the role and context of models can be drawn	4

The lower numbers indicate linkages that already exist or that could be developed within a relatively short time span at relatively low expenditures in research and development. Higher numbers indicate weaker linkages between the demand models and impact analysis and higher required levels of study to achieve useful ties. I hope to be able to demonstrate that demand modeling can now be directly applied to the analysis of some first-order impacts, and indeed the analysis of these impacts is the explicit intent of demand modeling. In the short term, it might prove possible and it certainly would be desirable to expand the concerns of demand modeling, through relatively specific research and development efforts, to the consideration and analysis of additional first-order impacts and perhaps some critical second-order impacts. I will contend that it will be more difficult and that it will take longer to employ demand models in the consideration of a wide range of second-order impacts and that this difficulty is a function of the institutional arrangements within which transportation planning is carried out as well as a function of the technical capabilities of modeling. Finally, I will assert that the third-order impacts are probably not effectively addressed by demand models, but that these effects help to define the role of demand models and the political climates within which they are employed. The implications of this division of impacts is not that first-order impacts are more important than those of second or third order; often the third-order impacts do directly affect decision-making. Rather, the value of the distinction is intended to relate more to the role of demand models in dealing with these impacts.

ISSUES AND OPTIONS FOR CONSIDERING IMPACTS IN DEMAND MODELING

Linkages Between Travel Demand Models and First-Order Impacts

First-order impacts include the most direct and measurable changes that take place among the inputs to and the performance and concomitant outputs from the transportation system as a result of physical or programmatic changes in that system. Transportation demand models have generally been applied to the forecasting of some of the first-order impacts that would occur under alternative system modifications. These forecasts, in turn, are used in the process of evaluating the alternative system changes.

Currently, the first-order impacts that have received the most attention in demand modeling include those that are related to the performance outputs of the transportation system. The traditional sequence of land use, trip generation, trip distribution, modal split, and traffic assignment, later efforts to produce direct and multimodal assignments, and recently developed procedures for the direct estimation of link volumes and for microassignment of traffic to detailed representations of neighborhood level networks, all produce estimates of performance characteristics of transportation networks such as modal and link volumes, aggregate estimates of point-to-point travel times, and information about typical trip lengths within the study area of different purposes. By applying these techniques to a reasonable number of alternative networks, the planner has attempted to generate information on the comparative performance of these networks for use in benefit-cost analysis or within other frameworks for comparative evaluation. The value and appropriateness of such demand modeling efforts should not be understated, for, in spite of the many flaws that we can all identify, these efforts represent the most systematic and detailed studies of any public service system that have taken place to date.

Existing modeling techniques are strongest in estimating the performance of future transportation networks at the regional or system-wide level, and this reflects the past emphasis on system-wide evaluations of alternative networks by the major regional transportation studies that developed existing model sets. Current models are weaker, however, in estimating some of the concomitant impacts of transportation systems at the regional level and are still weaker in producing estimates of both performance and concomitant outputs at the disaggregate level of individual links or neighborhoods. Current emphasis in evaluation is shifting toward the consideration of more localized effects and toward the establishment of more explicit linkages between the performance and concomitant effects of transportation investments at the localized level. As I have indicated earlier, I believe that the most immediate potential for expanding the capabilities of travel demand analysis is at the level of first-order impacts. Some of the most important possibilities for research and development in demand modeling involve a greater emphasis on performance measurement at the localized level as well as the consideration of first-order impacts of the concomitants of transportation investments at both regional and local levels.

Measuring Differential Accessibility Levels

Although travel demand models are already principally oriented toward the forecasting of performance outputs, there are several ways in which these models might be employed, even in the very short run, to provide additional system-performance information that would be of great value to planners. Generally, the models use information on socioeconomic characteristics of individuals, often aggregated to the travel-zone level, in the estimation of travel volumes. The outputs of the modeling sequence, however, are rarely presented in such a manner that system-performance differentials that exist among various subpopulations are made obvious. Because the gaps that exist in accessibility among major population components are becoming as important in transportation decision-making as the aggregate measures of system performance, this addition to the analysis of transportation-system performance can be a significant aid to planning.

Wickstrom has proposed that existing transportation models can be used to estimate the number of employment, shopping, or recreational opportunities that are available to spatially identified population groups within particular travel times (3). Carrying this concept further, we can use origin-destination survey data on employment of individuals and on the locations of employment opportunities to determine whether the transportation system is providing levels of accessibility between blue-collar workers and blue-collar jobs equal or inferior to the accessibility it is providing between professional workers and professional job locations. Initial indications from data that I am currently analyzing for Los Angeles are that population groups differ significantly in terms of the accessibility that the system provides to jobs for which they qualify and that these differences appear when the population is stratified spatially and also by income and by occupation category (4). The addition of some simple indexes of accessibility to current demand models and the aggregation of subpopulations according to socioeconomic characteristics rather than spatial location of residence are enabling us to use existing assignment models in the estimation of differential levels of system performance for these different population groups.

Similar comparisons can be made among trips made for a variety of purposes and between populations in which automobile ownership is high and populations that depend more heavily on the transit modes. For example, using very simple additions to packaged UTP model sets, we have estimated that, from one census tract in Los Angeles, residents who own automobiles may reach 1,678 physicians' offices, hospitals, and medical-group-practice offices within 30 min of their homes at off-peak hours. From the same tract, only 37 such health-care opportunities may be reached within 30 min of transit travel time. It is significant that this comparison was made for a zone in which car ownership is relatively low.

