Results of the testing efforts lead to some definite conclusions:

1. The CATS transportation proposals would adequately serve any of the proposed four land-use plans—within the CATS area.
2. The finger plan was the best land-use plan from the point of view of transportation. It organized land uses so that trip lengths were shorter and had a generally higher quality of service in the networks.
3. The CATS L-3 highway plan was clearly superior to an alternate plan devised for the finger plan. This conclusion is supported by the traffic analysis and by the marginal rate of return economic analysis.
4. The alternative transit plan did not provide marginal benefits to justify the additional capital costs. However, it did have desirable qualities, which suggests that CATS should restudy its transit proposals.

Results of these tests provided a large body of statistics in support of the CATS expressway proposals. It appears that a well-conceived plan based on spacing principles will work under a variety of land-use configurations. While there may be some severe local dislocations due to shifts in density within the CATS area, average trip densities did not vary greatly from one plan to another.

A conclusion not related to the technical aspects of the project is that two separate agencies can, each with particular skills and specialities, successfully work together in preparing and evaluating land-use and transportation plans.

REFERENCE

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Transportation System Development and Evaluation as Practiced in Seattle

STEPHEN GEORGE, JR., Director, Albuquerque Metropolitan Transportation Planning Program[1]

•A FEW months ago, the final published Summary Report (1) of the Puget Sound Regional Transportation Study was distributed. The 115-page document could not have been designed to give full justice to the initial four years' effort of a comprehensive land-use and transportation planning program. The interdisciplinary staff that was assembled in 1961 was able to expand on its previous experiences and sharpen up the tools of system development and evaluation, but the final report does not cover this area. What did we learn from this important exercise that can be applicable to a great number of medium-to-large-size metropolitan areas?

As a preamble to the general conclusions that I wish to emphasize, let me digest the study scope and the area's physical restraints before outlining the system development criteria and system evaluations.

SCOPE OF PSRTS WORK PROGRAM

The overall objective was to "formulate a transportation plan as part of a general development plan for the region." Alternative land-use patterns and alternative transportation systems including mass and rapid transit were developed, tested, evaluated,

[1]The author was associated with the Puget Sound Regional Transportation Study as Deputy Director and Principal Consultant from April 1961 to August 1967.

and an integrated land-use and transportation plan was recommended. The 1961 regional population was 1.5 million, forecast to grow to 2.75 million by 1990. The four-county area of study included more than 40 individual cities. Comprehensive studies of land use, population, economic base, traffic conditions, and travel patterns were the source of the facts and figures, which were stratified by 33,000 grid blocks, 662 analysis zones and 60 analysis districts within the study area of 1500 square miles, of which 200 square miles was in water bodies.

The 65-miles long study area has four separate central cities, varying in population from Seattle, over a half million, to Bremerton, 30,000. The area is divided by the very large body of water known as Puget Sound. Because of the many lakes and the Sound, topography suitable for major transportation corridors is limited and terrain difficult to cross in desired locations.

Over the years, development of the transportation system in Seattle was promoted north and south. With the construction of the north-south Interstate highway, the area found itself with a great number of east-west arterial deficiencies to the freeway interchange points. Because of the extreme depth of the Sound and lakes, the Northwest has pioneered in concrete floating bridges, a more economical but still costly solution to cross-Sound and cross-lake travel needs.

SYSTEM DEVELOPMENT CRITERIA AND STEPS

If the future travel is to be accommodated by planned transportation systems, all components—streets and highways, mass transit, ferry boats, bridges, and parking facilities—must be considered together. Although PSRTS studied each of these components and their interrelationship, only the transportation system made up of streets and highways will be outlined, for simplicity of this discussion. In addition, let us assume that a future trip table is available to us outside of this discussion. Now that we have access to a current and forecast trip table, with which system do we begin the assignment process and what criteria and steps do we follow?

System Development and System Evaluation Are Inseparable

System development is the evolution or transition of today's given transportation system into a planned or recommended system to serve a future time period. This time period could be a short-range plan such as 1975 or a long-range plan for 20 to 25 years hence. Systems research concepts are now utilized to analyze, update, modify, or extend a given current transportation system into a more complete network needed for tomorrow.

