HIGHWAY RESEARCH RECORD

Number 435 | Transportation Systems Planning and Analysis

6 reports
prepared for the
52nd Annual Meeting

Subject Areas

15 Transportation Economics
84 Urban Transportation Systems

HIGHWAY RESEARCH BOARD

DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

Washington, D.C. 1973

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ISBN 0-309-02166-9
Library of Congress Catalog Card No. 73-8481
Price: $2.40

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CONTENTS

FOREWORD

The papers contained in this RECORD present various concepts of evaluative techniques as related to systems planning and analysis.

Sharpe et al. present a sketch planning methodology and a set of models to facilitate the selection of the best growth patterns for future development as related to Melbourne, Australia. The focal point of their presentation is a general planning model developed to optimize land use allocation on the basis of some quantifiable benefits and costs.

Burkhardt and Eby analyze various methods of computing transportation needs. The use of need is discussed in the context of multisystems planning and other disciplines. An in-depth case study of the transportation needs of poverty groups in rural areas is discussed to illustrate methods of arriving at quantitative need estimates. Using travel behavior data, they calculated the number of trips required for persons in several areas of rural poverty to meet the average U.S. travel standard. The amount of trip-making required to meet such a standard, according to the authors, is so large that it was concluded that this means of calculating need was impractical. Another alternative, along the lines of demand and income expenditure analysis, is proposed by the authors for future research.

Miller and Rea present a corporative review of cost models for urban transit to identify a model or models, which can estimate costs for alternative transit systems with sufficient accuracy for use in transportation planning.

Neumann and Pecknold discuss an application of a time-staging approach to transport system planning when there are large uncertainties over demand and community acceptance of highway projects. A general strategic conditional approach is presented as one technique for handling the uncertainties associated with any long-range resource allocation problem.

Goldberg and Davis discuss an approach to urban modeling that seeks to extend the focus of model building activity from a product to a process orientation.

Stuart presents a method for analyzing transit service trade-offs.

URBAN SYSTEMS STUDY OF MELBOURNE

Ron Sharpe, John F. Brotchie, and A. Ray Toakley,
Commonwealth Scientific and Industrial Research Organization, Australia; and
John W. Dickey, Virginia Polytechnic Institute and State University

This paper deals with an urban systems study for the future development of Melbourne, a city that has 2.4 million people and is expected to have 5 million by 2000. The ultimate aim of the study is to develop a sketch planning methodology and set of models to facilitate the selection of the best growth patterns for future development; as many quantifiable and nonquantifiable factors as possible were taken into account. The focal point of this particular substudy is a general planning model developed to optimize land use allocation on the basis of some quantifiable benefits and costs. The general model allocates activities to zones and financial resources to activities over several time periods. The benefits and costs include those for travel among activities and for location of activities in certain areas. Some nonquantifiable benefits and costs are introduced subjectively using sensitivity analysis techniques. The model has been specialized to urban planning by inclusion of submodels for such aspects as trip distribution, land values, and building costs. It has been calibrated to Melbourne data in a cooperative effort between the planning authority and the research team, and preliminary information for urban planning decisions is now being produced.

•THE model discussed in this paper deals with urban planning and its attempts to bring about public benefits. The sum of the parts is not necessarily equal to the whole, however. Millions of personal decisions of maximum benefit to each individual do not necessarily make for total maximum benefit. Webber provides good examples of this situation relative to the automobile (2):

> The most obvious example within the transport sector attaches to the growing problems of air and noise pollution. Noxious emissions from individual vehicles are harmless; the problems arise only when the number of individuals gets counted in the millions....Externally, a few motor cars in the streets of the great cities of Europe do not really matter very much. When the numbers become large, the subtle qualities of the cities are rapidly eroded, to the loss of residents and visiting admirers as well.

Owen uses the very descriptive term, "the accidental city" (1), which is connotative of the way in which cities have developed:

> The basic difficulty of urban growth all over the world is that decisions about the use of urban land are being made by a host of private parties without the guidance of comprehensive plans or community goals.

What is happening is that each individual decision must be made in the context of the ones made previous to it. Although these individual decisions may be optimal in their own regard, they may build on each other organically so as to spiral out of acceptable bounds. Apparently this is what has happened in many urban areas—not necessarily

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that the city as a whole has become a comparatively disadvantageous place to live (for if it were, it certainly would be deserted by now) but that there are many disbenefits that could be eliminated if the atomistic approach were given up.

There are many alternative ways to guide urban growth if the concept of the overall public good versus the sum of individualistic goods is adopted. This study focuses on one way: the organization of land use activities to reduce both travel costs and establishment costs for water, sewer, schools, and other publicly supplied services. This is an initial formative attempt at using mathematical programming techniques to determine optimal land use activity patterns with respect to the foregoing costs. (Much has been done in the 2 years since the writing of this paper. The reader is directed to the references at the end of the paper.) If future endeavors using the approach suggested here are successful, it is hoped that some valuable inputs can be made to the development of local, state, and even national land use policies.

STUDY BACKGROUND

In 1970 an urban systems study for the future growth of the city of Melbourne, Australia, was proposed by the Division of Building Research, Commonwealth Scientific and Industrial Research Organization (CSIRO), and initiated under the sponsorship of the Melbourne Metropolitan Board of Works (MMBW), the authority responsible for the planning of future development of the city. Melbourne currently has a population of 2.4 million people (1971) and is expected to have 5.0 million by 2000. Current overall public and private establishment and operating costs in the metropolitan area amount to more than $1 billion per year. Roads and services are under increasing pressure as the area and its population expand. To make matters worse, the metropolitan government has deep financial problems. For instance, water and sewer service payments barely cover the interest on outstanding debts for these services (7). Future growth thus must be directed if the regional government is not to come under an even greater financial strain.