This type of analysis might be a step toward more explicitly recognizing travel needs of important subpopulations rather than focusing, as analysts have tended to do, on models that do not differentiate explicitly among different groups of travelers, modes, and trip purposes. Because the modifications needed in demand models to perform such comparisons are minimal and because the value of such information is potentially quite large in setting priorities for network improvement in terms of relative impacts, it is an area that is ripe for short-term research support and operational application.

What is really significant about such measures of system performance is that they represent a change in perspective for the planner and analyst. In the past, analysts have tended to judge system performance in terms of characteristics of trips that are actually made or that are forecast for some date in the future. With only simple modifications, the capability can also be developed to analyze performance of current and proposed networks in terms of opportunities to make trips by specific population groups. This is most significant for the analysis of social impacts of system performance because observed low levels of travel among the poor and the elderly might be derived from a failure of transportation systems to provide them with opportunities to travel rather than from innate tendencies of such citizens to travel less frequently.

Need for Greater Disaggregation in Demand Modeling

Emphasis on greater disaggregation in travel demand analysis has been growing for several years, and the above arguments do not exhaust the important reasons for pursuing this concept as a basic approach to the improvement of demand modeling. For example, under the rubric of "behavioral" models, researchers have modeled trip generation and modal split at the level of individual household or traveler rather than follow the traditional approach that uses the travel-analysis zone as the unit of analysis. It has been found that statistical relations that describe travel and mode choice at such disaggregate levels may differ considerably from zonal models. In part, this reflects the fact that total variance in travel includes within-zone variance as well as between-zone variance. The aggregate models operate only on between-zone variances, and we tend to assume that relations fitted to zonal averages between, say, income and daily trip-making are characteristic relations valid also at lower levels of aggregation. This is not necessarily so, however, for some recent studies have shown that within-zone variation about zonal means may be much greater than variation among the means for different zones (5). It would seem, therefore, that continued and further analysis of travel, disaggregated by personal characteristics and trip purposes, is important for more complete and valid representation of first-order impacts of transportation-system performance.

Linking Demand Models to First-Order Air Quality and Noise Impacts

Opportunities also exist for the establishment of direct linkages between travel demand models and the study of the concomitant outputs of transportation systems when these are considered at the first level of impact analysis. Thus, with the expenditure of some significant research energies, it should be possible to establish techniques to produce system-wide estimates of the production of environmental contaminants of transportation systems and perhaps to give more direct attention to the noise outputs of transportation links through more integrated modeling efforts. These linkages are important both at the level of regional transportation-system evaluation and at a more localized level as well.

In many metropolitan areas, levels of pollutants in the environment are derived primarily from the exhausts of motor vehicles. In Los Angeles, for example, it has been estimated that more than 90 percent of the CO, HC, and NO_x concentrations in the urban environment orginate in the transportation system. Efforts to improve the quality of the air in urban areas have been focused in the area of technological devices, such as the retrofit of older vehicles with pollution-control devices, and of research and development efforts aimed at producing cleaner fuels and a catalytic muffler. In the short term it is likely that technological solutions promise greater payoff than approaches that depend on the changing of travel patterns or the reorganization of land uses and population densities. There are, however, some contributions that might be made by the planner, using travel demand models as a tool in the analysis of alternatives (6).

One way of examining the effect of urban development and transportation systems on air pollution levels is with the aid of a simple "box" model as shown in Figure 1 (7). The urbanized area is the bottom of the box where the emissions due to automobile operation occur. Removal of pollutants from the box is for the most part accomplished by horizontal air motion and eddy flux out of the top of the box. The dimension h refers to the height of the mixing layer and the dimension D refers to the area's diameter. The long-term spatial average concentration of a pollutant can be approximated by the expression shown in Eq. 1 (8, 9).

$$\bar{c} = \frac{QD}{hw} \tag{1}$$

where Q is the pollutant emission (per unit time) per unit area and w is the average wind speed. This equation suggests that there are 3 basic aspects of the urban air pollution problem: (a) emissions (per unit time) per unit area, which is related to population levels, travel patterns, and technology; (b) city size or area, which is related to population levels and population density; and (c) pollutant dilution (hw factor), which is related to meteorological conditions.

Recent research has shown that Q is dependent on the total mileage driven within the region per unit time and on the average emissions per mile of driving. Although the emission per mile of driving is dependent on technological characteristics to a great extent, it also has been shown to bear a systematic and generally inverse relation to mean network speeds (7). Clearly, travel demand models can thus be used to estimate the inputs to such a box model because they provide estimates of network speeds and daily mileage of travel. Although such box models are simple and highly aggregated, if used in conjunction with land use and travel demand models they could be used to estimate some of the regional environmental effects of land use/travel network alternatives. For example, a coupling of land use, travel, and box models of this sort could compare estimates of the pollution consequences of high-density transit-dependent alternatives for a region with lower density development patterns that would perhaps increase total vehicle-miles of travel but lower the density of travel. Of course, the travel demand models applied in such an evaluation context would also produce information on other aspects of transportation-system performance to be included in the comprehensive evaluation of such alternatives.