System evaluation is a process of assessing the adequacy of any given system to satisfy desired criteria and overall goals. Experience of a number of transportation studies has indicated the preference for a continued systems evaluation of a logical series of systems under development.

System development coupled with continued system evaluations can be likened to zeroing in on a bull's-eye from the outer ring to the inner rings directed toward achieving a balanced capacity-demand network. The more we know about system mechanics, the more we realize the need to develop a system that will insure maximum utility of what we have today. Formulating alternative systems for the sake of alternatives, or to appease one pressure group or another, is a time-consuming and costly process that too often develops more data than can be digested and properly utilized in the development process. If one attempted to analyze several alternatives, for example, years could be required to evaluate the actual differences between them.

A continued system evaluations process at PSRTS followed the "minimum assignment-maximum analysis" technique of system development. "Maximum analysis" in this context includes (a) conventional system data plotting techniques, i.e., volume by link and volume-to-capacity ratio calculations by link, and (b) usual tabular summaries to measure overall system performance. By this process, continued iterations from a starting point increases the knowledge of the analyst of his particular system under development. I believe this has been demonstrated to reduce the overall time to reach a recommendation. The process also insures maximizing the full utility of what is given.

Application of Level of Service Concepts and Standards

The traffic assignment procedure usually begins with the assignment of current origin and destination traffic to a base year network. For this step, current travel time or speed data are collected, and usually these same speed data are inserted into the future system under study.

We all know of segments of our own existing networks where obvious improvements have lagged behind the need for one reason or another. In my own city, one of our most congested segments follows the centerline of the City-County boundary line. Delayed improvement has not materialized because of the complexity of developing a joint project to be assessed against the abutting property owners on both sides of the arterial. Using the resulting low speed or level of service will only guarantee perpetuating the condition any analyst would desire to eliminate. A constructive estimate of traffic demand will not materialize if a less-than-desired speed is assumed on a system.

In some cities, the traffic engineer has found himself attempting to increase traffic capacity on facilities improperly spaced due to the lack of a more constructive approach. One of the best means to overcome such deficiencies in today's conditions is to apply a level-of-service speed standard in the traffic assignment package. A level-of-service speed can be developed from the analysis of comprehensive travel time studies. Such standards should be both attainable and desirable speeds by functional classification and can be properly used to help measure existing and planned facility adequacy. The utilization of desirable speed standards in planning for future regional facilities will insure the proper appraisal of all needs without reference to current deficiencies. A level-of-service speed standard, if properly applied, should identify relative desired differences between freeways, major streets and collectors. If one of our goals is to develop "best and optimum" systems that will encourage a desirable environment, design and planning must be separated the same way that "administrative planning" is separated from "scheduling" in the critical path method applications.

Level of service in City A is not the same as in City B. In general, level-of-service speed differentials by functional classification are further apart in the West when compared to the East. This fact is a reflection that urbanization is older in the East and younger in the West and typifies people's choice and desire.

Basic Building Blocks of System Planning

In beginning a future-year system analysis, some studies start by testing the adopted major street and highway plan prepared by a local planning commission and find themselves making drastic surgery to it in the traffic assignment process. Only in recent years have such plans by planning commissions been based on a careful and factual study.

In Seattle, the basic building block for all study systems was the existing base year network of 1961. To this was added the additional facilities that were firmly and definitely committed, judged against uniform criteria across the multi-county study area. The committed system constituted the first future-year system that was also utilized to generate a trip matrix in the trip distribution model.

The Seattle study actually utilized the interim committed system for its accessibility inputs in the land-use allocation model. Since the full land-use impact of a committed transportation network is not felt until after its implementation, intermediate-year system parameters (year 1975 is between 1961 and 1990) were found to best satisfy the land-use allocation and the trip distribution model requirements.