STUDY SCOPE

The basic aim of the overall study is to find the best growth patterns for Melbourne based on as many quantifiable and nonquantifiable benefits and costs as possible. This initial study is set on a macroplanning level. Particular goals of this study include the following:

1. Definition of the type and accuracy of data necessary in the study,
2. Determination of macro land use patterns that are optimum for the metropolitan area over the set of planning periods considered,
3. Determination of possible effects of changes in future locational behavioral patterns, and
4. Consideration of some nonquantifiable factors, such as those involved in the conservation of natural resources and reduction of pollution, and presentation of measures of these qualitative factors in a form that allows them to be weighed against the additional costs and travel times incurred.

URBAN SYSTEMS MODEL

A city may be viewed as being composed of four basic elements:

1. Activities—all of the active and passive occupations and pursuits of the citizens living in the city. These activities may be grouped into subsets for ease of manipulation, e.g., industry, commerce, residential activity, education, recreation, and conservation.
2. Interactions—the flows or movements within and among activities of people including services, goods, information, finance, and pollution.
3. Zones—areas that are potentially suitable for the settlement or establishment of activities.
4. Paths—the routes over which the various activities interact. They take the form of networks of roads, railways, pipes, wires, rivers, and air currents.

Associated with the preceding components are quantifiable and nonquantifiable benefits and costs. These include the benefits and costs of establishing the activities in the zones, the paths and flows, and the maintenance, servicing, and operation of these elements. Included is the cost of subdividing and preparing land, of providing streets and network services, hospitals, schools, and recreation and commercial centers, and of block preparation and buildings. A major item is the cost of transportation and travel.

The measure used initially in this study for the expected benefits of location of a particular activity in a particular zone is the price that participants in that activity are prepared to pay in the market for land. Although there are many obvious and serious drawbacks to the utilization of land value in this manner (of which imperfections in the market is a major one), there are also many advantages. In an open supply and demand situation, people purchasing land will buy when the value they place on a particular block is equal to or greater than the selling price. In a residential area, for example, such values would include the benefits of social desirability, social amenity, recreational amenity, terrain attractiveness, environmental value, future development potential, and accessibility to workplaces, shopping, and external recreational areas. Thus, land value is a good surrogate measure of general desirability of a particular location.

Benefits and disbenefits of interactions in addition to traffic flows have also been introduced. These include the reduction in cost when adjacent zones share the same service trunks and headworks and disbenefits of proximity between activities. One measure of the latter is in land value increment. In addition, there is a time element to the process, which for convenience may be approximated by a series of time periods.

From these observations, it is possible to formulate a model to allocate activities to zones according to some socioeconomic objective subject to certain economic, technical, political, and social constraints. The nature of such a model must be an iterative one because the interactions, benefits, and costs are complex functions of the allocation patterns. Hence, the model may be divided into submodels for allocation, followed by derivation, and suitably damped to force convergence to an optimal solution (Fig. 1).

ALLOCATION MODEL

The allocation model is a modified version of a quadratic programming model developed by Brotchie (8, 9) for optimizing the layout of a group of activities on the basis of maximizing the total sum of benefits less costs of interactions among, and establishment of, given activities. This formulation is an extension of the assignment problem developed by Koopmans and Beckman (10).

The N activities of type i in time period m are of magnitude A_{im}. The M areal zones each have a capacity Z_j and may be filled with a single activity or a mix of activities or only partially filled. The objective function includes the benefits and costs of establishing and operating an activity i in a zone j over several time periods (T).

Any portion, a_{ijm}, of activity i can be allocated to zone j in time period m. The planning problem thus is to select the set of a_{ijm}'s to maximize a measure of merit $U(a_{ijm})$ where

$$\text{Max } U(a_{ijm}) = \sum_{i}^{N} \sum_{j}^{M} \sum_{k}^{N} \sum_{\ell}^{M} \sum_{m}^{T} \sum_{n}^{Y} S_{ijk\ell mn} R_{j\ell mn} B_{ijk\ell mn}$$

$$+ \sum_{i}^{N} \sum_{j}^{M} \sum_{m}^{T} a_{ijm} A_{im} C_{ijm} \tag{1a}$$

subject to

$$\sum_{i}^{N} \sum_{m}^{T} a_{ijm} A_{im} \leq Z_j \qquad \text{(all j)} \tag{1b}$$

$$\sum_{j}^{M} a_{ijm} = 1 \qquad \text{(all i, m)} \qquad (1c)$$

$$a_{ijm} \geq 0 \qquad \text{(all i, j, m)} \qquad (1d)$$

in which

$S_{ijk\ell mn}$ = volume of interaction between the portion of activity i in zone j and the portion of activity k in zone ℓ for the n th mode of interaction during time period m,

$R_{j\ell mn}$ = length of travel path or travel time between zones j and ℓ for the n th mode of interaction during time period m,

$B_{ijk\ell mn}$ = benefit less cost of a unit of interaction $S_{ijk\ell mn}$ along a unit length of path $R_{j\ell mn}$, and

C_{ijm} = benefit less cost of establishing and operating a unit of activity i in zone j during time period m.

The first constraint (Eq. 1b) ensures that no zone is overfilled, the second constraint (Eq. 1c) ensures that each activity is fully allocated, and the third constraint (Eq. 1d) prevents negative allocations from being made.

The model is a nonlinear programming problem with NMT independent variables a_{ijm} and M + NT linear constraints. The merit function will normally be nonlinear because the arrays S, R, B, and C will be complex functions of the independent variables, to be determined by derivation submodels at each step of the iteration. The method of solution is presented in other papers (3, 11).

SUBMODELS

The submodels are used to predict the interactions, path lengths, and benefits and costs of interaction, establishment, and operation of activities. The overall system has been set up such that the submodels developed initially are relatively crude. It is anticipated that more detailed models will be employed after this sketch planning endeavor indicates the general types of beneficial solutions. Following are examples of the submodels utilized: trip generation, trip distribution, modal split, traffic assignment, trip cost, highway network construction and maintenance cost, service cost other than traffic, and land value increment.