Although the inclusion of environmental concomitants in modeling the first-order impacts of alternative transportation systems at the regional level would be an improvement over current demand modeling and one that would be valuable in providing a more comprehensive network evaluation capability, there are good reasons for researching the possibilities for providing disaggregate measures of environmental impacts as well. Many of the air, water, noise, and visual impacts of transportation facilities have their greatest effects on the population most closely located to the facilities themselves. For example, certain components of air pollution and noise levels generated by transportation facilities depend heavily on link volumes and the design characteristics of the facilities, such as grade, presence or absence of barriers, and density of development in the vicinity of the facility. Noise levels, for example, are also dependent on acceleration and speeds of traffic and the proportion of the vehicle stream that consists of heavy trucks (10). Although not yet operational, several researchers are working toward models that use information on traffic volumes and speeds and information from land use models on development characteristics of an area to derive necessary design characteristics of particular transportation links. The designs would result in the facility meeting some predetermined noise level standards (11). For example, given travel volumes, link speed, and composition of the vehicle stream, it might be estimated that a depressed facility might be needed to meet a standard of a particular noise intensity at a particular distance from the freeway in an area of single-family homes. This type of modeling is a logical extension of noise-impact research already performed and could provide additional information to the planner for estimating the cost-benefit relations for alternative systems. Similar opportunities exist for the analysis of other environmental concomitants of transportation facilities.

Potential for Goal-Seeking Planning Models Within Environmental Constraints

For the past 100 years American economic and political history has largely reflected an orientation toward growth. In almost every dimension of public policy-making at the national and regional levels, it has been assumed that there would be a continuing high level of population growth and economic and physical expansion in human activities. In every sector of public policy-making, emphasis has been on the accommodation of growth, and rarely were alternatives of limited or controlled growth ever considered.

Urban and regional land use and transportation planning have not been exceptions to the general rule of growth orientation. The modeling processes associated with land use and transportation planning have essentially treated forecasts of growth in population and economic activity as exogenous to planning and management. These forecasts have been taken to be the starting points for a planning process that basically consists of the application of mathematical methods to the evaluation of alternative means for the accommodation of projected growth within an acceptable range of system performance.

Recently, however, concern for environmental quality and the perception that zero-population growth might become a reality have lead to a shift in thinking. It is now becoming more common for public policy-makers to consider limited-growth alternatives, especially in program areas where the first-order environmental impacts of continued high rates of growth are seen as leading to environmental degradation. Regional land use and transportation planning is one sector in which limited-growth alternatives are now viewed as desirable in order to impose less of a burden on natural resources such as surface and ground water, open space, and air quality. Because data collection, analysis, and modeling methods used in urban planning have been based on assumptions of accommodation to growth, these current technical components of planning may require modification in order to be applied to the analysis of alternatives that include strategies for limited growth.

I believe that many of the functional relations captured by land use and transportation models are valid and that the manner in which such models are employed might be modified to incorporate environmental quality objectives in the planning process from the very beginning. This kind of a planning process, shown in Figure 2, would build on existing modeling capabilities, but would not employ the models simply to accommodate all forecast growth in population, economic activity, and travel. For example, current knowledge about vehicular emissions and federal air quality standards might be combined with knowledge about a region's meteorological conditions to produce estimates of the maximum amount of travel that could be permitted in the region if air quality were kept within the recommended levels. Next, existing models that relate travel to levels of economic activity could be used, with some necessary but tractable modifications, to derive tolerable levels of economic activity. Models that relate population and economic activity and that are currently in wide use could, in turn, be employed for the region to estimate total population growth limits that would be consistent with the levels of travel allowed by the air quality standards. Notice that, while retaining the functional relations among population, economic activity, and travel of the current models, the proposed approach reverses the role of predicted and predictor variables. In effect, it amounts conceptually to running some of the models backward; instead of proceeding from forecast growth to environmental impacts, the process being proposed begins with environmental standards and environmental "holding capacity" and derives a desirable upper limit on travel and, in turn, on economic activity and population.

One step toward dealing more effectively with first-order environmental impacts in such a "backward-seeking" or goal-directed manner is the development of network generation or design models as part of the demand-model package. Such models have been proposed and formulated in rudimentary form for the purpose of searching among the huge number of possible transportation-network alternatives for those that have the greatest potential for further elaboration and more detailed evaluation. These models may employ optimization techniques as a search method, using such system inputs as cost in the role of the objective function and possibly using information on high-valued resources as constraints. They provide a starting point for the selection of transportation-network designs that satisfy a set of constraints related to such first-order environmental impacts as air quality within the planning region. Network design models and the potential that they have for parametric analysis will also help to shed greater light on the sensitivity of the process of selection among alternative networks to variations in the valuation of the required inputs, such as land. Although such models already exist and are in the process of being refined (12, 13), more research is required to make them operational in actual planning situations and to link them more effectively with variables not incorporated in the more traditional forms of travel demand models.

Repro-Modeling: A Short-Range Option

If effective linkages are to be achieved between transportation demand models and impact-estimation models such as those for air quality and noise, careful attention will have to be given to the data requirements and computational burdens that are imposed by such modeling efforts.