In planning a transportation system, we too often "muddy the waters" by expecting design output from each assignment run. For example, a capacity restraint assignment was not used in the PSRTS development simply because the multiple screen line analysis resulted in significantly deficient capacities across the metropolitan area. The capacity restraint assignment process can only be used if you have some place to divert the traffic and should be postponed to refine the design data needs after a future system has been properly developed. A few of us believe that capacity restraint assignments, in general, have been promoted too early in the planning process and are not a panacea to system development.

Use of Selected Link and Screen Line Analyses

Discussion with other practitioners and computer service bureau staffs indicates that selected link loads and selected zone loads programming options are not used often enough in our computer library. Those of us who have used it extensively feel that we would still be "spinning our wheels" in constructive system development and evaluation without this powerful tool. How can you use it to your advantage?

Selected link or zonal analysis permits the analyst to isolate the network link or zone in question and graphically summarizes the problemized travel pattern. If the link is significantly overloaded, knowledge about the component of the traffic demand creating the overload can be compared with the desires. Such analysis will contribute significantly to evaluating alternative extensions to the network and to selecting the more reasonable link updates to resolve the problem. Too often problems in one corridor are the result of deficiencies in another corridor 90 degrees removed from the problem.

Selected link analysis permits the analyst to define the zone of influence of that link with supplemental knowledge about its probable usage characteristics.

With selected zone loading analyses, the analyst can determine at what level of increase in traffic attractions in a zone interchange design breakdowns will occur. Any desired modification in trip generation can be inserted in selected system design analyses by way of a selected zone loading. Traffic flows can be increased or decreased in special analysis areas, provided the particular distribution pattern is still valid.

Screen line evaluations still appear to be the backbone step of system development. Comparisons of demand vs available and assumed capacity tell the analyst whether the total overload is of freeway or expressway proportions. Evaluations also identify whether an adjacent screen line can absorb the diversion of traffic provided level-of-service standards are modified or linkages are modified.

Three principles are involved in this activity, which can be summarized as follows:

1. Initial network evaluations should be viewed as part of normal study procedures to develop staff analyst comprehension of system operating characteristics.
2. Continued system evaluations should be keyed to a demand-type analysis until system balances are resolved as contrasted to performance analysis where individual link operational analysis is emphasized, i.e., capacity restraint.
3. Network performance analysis can then proceed to refine or perform detailed evaluations of the recommended systems and/or their alternatives for implementation purposes.

GENERAL CONCLUSIONS APPLICABLE TO OTHER METROPOLITAN AREAS

The Limits of Future Population and Employment Distributions Are Not the Same

The Seattle study developed a population distribution model based on a statistical evaluation of the factors that determined the growth that occurred in the region between 1950 and 1960 (2). Five factors were isolated as attracting and influencing the locations of population growth. An employment distribution model was also developed (3, 4). Based on this research and application, radically different future population distributions did not result when alternative land-use patterns were tested in 1964. Seattle is now experiencing accelerated growth due to the Boeing expansion program and significant modifications in the distribution of population in the alternative land-use plans are not indicated. Continuing industrial expansion is following the study's land-use plan B concept.

Dispersion of residential growth is a general trend across our land. From Albuquerque to Minneapolis, land ownership characteristics, quality of the homes desired, extent of utilities, and the intangible amenities are becoming more important than access to place of employment.

With regard to employment distributions, the Seattle study demonstrated that the alternative plan responsive to regional goals, if supported by policies to guide regional development, can result in a different distribution of employment location, and thus have a major effect on traffic capacity needs. Based on a more desirable development pattern, less capacity may need to be provided for future travel needs to the CBD's and

more capacity may need to be provided on major corridor facilities in today's suburban areas.

The Importance of Alternative Land-Use Patterns

Let me briefly discuss the importance of alternative land-use patterns as they permit flexibility in transportation planning. With a given mileage of committed major facilities, quantification of alternative land-use patterns when translated into system demand can significantly strengthen the basis for transportation facility recommendations by insuring the identification of the major corridors of travel. If committed mileage is significant, as was the case in Seattle (and such committed mileage can be a major shaping tool for land-use activities), alternative land-use or employment patterns will help delimit or confirm the major corridors of travel and provide a workable volume demand range on each facility applicable to the limits of the alternatives studied. A more flexible transportation plan can thus be developed should one part of the study area develop one way while another part follows more closely the alternative pattern.