In the current study of Melbourne, several of the preceding submodels have been developed to a level worthy of comment and are described as follows.

Trip Distribution Submodel

The submodel used for trip distribution is of the gravity type. The flow generated by an activity i in zone j to an activity k in zone ℓ for the n th flow mode over the m th time period may be assumed (12) to be given by

$$S_{ijk\ell} = P_{ij} Q_{k\ell} F_{ij} F_{k\ell} f(B_{ijk\ell}) \qquad (2)$$

where

F_{ij} = number of trips generated by activity i in zone j,

$F_{k\ell}$ = number of trips attracted by activity k in zone ℓ,

$P_{ij} = 1/\sum_{\ell} Q_{k\ell} F_{k\ell} f(B_{ijk\ell})$, (3)

$Q_{k\ell} = 1/\sum_{j} P_{ij} F_{ij} f(B_{ijk\ell})$, (4)

$f(B_{ijk\ell})$ = cost and time function influencing trip length = $e^{-\beta t_{ijk\ell}}$, and (5)

$t_{ijk\ell}$ = trip time between zones j and ℓ.

Service Cost Submodels

Services such as water, sewerage, drainage, telephone, electricity, and gas have similar characteristics. They usually consist of source(s) or sink(s) (headworks), a network of trunks or mains or both, and a distribution network.

The staging of headworks and trunks is of major importance in the growth of a city and is highly dependent on the pattern of development. Distribution costs may vary from zone to zone but may be assumed to be relatively independent of development in other zones.

In the proposed submodel, the potential trunk network is assumed for a full set of zones and headworks. The network may then be modified to suit different development patterns by the omission of links and headworks or by changes in their capacity during a time period. Thus, with respect to the first time period, for example, each link and headwork may have one of five state conditions: built during the first time period, built later, partially built during the time period and upgraded during later time periods, already existing, and not to be built at all. Other models are required to calculate the costs of establishing each set of headworks; the cost of building each link as a function of link capacity, terrain conditions, and staging; the flow in each link of a network; and the cost per unit activity of distribution networks as a function of local terrain.

Land Value Increment Submodels

Current land values are available from various sources, and records of land transactions provide hard data in this area. Predictions of land values in future time periods will vary with time and with development and expectations of development.

Two approaches are being followed in the present study. The first is to neglect future land value increments, as a first approximation, or to project them simply from present trends. The second is to build a predictive model based on amenity changes and calibrated on previous data. This second model can then allow for changes in land value with activity allocations in an iterative process. This second approach now is being formulated and the corresponding models calibrated.

GENERATION OF AN INITIAL FEASIBLE SOLUTION

An initial feasible solution needs to be generated at the start of the iteration process. This can be readily accomplished by using any random solution that is not feasible, i.e., one that does not obey the constraints (Eqs. 1b and 1c), and the first step of the iteration process to generate a feasible solution. Alternatively, an initial solution may be generated by the planning authority using conventional planning techniques. Such a solution may be technically evaluated and compared with the optimum solution generated from it.

SENSITIVITY ANALYSIS

A sensitivity analysis may be used to determine the sensitivity of the solution to an increment in a single parameter or group of parameters. The parameter may be a data item, a constraint limit, or an integer type of variable.

In the case of data, it permits the accuracy required of a critical data item or data set to be established by observing the sensitivity of the solution to the item(s). Thus the expense and effort of collecting data may be reduced if the model is insensitive to certain items.

Sensitivity analysis allows the planner to interact with the model. In this way, the planner can control all constraints, data, and certain design variables and allow the model to optimize the remaining design variables. In this way, sensitivity analyses may be used to find the consequences of planning norms and standards, to determine the effects of changes in predictions of population and its behavior, and to determine the effects of future changes in technology or economic structure or nonquantifiable entities. In the latter case, the less tangible factors associated with overall merit (or the weighting placed on them) may be varied and traded off against their economic and technical costs, allowing the directions of an overall optimum solution to be subjectively determined and a course to be set in this direction. A series of these interactive steps would allow the overall optimum to be located approximately.

Long-term use of the model would allow course corrections to be inserted as additional data become available with continuing urban growth. This model, or models of this type, can be used to help develop an effective information system for urban planning. Various developer proposals and strategic decisions may be tested and analyzed, allowing day-to-day as well as long-term decisions to be made taking many consequences into account.

APPLICATION

The study to date has been carried out at a macrolevel by considering aggregations of activities and zones at a coarse-grained level to simplify initial data collection and computer program development.

Three activities have been considered:

1. High-density residential redevelopment at an average increase of 20 people per gross acre;
2. Low-density, new residential development at an average density of 10 people per gross acre; and
3. New industrial and commercial development at an average work force density of 20 workers per gross acre.

Each of the preceding densities is assumed to include development of streets and other public purpose open space. The residential activities also include local shopping, commerce, education, and park land. The residential increase in population is assumed to be 1.2 million by 1985 and split in a ratio of 1 to 3 between high- and low-density development. The increase in work force is expected to be 0.4 million persons.

The city has been divided into 34 zones (Fig. 2), each composed of one or more local government areas. Each is assumed to be homogeneous in character throughout the zone, and all interactions with other zones are assumed to act through the zone centroids of the area. In general, each zone has areas of land vacant and available for one or more of the three activities. The outer zones have large areas of unzoned land available for development, more than that required for development to year 2000.

The interactions among activities considered are the flows of people for journey to work, residential and industrial trips, and the flow of goods among industrial activities. The volume of these interactions has been extrapolated from a 1964 survey carried out by the Melbourne Transportation Committee (13).