The box model introduced earlier was extremely simplistic; many pollution-dispersion models in use today are a great deal more complex, especially those that incorporate representations of the changes in air quality that take place because of photochemical reactions. Indeed, such air quality models may be more complex and more demanding of data than is the entire transportation planning model sequence. It is difficult to imagine, therefore, a combination of the 2 sets of models for routine use by operating planning agencies. The resulting product would simply be too unwieldy and too expensive to operate. Simplified modeling structures are required, and their development should be given high priority.

One way to achieve simplified models that can link travel and impact forecasting in the relatively short run is through the application of repro-modeling (14). Repro-modeling is the use of the existing complex environmental and travel models as sources

Figure 1. Box model for examining air-pollution levels.

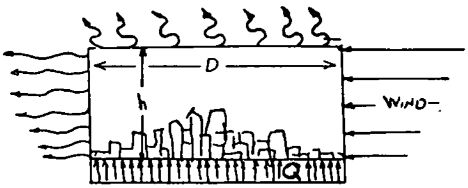

Figure 2. Proposed planning process based on environmental quality standards.

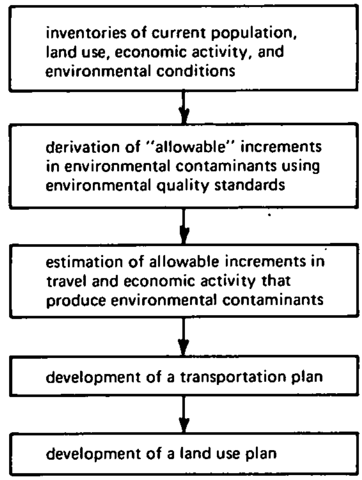

Table 1. Relation of successive orders of impacts and inputs and outputs of transportation system.

Impacts	Transportation System Inputs	Performance Outputs	Concomitant Outputs
First order	Measured as direct changes in inputs or outputs, principally within the transportation system		
Second order	Social, economic, and environmental consequences, measured in terms of interrelations between system and environment		
Third order	Structural and institutional changes occurring principally in the environment of the transportation system, a few steps removed from the inputs and outputs themselves		

Table 2. Examples of impacts resulting from transportation system inputs and outputs.

Impacts	Transportation System Inputs	Performance Outputs	Concomitant Outputs
First order	X acres of land taken in community A for freeway right-of-way	Travel time between community B and public park in community C decreases by 50 percent	Ambient air quality in valley D falls because of 20 percent increase in automobile exhaust emissions
Second order	Property taxes increase by Y percent in community A	Utilization of public park C increases by 25 percent	Respiratory illnesses in valley D increase by 10 percent per year
Third order	Industry in community A decides to expand elsewhere	Citizens in community C organize to exclude nonresidents from using the park	Population of valley D organizes to prevent additional road building in valley

Table 3. Current and potential linkages between travel demand modeling and impact analysis.

Impacts	Transportation System Inputs	Performance Outputs	Concomitant Outputs
First order	2	1	2
Second order	3	3	3
Third order	4	4	4

of data for the construction of simpler operational models that replicate the input-output relations of the more complex modeling set. For example, a complex pollution-dispersion model might be used as a "black box" to generate relations among vehicle speeds, traffic volumes, and various pollutants produced by the internal combustion engine. Next, piece-wise linear relations might be fitted through regression analysis to the most significant input-output relations represented by the complex model set; the complex models could be used to generate the data for the regression runs. For transportation-network planning, the simplified repro-model could be used in place of the complex model, sacrificing detail and theoretical precision for operational models that are computationally feasible. Such reduced models could be developed within a couple of years and appended to the current packaged model sets as a first step toward systematic environmental evaluation of transportation-network alternatives.

Linkages Between Travel Demand Models and Second-Order Impacts

In the previous section, attention was given to current and potential linkages between demand models and the basic measures of system input, performance, and concomitant output. It was shown that, although demand models are already quite directly concerned with the analysis of first-order impacts, there is great potential for broadening the range of first-order impacts that can be considered by using demand models and by using linkages between demand models and other predictive and analytical techniques.

In addition to these first-order impacts, the inputs and outputs of transportation systems interact with the environment of those systems and produce second-order effects that have become increasingly more important to transportation planners and to regional planners. Examples of the second-order impacts include (a) the social reorganization of communities due to the space consumed and social interaction patterns disrupted by the input of land for transportation facilities; (b) the reorganization of land uses in response to changes in physical accessibility due to new facilities; and (c) changes in community health or aesthetics due to such concomitant outputs as pollutants or visual impacts.

It is these second-order impacts that have formed the basis for the body of literature that exists under the heading of "impact studies" and that deal with issues such as changes in land values after freeway construction and suburbanization of residence and industry as a function of transportation network investments. Such impact studies are yielding an increasing level of understanding of the relations between transportation systems and the remainder of the urban environment, but there are several factors that make it difficult to immediately adapt this understanding to modifications in travel demand modeling. First, because the second-order impacts follow (both functionally and temporally) the first-order impacts, which were the subject of the previous section, many of the potential linkages that were described in that section will first have to be established in order to facilitate further efforts at incorporating higher order impacts. Second, additional knowledge of portions of the environment beyond the transportation system will be required in order to establish interrelations with demand models. Third, the institutional arrangements within which transportation planning is carried out tend to limit the planner's capability to deal effectively with the second-order impacts, and this reduces his motivation for establishing direct linkages between them and demand models. Because of these impediments to the immediate joining of second-order impact considerations with demand modeling, I conclude that direct linkages are probably at least a decade away, but that a great deal of learning will result from transportation modeling and research that will be carried on during that period and from knowledge that will be drawn from other fields and applied to transportation systems and their consequences.