If, on the other hand, committed mileage is limited, as appeared to be the case in some of the Upstate New York studies, and the impact of transportation on land-use activities is minimal, the analyst will not know if he has delineated all possible major corridors of future travel unless he has studied the limits of the reasonable alternatives that may result from a different distribution of population and employment. Either way, regardless of how extensive our committed transportation systems are, the inclusion of alternative land-use patterns study in our continuing program must be emphasized, and definitely should be included in more land-use and transportation planning programs.

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2. Graves, Charles H. Two Multiple Regression Models of Small-Area Population Change. Highway Research Record 102, p. 42-53, 1965.
3. Graves, Charles H. Forecasting the Distribution of 1985 Population and Employment to Analysis Zones for Plan A. Staff Report No. 15, Puget Sound Regional Transportation Study, Seattle, 1964.
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NOTE

During the formal presentation at the Highway Research Board, the author referred to ten 35-mm slides as graphical examples of system development results extracted from the Puget Sound Regional Transportation Study Summary Report of September 1967. The slides are available on loan from the author. They are not available from the Highway Research Board.

Discussion

THOMAS B. DEEN, Alan M. Voorhees and Associates, Inc.

•ONE must always begin any criticism of another's work on network evaluation with an expression of humility and apology for ignorance in the face of this awesome task, in which everything affects everything else and which covers such a broad spectrum of human activity. Besides, anyone actively practicing as a transportation planner has at one time

or another been, and will likely in the future be, forced by lack of time, budget, and knowledge to use techniques similar to or sometimes worse than the ones he criticizes at Highway Research Board meetings. In any case an annual soul-searching and confession is probably useful; otherwise we might complacently fall into the trap of believing that we really do have reliable objective techniques for systems evaluation.

Campbell's paper covers testing of various regional land-use schemes as well as evaluation of networks required to serve a given land-use plan. George's paper covered only the networks and since this session is sponsored by the Transportation System Evaluation Committee, I will restrict my remarks to network evaluation problems. It is interesting to note in passing, however, that Campbell's land-use analysis concerns several radically different regional land-use plans. In contrast, the Puget Sound analysis concludes that substantially different land-use schemes are not possible.

The two papers presented here were a fortunate selection since they are better than average examples of the two evaluation techniques currently in vogue in the United States. George presented the "capacity to meet demand" school of thought while Campbell illustrated the "economic evaluation" school.

The "capacity to meet demand" procedure aims at developing a network that meets the projected travel demand for some future date, eliminating or reducing to a minimum segments with either deficient or excessive capacity, providing directness of movement, and keeping construction costs to a minimum. It involves several implicit assumptions, including

1. That the objective of a transportation study is to devise a network that will accommodate all projected travel demands; and
2. That all travel demands are worth the cost of providing facilities to meet them.

The process employed in Campbell's work implicitly questions whether either of these assumptions is justified, since he goes to great length to determine whether the extra costs of new facilities can be recovered in user savings. Furthermore, the term "travel demand" deserves scrutiny. Demand will be high or low depending on the facilities available and the price charged for their use. Are we really required to meet all travel demands, however trivial, at any cost? Possibly not; "in a world in which resources are limited we make no attempt to meet all demands. An auto manufacturer is not interested in meeting all demands for his cars, but only the demand at the price that will cover his production costs. An investigation aiming to ascertain all projected travel demands neatly avoids considering the level of demand that should be met" (1).

Our greatest problem in transportation systems evaluation stems from our lack of knowledge on "which demands are worth meeting" and therefore "which facilities are worth building." Our problems are different from the makers of autos or the suppliers of electric power, for example, because the price of cars and electricity to consumers is directly related to individual consumption. However, the price of the use of roads or transit facilities in our cities is unrelated to whether one is using a high-cost or a low-cost facility, or to whether that use is during peak or off-peak hours.