The modes of interaction considered are private vehicles and public transport (bus, tram, and train). The 1964 travel-time trees for these modes between the 34 zone centroids have been obtained from the MTC together with the 1985 predicted travel times. At present only a portion of the proposed freeway network is included, but studies shall be made later to ascertain the overall benefits of full upgrading of the freeway and rail networks in stages to the proposed 1985 condition. Associated with each mode of interaction are unit costs of travel, which are functions of travel speed, journey length, and traffic volume.

The costs of establishing services of gas, sewerage, water, local roads and streets, telephone, drainage, schools, and electricity have been assumed initially to be independent of level of development within each zone. These costs have been obtained from the various service authorities on the basis of an assumed 1985 development pattern (8) and reduced to unit per capita costs by dividing the total development cost of each service in each zone by the expected 1985 population increase in each zone. Later, these crude cost estimates will be replaced by using the submodels previously discussed. Land values have been based on records of land sales and averaged in each zone. The land value submodels will later allow for future changes with activity and time.

EXAMPLES OF SOLUTIONS AND SENSITIVITIES

A few examples are presented here to illustrate the results generated by the model. The distributions of activities to zones are shown in the accompanying figures as circles drawn to scale and shaded to distinguish among activities, and Tables 1, 2, and 3 give the per capita costs for each of the examples.

Solution 0 gives the existing work-trip travel times and costs using an uncalibrated gravity trip distribution submodel. After calibration of the submodel (currently being undertaken), it is expected that these costs and times will increase because the activities are not as homogeneous in the real-life situation as assumed in the study. After allowing for errors due to nonhomogeneity, however, it is interesting to note the relative orders of magnitude of the different interaction costs and travel times.

Solutions 1, 2, and 3 give the results of model allocations of the future growth to 1985 in three successive stages, including land values as a benefit (negative cost). The establishment cost breakdown shows the cost of each service on a per capita basis. The overall cost less benefit of establishment rises with time because the best sites are occupied early in the development period, leaving the least attractive sites to be developed last. The interaction costs and times do not appear to be significantly affected, although during the earlier part of the 15-year time period there is a slight decrease in travel costs and times because of a more efficient rearrangement of trip destinations. For these solutions, only 25 percent of the proposed 1985 freeway network was included. Greater economies are expected when larger portions of the network are included.

Figures 2, 3, and 4 show the growth over the three time periods as circles of activity. For easy visual comparison, the allocations are idealized as circles rather than dispersed.

Figure 5 shows the development pattern if the growth to the year 2000 is allocated simultaneously for a 30-year period. The average costs and travel times for this solution are the average over the 30-year period. The interaction costs and travel times are significantly higher than in the preceding solutions because of the greater dispersion of the low-density residential areas.

Solution 5 (Fig. 6) is a sensitivity analysis of the effect of constraining all future low-density development to 1985 to three satellites as shown. Even though the nonquantifiable benefits of decentralization have not been included, the increases in establishment and interaction costs over those in the other solutions for the same time period are not great. Hence, a satellite solution such as this (or some variation of this) is worthy of further investigation. The small additional costs and travel times may be weighed against the benefits of dispersion involved.

Other studies for sensitivity purposes that have been made, but that are not included here, are as follows:

1. Solution excluding land value as a benefit.
2. Solution with a different ratio of population increment split between high- and low-density residential activities.
3. Solution with establishment and/or interaction costs excluded.
4. Solution with population increment constrained to be equally split between the northwest and southeast sectors of the city.
5. Solution with a constraint that 25 percent of future industrial development to take place on edge of Westernport Bay (zone S2). This provides a means of testing the effect on the city if the proposed port development actually does take place.
6. Solutions for layouts optimized for individual service costs such as sewerage, water, and gas. These solutions may be presented to the individual service authorities to enable them to check the accuracy of the data they have provided.

CONCLUSIONS

The systems approach to urban planning provides a framework in which many factors affecting the future growth of our cities may be given due consideration.

An important part of this approach is to create or formulate a flexible structure whereby the model and the data may be continually refined as the study progresses and the general body of knowledge of urban modeling advances. This is facilitated by structuring the model into a hierarchy of modules or submodels that may be refined individually without producing premature obsolescence of the system model.

Figure 1. Urban system model.

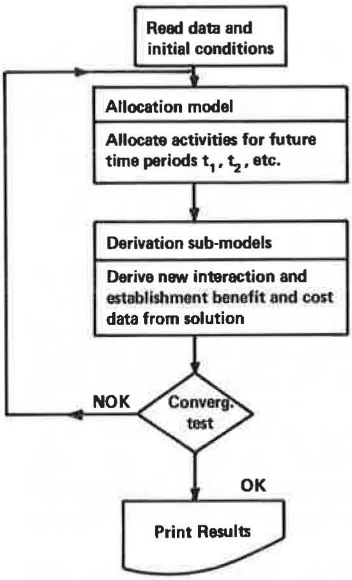


Figure 2. Model allocation for 1970-1975.

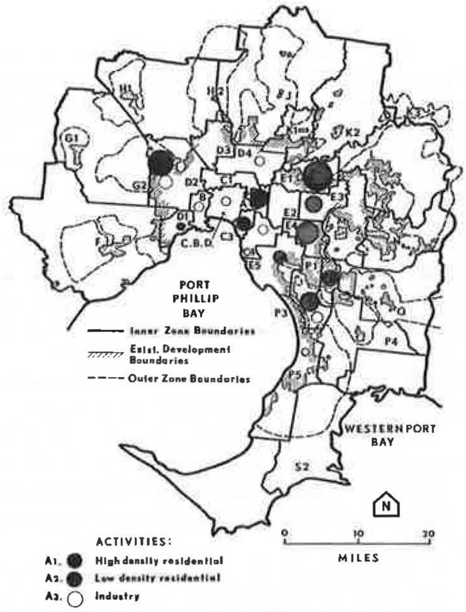


Table 1. Suboptimal solution for establishment cost breakdown.