The spiral of second-order impacts that result from changes in transportation-system performance is extremely complex and interesting. After 20 years of study, the transportation planner is well aware of the land use changes that take place in the vicinity of freeway access points or rapid transit stations, and documentation exists from dozens of impact studies that have been performed and are now under way. We would like to include such information much more directly in demand modeling, but the task will prove more complex than might appear at first glance.

Recent writings on the concept of "equilibrium" models have emphasized the joint determination of activity patterns and transportation, and the implementation of such models would be a step in the direction of merging second-order performance impacts with demand models (15, 16). In fact, the extent to which these impacts have in the past departed from the land use forecasts on which travel demand models were based is partly an indication of the extent to which the demand models have failed to deal with actual equilibrium conditions. To a certain extent, this shortcoming can be traced to inabilities to produce accurate projections at low levels of aggregation. Thus, our travel models might be based on forecast growth of 10 percent during 20 years in a fairly large subarea, and transportation facilities might be planned and built to accommodate this projected growth. Even if the projected growth level of 10 percent were achieved, impact studies might reveal that the growth took place quite unevenly within the sector, perhaps the vast preponderance in a small proportion of the area that is directly adjacent to the new facility and not much elsewhere. Thus, the models might have achieved a valid prediction of equilibrium at the large scale, but might demonstrate large errors at the level of individual travel zones. This portion of the problem can be addressed by systematic research within the transportation community.

In addition, however, many of the shifts in development that take place in urban areas depend on many factors that go far beyond considerations of accessibility. For example, some forecasts of economic activity for Los Angeles in the 1970s were performed during the 1960s and showed an increasing growth and dominance of the aerospace industries in the region. Of course, that growth has not come about. More precise forecasting models, which are based on more adequately defined notions of equilibrium between transportation and development, could not have resulted in more accurate forecasts of travel demand if the basic estimate of economic activity was grossly in error. Although travel demand models based on equilibrium concepts are theoretically and conceptually superior to the older "sequential-independent" models, they will not necessarily result in more effective travel forecasts or more effective consideration of developmental impacts. Research is required to clarify these issues, for we know relatively little about the sensitivity of alternative systems of demand models to inputs (such as economic-activity estimates) and relatively little about the joint influence of aggregation levels and accuracy of input data. Increased understanding of these phenomena will be required to deal more effectively with such impacts within the processes of travel demand modeling.

As new research results in a greater understanding of the ways in which equilibrium between economic-activity patterns and travel is jointly determined, it would seem possible to merge the concepts underlying equilibrium arguments and the process of building network-generation or design models. For example, we might envision using equilibrium concepts and such environmental constraints as air quality standards to reverse the order that we currently use in forecasting population, economic activity, and travel. We might ultimately begin with a series of constraints representing reasonable environmental standards and use something like the simple box model in order to derive from these constraints an allowable volume of travel in the region. Next, the equilibrium concept might be employed to work backward from this total volume of travel to estimates of "permissible" levels of development in the region and then to allowable economic-activity and population levels that would be in balance with regional travel volumes and environmental constraints. Except at the grossest level, this type of effort would be quite difficult within current understandings of the relations of travel, economic activity, and environmental holding capacity, but the capability to engage in such modeling efforts should be the subject of research during the next decade.

Of course, the extreme fragmentation that exists within most planning regions among agencies that have control over land use and those that have regional transportation planning responsibilities also influences the extent to which the planner can adequately deal with the second-order impacts. Indeed, in many regions transportation planning itself is fragmented by mode and administratively separated from those responsible for implementation. Thus, potential for joint control of spatial patterns of activities and transportation network performance is small in the intermediate future, and this might lessen the motivation for joint consideration of impacts and demand models. We should not let administrative fragmentation and concern for the current limitations on implementing models that deal jointly with movement, land use, and environment deter us from the development of such models. In many other areas (e.g., critical path scheduling, program budgeting) administrative practice and organization have followed the development of new analytical techniques. The development of new modeling capabilities could also contribute to the ultimate reorganization of planning practice to permit a more unified approach.

The second-order impacts of the inputs and concomitant outputs of transportation systems are subjects of a great deal of important and promising research that is already under way and should be continued. For example, in dealing with the social disruption caused by the consumption of space and the barrier effects of transportation facilities, Burkhardt has proposed a neighborhood social interaction index (17) and has shown that the social cohesiveness of communities is generally correlated with several demographic variables that are normally reported in census data and origin-destination survey data. As with the physical environment impacts, the potential exists for merging such social impact indexes into the transportation modeling process. One promising avenue of attack might be the incorporation of such community indexes within network generation and search models that have been referred to earlier. In addition to physical and cost considerations, constraint sets that influence such design procedures might be expanded to include the specification of socially cohesive spatial units in an attempt to minimize the undesirable community disruption caused by facilities. In similar ways, it might be possible to identify areas of high potential impact, such as where illness occurs because of automotive air pollution, based on data such as preexisting ambient air quality, proportion of elderly persons in the population, and local wind conditions, but relatively little is currently known about the relations among these variables beyond observed correlations. For this reason, although a great deal can be learned during the next decade about these relations, the potential for their direct inclusion in demand modeling is small during the short-term future, but greater in the longer term.