When all users pay the same, the result is equivalent to the situation of an electric company that decided to eliminate individual electric meters and bill customers not on the basis of individual consumption but by measuring total power usage and charging each consumer an equal part of the total bill. Not only is this inequitable; more importantly it will eliminate incentive for conserving electricity. Many new homes would be heated with electricity, since an individual's cost would not be increased by a decision to install electric heating. Demand for power would soar, and new investment would be needed for new generating facilities. There would be no real basis for determining the proportion of total resources that should be devoted to power generation.

Such considerations are leading the British into serious thinking of road pricing mechanisms which closely tailor transportation pricing to costs. Whether they can overcome the technological, political, and financial barriers to such a scheme remains to be seen. We probably can agree, however, that the time for such a move in the United States has not yet come. Nevertheless, we must give consideration to the economic elasticity of traffic demands if we are to make meaningful network evaluations.

That George's "capacity to meet demand" procedure, or variations of it, has been employed in many U. S. cities with apparent success can probably be attributed to several factors:

1. We are a wealthy nation and have committed large resources to providing for new transportation facilities;
2. Economically unrestrained travel demands are not so large as to be impossible to accommodate because of the low-density nature of our cities; and
3. Our cities are not so intensely developed but that new rights-of-way can usually be developed without too much trauma.

In other words, in most cities the accommodation of all travel demand is possible, though we must add, not necessarily economic.

But in our largest, densest cities it is becoming increasingly evident that all demand cannot be accommodated at a reasonable cost. Even "capacity restrained" assignments show projected volumes out of proportion to the facilities that can be provided considering political, financial, and sociological realities. In these situations one is forced to re-think goals and objectives. It is clear that in these cases demand is going to be restrained by price, only the price will be in the form of congestion and time losses instead of money. Unfortunately restraint by congestion makes no discrimination between essential and nonessential travel. All are equally restricted.

Campbell's evaluation is a more sophisticated, complex approach to the problem that has better theoretical underpinnings than George's. It attempts to develop the "least cost" system, considering all the user costs including time spent traveling, and then further uses marginal cost analysis to test the least-needed system increments. Its deficiencies seem to be that:

1. It puts heavy emphasis on factors quantifiable in economic terms such as time, operating costs, accident costs, and construction costs. It thus tends to de-emphasize other factors such as neighborhood disruption and displacement costs and environmental aesthetics. Consideration of these costs is relegated to the route location phase; it is suggested they should play no role in system planning. This is a difficult position to maintain, because the status of the highway network in a number of our larger cities is in jeopardy as a result of these factors.
2. It generally assumes no elasticity of demand with supply. Trip lengths are fixed as between alternative networks which must, to some extent, tend to bias the analysis toward larger systems. Time and operating cost savings from larger systems will appear bigger if no travel is induced by the larger system.
3. The assumptions on costs that must be made to carry out such alternative analysis with computational efficiency are sufficiently coarse as to invite questions. Sensitivity analysis on some of these costs to see their effect on conclusions might be justified.
4. All our techniques are coarse when compared with the precision required to evaluate the merits of land-use transportation plans involving carefully structured metro-towns around transit stations. The scale at which we conduct tests of regional plans is in contrast to the "walking-distance scale" critical to the concept of planned towns. In this regard our examinations can be compared to a person searching for a pin in the dark while wearing fur-lined mittens.
5. If an effective trip-pricing mechanism were in use that could input differential costs to users in accordance with their use of individual facilities and for different times of the day, one would assume that the less essential trips might be deferred to less congested time periods, use cheaper facilities, go a lesser distance, or indeed not be made.

If this is so, a different level of travel demand would result, which could produce a different "least-cost" network. While such thinking is only academic until the time that such pricing is feasible, it is useful to reflect that the optimum networks derived through Campbell's procedures might be less than optimum under different pricing and financial policies, and possibly result in even lower total costs.

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