Solution	Population Increase (percent)	Establishment Cost Breakdown (average cost per additional person in dollars)									
		Gas	Sewer-age	Water	Local Roads	Tele-phone	Drain-age	Schools	Elec-tricity	Land Value	Total
0 (1970 conditions)	–	–	–	–	–	–	–	–	–	–	–
1 (1970-1975)	17	67	285	160	680	280	133	370	490	-2,860	-400
2 (1975-1980)	33	73	298	180	710	295	122	368	600	-2,050	642
3 (1980-1985)	50	83	388	196	675	310	83	370	555	-1,700	960
4 (1970-2000)	100	84	641	236	690	310	114	368	528	-1,720	930
5 (satellite growth, 1970-1985)	50	91	410	420	760	320	175	370	500	-2,000	900

Table 2. Suboptimal solution for interaction cost breakdown.

Solution	Population Increase (percent)	Interaction Cost Breakdown (average cost per person per year in dollars)					
		Journey to Work	Industrial Trip	Residential Trip	Total	Public Transportation	Private Transportation
0 (1970 conditions)	–	167	77	58	302	78	224
1 (1970-1975)	17	167	73	55	295	76	219
2 (1975-1980)	33	167	73	55	295	72	223
3 (1980-1985)	50	172	75	56	303	69	234
4 (1970-2000)	100	206	85	59	350	72	278
5 (satellite growth, 1970-1985)	50	182	85	62	329	78	251

Table 3. Suboptimal solution for average travel times.

Solution	Population Increase (percent)	Average Travel Time (min)			
		Journey to Work	Industrial Trip	Residential Trip	Overall Average
0 (1970 conditions)	–	36.8	13.8	14.9	25.3
1 (1970-1975)	17	36.2	13.9	15.1	25.1
2 (1975-1980)	33	35.5	14.1	15.1	24.8
3 (1980-1985)	50	36.0	14.6	15.6	25.2
4 (1970-2000)	100	44.1	16.4	16.0	29.9
5 (satellite growth, 1970-1985)	50	38.8	16.0	15.8	27.2

Figure 3. Model allocation for 1975-1980.

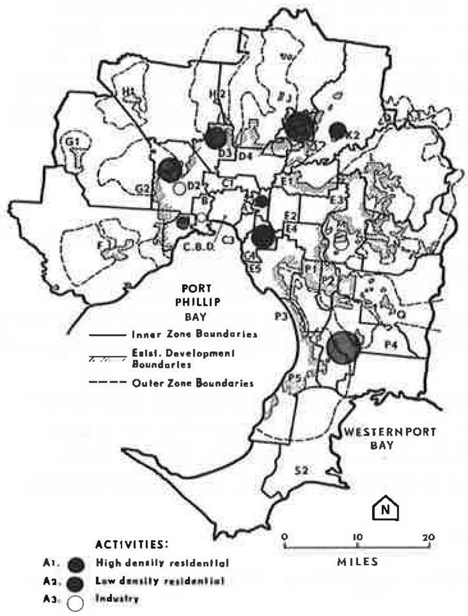


Figure 4. Model allocation for 1980-1985.

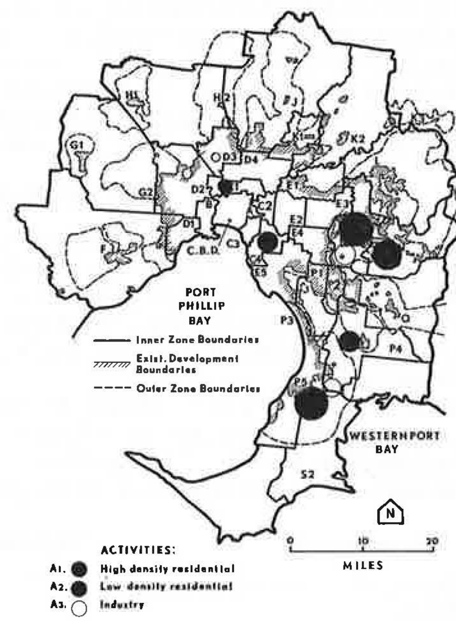


Figure 5. Model allocation for 1970-2000.

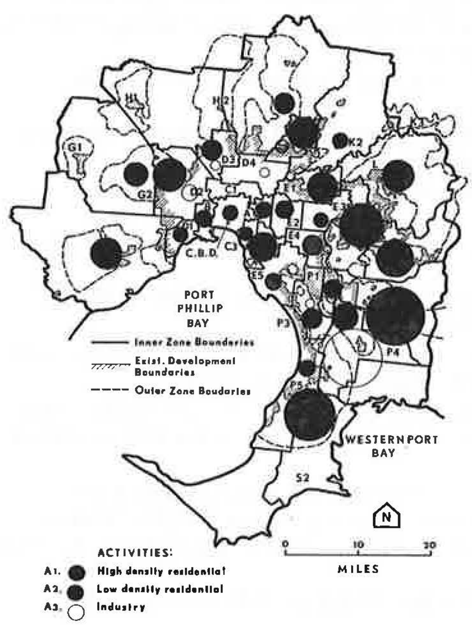
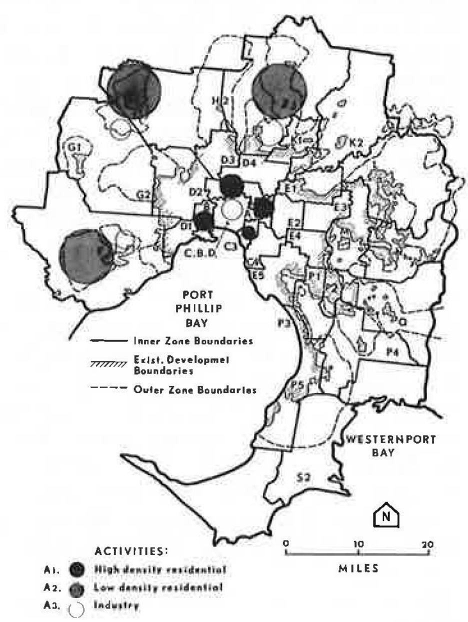


Figure 6. Sensitivity analysis, 1970-1985 (growth constrained to three satellites).