Demand-Model Considerations Related to Third-Order Impacts

Third-order impacts have been referred to earlier as relatively long-term social and institutional reorganizations that might result within communities from the inputs and from the performance and concomitant outputs that are related to transportation-system investments. In response to first- and second-order impacts, we are beginning to learn a great deal more about how community leadership changes, how facility location and corporate marketing patterns change, and even how individuals' perceptions of their environment and of the quality of its management change. Although increasing knowledge of these phenomena is of interest to transportation planners and the influences of transportation systems may be among the most important in decision-making in the coming decade, it is not likely that this knowledge can ever yield mathematical statements that can be directly incorporated into demand models.

Techniques, such as sociological field work, and extensive case studies are beginning to yield fairly reliable and systematic information on the effects of transportation on community power structures, leadership, and the processes of information and influence in decision-making. This information, however, is often of such generality that it cannot constitute the specific inputs and outputs of demand models. After all, demand models do still deal with fairly well-defined concepts of system performance, and the concepts of system performance that are relevant at the level of third-order impacts are much less specific and less subject to measurement or operational definition.

There are some important conclusions about the role of demand modeling in decision-making and about the political-administrative environment within which modeling takes place to be reached from a greater understanding of third-order effects. For example, case studies of transportation planning in the Boston region have shown that a third-order impact of transportation planning activities there, given the particular characteristics of that environment, was to raise transportation planning concerns to the level of major statewide political concern and to the status of major election issues (1). Within this context, the use of the projections produced by demand modelers seemed quite irrelevant, and the planner's technocratic adherence to the narrow measures of performance defined by his models clearly placed him at a disadvantage in arguing his case in the political arena. Such studies, then, have emphasized the importance of broadening demand-modeling concerns to include the systematic consideration of inputs and concomitant outputs as well as the traditional performance outputs in analyses and projections and to include, as far as possible, second-order impacts as well as immediately measurable first-order effects.

We may conclude, therefore, that research on the relation of demand modeling to the planning process and to political decision-making is relevant to the modeling community because it helps to define, although sometimes in very painful ways, what performance requirements should be set for the models and what kinds of information the models can and cannot provide in decision situations.

Relation of Demand Models to Decision-Making Frameworks and Rules

It is important to emphasize that demand models are not an end in themselves, but rather they are tools that are used in the production of information that is then employed in the evaluation of alternative network proposals. It is important, therefore, to relate the demand models themselves to the techniques or methods of evaluation that will be employed in the comparison of alternative transportation systems in the future. Although our evaluation framework should strongly influence the nature of demand models by specifying the types of information that those models are called on to produce, it is also true that the flexibility and effectiveness of demand models will strongly influence our approach to evaluation.

Historically, the evaluation of alternative transportation systems has been based largely on engineering-economic principles. This was reflected in the evaluation criteria of the Chicago Area Transportation Study, which in the early 1960s evaluated alternative networks by seeking the one that provided "least total transportation cost" per vehicle-mile (18). A similar rationale led to extensive use of benefit-cost comparisons in many regional transportation studies. In part, the need to produce monetary estimates of the impacts of transportation systems in order to use such evaluation frameworks may have limited the range of system performance and impact measures that have been incorporated into demand modeling. More recently, however, many planners have argued for newer evaluation frameworks that are more flexible than the foregoing decision rules. Thus, subjective-scoring and linear-weighting techniques (19), the "goals-achievement" matrix (20), and other systematic, though subjective, evaluation approaches have been proposed. The cost-effectiveness framework for evaluation has been used to emphasize the capability for reaching rational decisions while including some criteria for which dollar values may be derived plus other criteria that are difficult to translate into dollar terms (2, Chs. 8 and 10). These alternative evaluation frameworks should be of great interest to those principally concerned with demand models because of the close linkage between demand modeling and system evaluation. Enough is now known about the alternative evaluation approaches that research and experimentation could be carried out with the goal of determining their relative utility in current transportation-system applications.

Earlier, it was suggested that additional impact measures should appropriately be incorporated into the processes of demand modeling and that some dimensions for the broadening of the variable set included in demand modeling are within the current state of the art. We might ask whether these new variables (e.g., the differential accessibility to opportunities provided to different population groups) would more easily be incorporated into system evaluation under one decision framework or another. Can dollar values appropriately be placed on a wider range of impacts for use within the benefit-cost framework, or would the consideration of new variables best be achieved with more subjectively based evaluation techniques? Do the alternative evaluation approaches result in similar or widely different sensitivity to input variables, and can the requirements of these techniques be used in the specification of needed levels of accuracy and aggregation in demand models? In addition, we might turn the process around and prescribe changes in evaluation methods based on the range of variables, levels of aggregation, and precision of estimates that can be produced by an expanded set of demand models. I believe that each of these questions can be addressed through research and experimentation that are currently feasible and that would yield a relatively high payoff to transportation planners.