Likewise the study itself may be treated in a hierarchical fashion, where initial objectives are to determine what data are necessary and what macro layout patterns should be pursued in greater detail, e.g., satellite versus fringe development, thus enabling later stages of the study to concentrate on specific patterns of development.

The set of models developed is intended to form the basis of an information system for urban planning, allowing developer proposals to be analyzed, on a day-to-day basis, and long-term strategies for future growth to be tested and evaluated.

ACKNOWLEDGMENTS

The authors wish to thank the officers of the MMBW for the sponsorship of this study and for their constructive criticism in helping to synthesize the model and data.

The results and conclusions presented here are of an interim nature, being based at this time on incomplete data. They are presented primarily to show the methodology and are not to be taken as being the views held by the MMBW for the future development of Melbourne.

Thanks are also due to I. Abidin, P. Ahern, and D. Weinstock of CSIRO and to the officers of the many government authorities and private organizations who have supplied information and data for this study. The writers are particularly grateful to J. Paterson, economic consultant to the project, for his advice on benefits and costs.

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COMPARISON OF COST MODELS FOR URBAN TRANSIT

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Urban transportation planning often requires a comparative evaluation of alternate modes of transportation. One of the key criteria for comparing systems is the cost of operation. Some of the most common cost descriptors used to compare different modes are capital costs, total annual operating costs, total costs including depreciation and debt service, and cost expressed in terms of units of output such as route-miles, ton-miles, passenger-miles, or vehicle-miles. To evaluate proposed urban transport system alternatives, it is normally necessary to completely describe a hypothetical system and then determine each cost element item by item. Although this approach is useful and in many cases necessary in making final system selection, it is unnecessarily burdensome when attempting to screen a large number of alternatives. A more useful transportation planning tool would be a relatively simple model that would predict costs based on a limited set of input data. A review of the literature revealed several efforts at modeling urban transportation mode costs. It is the purpose of this paper to review these models and to evaluate their suitability for use in urban transportation planning. It should be noted that this study results from work done to establish the viability limits for urban transit modes. It does not purport to be an exhaustive study of operating cost models.

•SIX models will be considered in the following sections. These models differ in two important ways: the type of independent variables considered and the method used to determine the coefficients assigned to the dependent variables. Three types of independent variables are used. They are system output measures, e.g., vehicle-miles, vehicle-hours, and passenger-miles; system characteristics, e.g., number of vehicles, length of station platform in feet, and length of right-of-way in miles; and system environment factors, e.g., age of city and density of land use. Most models use combinations of the types of variables. Parameters for the dependent variables are either estimated by regression analysis or determined on a unit-cost basis. This latter term will be defined in the next section. Table 1 gives the six models by type.

As given in Table 1, the models have been developed to determine operating costs for bus systems. Operating costs are defined as the variable costs of operation excluding allowances for depreciation, interest payments, and taxes. Exclusion of fixed costs from bus cost analysis is not a serious omission. For modes without the high capital costs of separate right-of-way, operating costs constitute 90 percent or more of the total cost. Variable costs for exclusive right-of-way systems such as the proposed Pittsburgh Skybus account for less than half the total cost; therefore, operating cost comparisons are less conclusive than for bus or similar modes that are less capital-intensive.

BUS COST MODELS

Four-Variable Unit-Cost Models

Operating cost models for bus operations were evaluated by Alan M. Voorhees and Associates (1). These models were designed to reflect certain operating costs such as

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equipment maintenance and garage expense, transportation expenses, traffic and advertising expenses, insurance and safety costs, and administrative and other general expenses. They do not reflect moneys needed for depreciation, interest payments, operating taxes, special fare-collection equipment, or income taxes. Two models evaluated are identical in general form, the only difference being in the method of estimating parameters for the independent variables. Both cost models have the following general form: Cost = A x vehicle-hours + B x vehicle-miles + C x peak vehicles + D x revenue passengers, where A = cost related to an hour of vehicle operation, B = cost related to a mile of vehicle operation, C = cost related to a peak vehicle, and D = cost associated with a revenue passenger other than transportation. Parameters A through D were estimated in two ways, first by the unit-cost method and then by multiple regression analysis.

To determine the values of parameters A through D, we use the unit-cost system to first divide the various accounting cost items in a manner given in Table 2 and then calculate the cost of each item on the basis of the output most directly associated with it. For example, transportation expenses of supervision, operator wage, and other transportation expenses, as well as welfare expenses for the employees, are most closely related to vehicle-hours; whereas insurance and safety costs, for example, are mostly a function of either the number of passengers or the total amount of revenue received. Using March 1968 data from D.C. Transit System, Inc., the cost for fuel was $0.0312 per mile. (Records indicate that a total of 2,786,050 vehicle-miles were traveled, and $86,786 was spent for fuel.) Assuming that during 1969 D.C. Transit System, Inc., operated 30 million vehicle-miles, the cost for fuel would be $0.0312 x 30,000,000, or $936,000. A unit-cost model for that situation would be as follows: Cost = $0.0312 x vehicle-miles (2).

The unit-cost bus models (1) for the four transit operating companies in the Washington, D.C., area are as follows:

1. D.C. Transit System, Inc.—

   Annual cost ($) = (6.431 VH + 0.2187 VM + 1,802 PV + 0.01067 RP) Y

2. Washington-Virginia and Maryland Coach Company, Inc.—

   Annual cost ($) = (5.825 VH + 0.1364 VM + 850 PV + 0.01872 RP) Y

3. Alexandria, Barcroft and Washington Transit Company—

   Annual cost ($) = (4.244 VH + 0.1824 VM + 1,402 PV + 0.01442 RP) Y

4. WMA Transit Company—

   Annual cost ($) = (2.985 VH + 0.1264 VM + 3,114 PV + 0.03281 RP) Y

In these models VH = annual vehicle-hours, VM = annual vehicle-miles, PV = number of scheduled peak-hour vehicles, RP = annual revenue passengers, and Y = contingency at 2½ percent. It can be seen that the parameters vary widely. In some cases more than 100 percent variation is seen among the various transit operations. Based on this example and other experiences of this type of model, it must be recognized that generalization to other transit operations would not be warranted because of the wide variation in the sizes of the companies, age and condition of equipment, and labor conditions faced by each company.

The advantage of the four-variable model is the relatively small amount of information required to estimate parameters for the equation. The only information that might not be directly available from operating records would be the number of vehicle-hours operated. However, this could be obtained by analysis of schedules. After comparison of the results of the unit-cost model with the regression model, the Voorhees consultants determined that the unit-cost model more accurately predicted costs for its study.

The unit-cost model can be used to predict future costs for a particular system; however, any future estimates of cost should be stated in terms of the base-year dollars. If actual dollar costs are to be estimated, the various parameters should be inflated by a suitable index of the change in cost of that item.

Four-Variable Regression Model

The second type of parameter estimation for the WMATA study (2) was based on a multiple linear-regression analysis of the system characteristics and annual operating costs. Data for the period 1962-1970 were used to estimate parameters for the equation. Costs were stated in terms of 1970 dollars (Table 3); seven different variations of the basic equation were tried. However, as given in Table 3, at least four of the regression models did not do an acceptable job of forecasting even though they had a high coefficient of determination. This is an indication of the sensitivity of the models to changes in relation among operating characteristics. The consultant concludes as follows (2, p. 4):

> The models were developed using data for a period of operation when passengers were declining [and] efficiency was constant. The application of the equations to date where there is an increase in both passengers and system speed results in cost estimates which are questionable.

The advantage of the regression equation model is that the parameters are estimated based on several observations rather than on one and, therefore, should be a more reliable indication of the relation among the variables. However, as just explained, regression equation coefficients are based on one set of operating characteristics, which may change in the future. It is especially true when the model is being used to aid in planning new transit systems.

Daily Cost Four-Variable Model

Ferreri developed a similar cost model for use in a Metropolitan Dade County Transit Authority study. The cost model used in this study is in the following form: $C = A_1M + A_2H + A_3R + A_4V$, where A_1 through A_4 = parameters determined by the unit-cost method, C = average daily cost of route operation, M = average daily vehicle-miles of service on route, H = average daily vehicle-hours of service on route, R = average daily passenger revenue on route, and V = peak vehicles needed on route (3). As can be seen, the model differs from the Voorhees model in two ways:

1. The costs and other characteristics are determined on a daily basis instead of an annual basis, and
2. Total passenger revenue for a day is used instead of number of passengers.

For the purpose of estimating parameters, accounting cost items were again assigned to the various output measures or system characteristics. To determine the validity of this approach, Ferreri performed separate regression analysis comparing the transportation expenses and measure of output for 11 transit properties.

As a more comprehensive check on these assignments, cost data from a sample of 66 transit properties were analyzed by the authors using regression analysis. Figures 1, 2, and 3 show the scatter diagrams and the related R^2 values. The cost items shown in these figures correspond to accounts prescribed by the ICC Uniform System of Accounts for Class I Common and Contract Motor Carriers of Passengers.

As can be seen, assignment of operating costs in a manner similar to the system used by Voorhees (Table 2) is certainly justified. In addition to the four-variable formulas, a two-variable formula was also tested by Ferreri. This formula only included vehicle-hours and vehicle-miles as the independent variables. The premise behind this comparative investigation is that, for planning purposes, the simpler the formula the easier the application if a sufficient degree of accuracy can be maintained. He also made a route-by-route estimate of costs using the two- and four-variable versions of the formula for the Miami Transit Authority. When compared to actual

Table 1. General typology of cost models.

Model	Type of Independent Variable	Method for Parameter Determination	Mode Described	Type of Cost Estimated
WMATA four-variable (2)	Output and system characteristic	Regression	Bus	Total annual operating cost
WMATA four-variable	Output and system characteristic	Unit-cost	Bus	Total annual operating cost
Slowness function (4)	Output	Regression	Bus	Cost per mile
D.R. Miller (6)	Output and system characteristic, environment	Regression	Bus	Cost per mile
M.G. Ferreri (3)	Output and system characteristic	Regression	Bus	Average daily cost per route
DOT-IDA (9)	Output and system characteristic	Regression	Bus	Total cost

Table 2. Allocation of account items to operating cost model.

Item	Vehicle-Hours	Vehicle-Miles	Peak Hour Vehicle	Revenue Passengers
Equipment maintenance and garage expenses				
Supervision		X		
Maintain service equipment			X	
Maintain buildings and grounds			X	
Maintain revenue equipment		X		
Tires and tubes		X		
Others		X		
Transportation expenses				
Supervision	X			
Operators' wages	X			
Fuel and oil		X		
Station expenses			X	
Others	X			
Traffic and advertising		X		
Insurance and safety				X
Administration and general				
Officers' salaries			X	
Employees' wages			X	
Legal expenses			X	
Welfare expenses	X			
Others			X	

Table 3. Regression models of bus costs.