A particular area of current interest is the use of interactive computer techniques for the efficient combination of the analytical capabilities of computerized network models and the subjective judgment of the analyst or planner. Several partial models have been developed that have potential for expansion and wider application in the evaluation of network alternatives. One of the serious problems that currently exist is the large amount of computer core required for the software associated with the interactive evaluation system itself and the large demands that complex sets of travel demand models also place on most computer installations. For example, the INTUVAL system developed at UCLA (21) is capable of rating as many as 10 alternative alignments for a particular route on as many as 10 dimensions of evaluation, but it uses so much of the computer's capacity and requires so much computer time to operate that only a single and exceedingly simple representation of travel demand may be employed. Even with limited computer capabilities it is possible to use such interactive methods in fairly broad screenings of alternatives in much the manner that network generation and search models are proposed to be used. Interactive capabilities also cause us to raise questions about how much fine-grained detail is really required for network evaluation and whether a more effective evaluation tool might be one that allows the comparison of many alternatives according to a large number of dimensions, but perhaps with much less precision than current demand models. This argument is especially attractive to those who feel that the precision of current demand models is far greater than their accuracy.

RECOMMENDED RESEARCH DIRECTIONS

In previous sections mention was made of a number of possible research directions that, if followed, might result in modifications to the demand-modeling process and make that process more capable of producing realistic estimates of the social, economic, and environmental impacts of transportation facilities. In this section I make these recommendations more explicit by listing several research directions that can be pursued in short and intermediate time frames. This listing represents only a starting point because it consists of my personal priorities and expectations. The short-term proposals are for 1 to 3 years, and the longer term proposals are for 3 to 10 years.

Short-Term Proposals

1. Transportation demand modeling should be supplemented by estimates of the extent to which new network configurations would influence the accessibility to opportunities (jobs, services, recreation) of specific population groups (poor, aged, carless). This can be accomplished in the short run by simply measuring the changes in distributions of trip opportunities by time and cost as a result of alternative network configura-

tions. The provision of opportunities through new linkages between population subgroups and potential trip ends should be recognized as a transportation planning objective that goes beyond the matching of supply to manifest demand.

2. Demand models should be extended so that estimates of link volumes and speeds can be supplemented by existing knowledge of noise attenuation to produce estimates of noise exposure at any point within the corridor. Highly precise estimates are probably not required for transportation planning purposes.

3. Efforts should be made to link regional air quality estimates to transportation-network characteristics. For macro- or regional-level and for system-level transportation planning, estimates of sufficient precision can be produced within a short time horizon by employing repro-modeling on existing air pollution concentration and dispersion models.

Longer Term Proposals

1. More definitive study should be conducted relating transportation-system parameters to air quality at the local as well as regional scale. Although a great deal is being learned about air quality, and the transportation system is the major source of contaminants in most regions, transportation modeling and air pollution modeling have remained functionally independent. Specific research efforts are required to link these so that transportation-system planning can be carried out within environmental-quality objectives. Recent research in network-generation models constitutes a useful starting point for the ultimate development of models that search among alternative transportation-activity patterns for those that meet environmental as well as cost constraints.

2. Research should continue on the development of disaggregated models of travel at the levels of individuals and households. Such models have potential for enabling the transportation planner to make more effective estimates of social impacts of transportation projects by enabling him to trace out the behavioral outcomes of transportation-network changes. Basic behavioral research is still needed on the processes by which individuals decide between transportation alternatives as travelers and how they relate to transportation facilities as components of the total urban environment. Attitudinal studies of the past decade have yielded some useful results, but basic theoretical frameworks are still absent. This absence limits our ability to incorporate the findings into demand modeling or impact modeling in a predictive rather than analytical manner.

3. There has already been a great deal of research on the second-order impacts of transportation investments. Impact studies are continuing and contribute increases in understanding of the relations between transportation and economic-activity patterns, land values, and timing of development. A major research effort is now warranted to collect and collate the results of scores of impact studies already completed and under way and to generalize from the various efforts. The richness of empirical data from numerous before-and-after studies should be employed in a new round of theory building. The ultimate payoff will be in the construction of models that more effectively represent the dynamic interdependencies between transportation networks and urban development trajectories.

4. Research is required on new decision-making frameworks that would enable the planner to evaluate alternative network proposals in multidimensional decision spaces. Benefit-cost and subjective-weighting schemes limit our abilities to effectively distinguish between alternative networks and to incorporate our knowledge of social and environmental impacts with the transportation-performance consequences of choices among alternatives.

5. Efforts should continue to develop computer-graphics and other interactive settings for the quick screening of alternative transportation-network proposals in terms of their social, economic, and environmental consequences and to allow implementation of new decision-making frameworks.

6. Additional research is required on the relations between the political processes

in transportation decision-making and the technical and analytical processes involved in demand modeling as well as impact modeling. At times, it appears that the results of the technical analyses carry too little weight in the making of political decisions, but the reverse may also be true. Research by social scientists on the nature of the decision-making process and the role of the technical processes could help establish more realistic performance specifications for demand modeling and impact analysis.

CONCLUSIONS

Urban planners and modelers in general have a natural tendency to propose, at the drop of a hat, that any currently identified shortcomings in their models can be eliminated within one decade if they are only given enough encouragement, cooperation, and money. I have avoided making assertions of this type with respect to the potential for making travel demand models more consistent with our current perceptions of needed improvements related to the treatment of the social, economic, and environmental impacts of transportation. I have tried hard to be realistic and have not suggested that all of the complexities associated with impact issues can be or should be addressed through demand modeling. I am optimistic, however, that significant improvements in demand modeling can be made in the years to come and that those improvements will make them more responsive to impact considerations. In areas where the models themselves probably will not be responsive, I have suggested that we can still learn a great deal by considering alternative evaluation frameworks within which demand models can be used and by considering new institutional arrangements within which modeling and other parts of the planning process might take place.

In summary, it appears that the most immediate impact issues that might be addressed through demand models relate to the measurement and prediction of network performance provided to particular subpopulations defined by socioeconomic, demographic, and spatial characteristics. There is evidence that the gaps in service provided to different groups are significant and that relatively little modification in current modeling practice could help us to plan more effectively toward the elimination of gross inequalities. It also seems that steps could be taken to deal more effectively with the interrelations between network and link characteristics and immediate concomitants of transportation service such as air pollution and noise at both regional and neighborhood levels. In the somewhat longer term, it would appear that demand models could more effectively be linked with measures of intrusion into established social and behavior patterns at the community level. In addition, attempts should be made to develop operational network-generation and screening models to supplement demand models in the development of strategies for avoiding extreme negative impacts on communities or the taking of properties of high social and symbolic value. I have also suggested that, although it is not likely that third-order impacts such as political struggles and community leadership changes could ever be incorporated into demand modeling, these issues should be studied for clues as to the appropriate focuses and roles that demand modelers should seek to meet with their efforts. In addition, it is important to match demand models with the new and emerging evaluation frameworks because system evaluation requirements will help to dictate the scope and form of the information sought from the models.

REFERENCES

1. Lupo, A., Colcord, F., and Fowler, E. P. Rites of Way: The Politics of Transportation in Boston and the U.S. City. Little, Brown, Boston, 1971.
2. Thomas, E. N., and Schofer, J. L. Strategies for the Evaluation of Alternative Transportation Plans. NCHRP Rept. 96, 1970.
3. Wickstrom, G. V. Defining Balanced Transportation: A Question of Opportunity. Traffic Quarterly, Vol. 25, July 1971, pp. 337-350.

4. Wachs, M., and Kumagai, T. G. Physical Accessibility as a Social Indicator. Urban Transp. Program, Univ. of California, Los Angeles, Res. Rept., Oct. 1972.
5. Guidelines for Trip Generation Analysis. U.S. Govt. Printing Office, Washington, D.C., June 1967, pp. 38-42.
6. Hagevik, G., ed. The Relationship of Land Use and Transportation Planning to Air Quality Management. Center for Urban Pol. Res., Rutgers Univ., State Univ. of New Jersey, New Brunswick, 1972.
7. Klett, F. Urban Fringe Development: Air Pollution Certainties Versus Mass Transit Possibilities. Urban Transp. Program, Univ. of California, Los Angeles, Res. Rept.
8. Lettav, H. H. Physical and Meteorological Basis for Mathematical Models of Urban Diffusion Processes. Proc., Symposium on Multiple Source Urban Diffusion Models, U.S. Environmental Protection Agency, Nov. 1970.
9. Fay, J. A., and Flower, W. L. A Generalized Model of Urban Pollutant Distribution. Paper presented at Fluid and Plasma Dynamics Conf., AIAA, Boston, Paper 72-647, June 26-28, 1972.
10. Gordon, C. G., Galloway, W. J., Kugler, B. A., and Nelson, D. L. Highway Noise: A Design Guide for Highway Engineers. NCHRP Rept. 117, 1971.
11. Edwards, J., Schofer, J. L., and Spacek, D. Noise Estimating Relationships for Use in the Design of Urban Highway Networks. Dept. of Civil Eng., Northwestern Univ., Evanston, Ill., Interim Rept., Aug. 1972.
12. Morlok, E. K., Nihan, N. L., and Sullivan, R. F. A Multiple-Mode Transportatation Network Design Model. Transportation Center at Northwestern Univ., Evanston, Ill., Res. Rept., 1970.
13. Rea, J. C. Designing Urban Transit Systems: An Approach to the Route-Technology Selection Problem. Urban Transp. Program, Univ. of Washington, Seattle, Res. Rept. 6, 1971.
14. Collins, D. C., and Meisel, W. S. Repro-Modeling in the Practical Utilization of Complex Environmental Models. Paper presented at Joint Automatic Control Conf., Stanford Univ., Calif., Aug. 1972.
15. Manheim, M. L. Practical Implications of Some Fundamental Properties of Travel Demand Models. Highway Research Record 422, 1973, pp. 21-38.
16. Brand, D. Theory and Method in Land Use and Travel Forecasting. Highway Research Record 422, 1973, pp. 10-20.
17. Burkhardt, J. E. Impact of Highways on Urban Neighborhoods: A Model of Social Change. Highway Research Record 356, 1971, pp. 85-94.
18. Chicago Area Transportation Study. Transportation Plan. Final Rept., Vol. 3, April 1962, pp. 6-44.
19. Jessiman, W., Brand, D., Tumminia, A., and Brussee, C. R. Rational Decision-Making Technique for Transportation Planning. Highway Research Record 180, 1967, pp. 71-80.
20. Hill, M. A Method for the Evaluation of Transportation Plans. Highway Research Record 180, 1967, pp. 21-34.
21. Kamnitzer, P., and Hoffman, S. INTUVAL: An Interactive Computer Graphic Aid for Design and Decision-Making in Urban Planning. Proc., 2nd Annual Conf. of Environmental Design Res. Assn., 1971.