Model	R^2	Percentage of Original Estimated Costs	
		1975	1990
1 Y = 28.3462 VH + 0.5433 VM + 976.582 PV - 0.1841 RP - 52,235,544	0.997	68.8	44.2
2 Y = 33.2481 VH - 0.1971 RP - 47,658,800	Not given	71.0	39.0
3 Y = 1.0717 VM + 10,669 PV - 10,437,042	0.691	91.8	99.0
4 Y = 1.0104 VM + 2,729,693	0.649	94.5	104.6
5 Y = 25.1411 VH - 0.0532 VM + 2,385 PV + 821,010 (VH/RP) - 68,389,056	0.995	75.7	57.1
6 Y = 0.6028 VM + 274,656 (VM/RP) + 8,911,720	0.738	91.9	99.2
7 Y = 25.4827 VH + 793,072 (VM/RP) - 68,004,768	0.993	76.2	58.3

operating results, it was concluded that the four-variable model was substantially more accurate and warranted the gathering of additional data. The only information that would not be readily available when proposing a new transit system would be the number of vehicles needed for peak-hour operations on a route. However, by making several assumptions about schedules and spare bus requirements, it is possible to estimate peak vehicle needs. The consultant concluded that, for long-range estimates, the two-variable model might be adequate. However, for short-range planning and fiscal planning, the additional effort required to use the four-variable model would be warranted (3, p. 9).

Slowness Function

A slightly different approach to modeling operating costs was taken by Miller and Holden (4). They have formulated what they call a slowness function, based on the premise that vehicle-miles operated and number of hours operated are the two most important determinants of operating costs. They have combined these two variables into one that they call slowness stated in minutes per mile (4). Starting with Ferreri's model, which has the form $C = A_1M = A_2H + A_3R + A_4V$, they divide this expression through by M and get $C/M = A_1 + (A_2H/M) + (A_3R/M) - (A_4V/M)$, where H/M is slowness in terms of hours per mile. If $B_1 = 60A_2$, the second term becomes B_1S_3, where S_3 = minutes per mile or slowness.

The last term in V is also a function of slowness because $V = S_3L/H$, where L is the total round-trip mileage of the route under consideration, and H is a peak-hour headway in minutes. The term R represents the cost of injuries and damage because insurance is often based on revenue. For purposes of this paper, it is assumed, however, that large transit properties may operate in a self-insured manner; therefore, this variable is dropped. The form of the final cost model then is $C/M = B_1 + B_2S_3$.

To estimate the parameters B_1 and B_2, Holden and Miller used data mainly from the New York City Transit Authority (NYCTA) and the San Francisco Municipal Railway. Some of the data from the Southern California Rapid Transit District and Chicago Transit Authority were also used. Table 4 gives parameter values determined in subsequent applications of this slowness function as reported elsewhere (5).

The advantage of this model is its simplicity. With only one independent variable, and depending on only two measures of output, it is the simplest of all the models evaluated. Holden and Miller have also included a factor to reflect variations in labor costs. However, even with this, the model does not adequately consider differences in operating systems and, therefore, is only valid for the particular transit system whose data were used for calibration. As will be seen in a later section that compares these various models, the slowness function cannot be used to generalize operating costs for systems other than those with identical characteristics to the one used for estimation of parameters.

Urban Environment Cost Model

Figure 4 (8) shows that, for bus operations in 1970, operating costs per mile varied greatly, from $0.29 per mile to $1.97 per mile. Obviously, managerial efficiency alone does not account for this wide range in operating cost. An analysis of variance study indicates that per-mile operating costs are related to fleet size ($F = 54.3$, significant at 0.001 level), possibly suggesting diseconomies of scale. However, because large fleets usually operate in large congested cities, there can be little doubt that the cost is more directly related to environmental operating context than to fleet size, which explains the variation in operating costs.

Miller (6) has attempted to identify factors that explain this wide variation in cost. Variables that help explain variations in cost include population density of the urban area, the age of fleet, the age of city, scheduled speed, and labor costs in a particular area. Inclusion of these variables improved the explanatory power of the regression model. Labor rate, scheduled speed, and city age were all significant. Miller's conclusion was that the other variables, such as fleet age and population density, influenced operating costs; however, because of inaccurate or inappropriate measurement of the variables, they were not statistically significant in the regression model.

Figure 1. Relation between administrative expenses and peak number of buses.

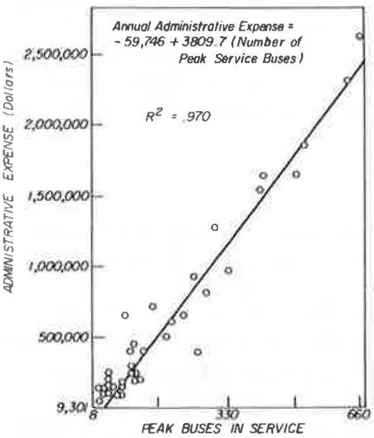

Figure 2. Relation between annual equipment and garage expenses and bus-miles.

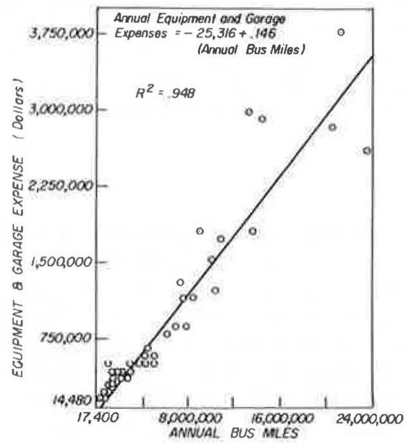

Figure 3. Relation between annual transportation expense and total bus-hours.

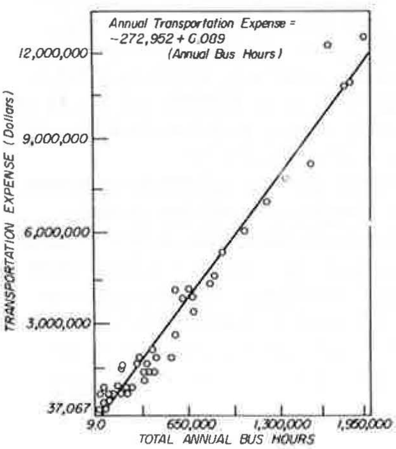

Figure 4. Frequency distribution of operating costs (8).

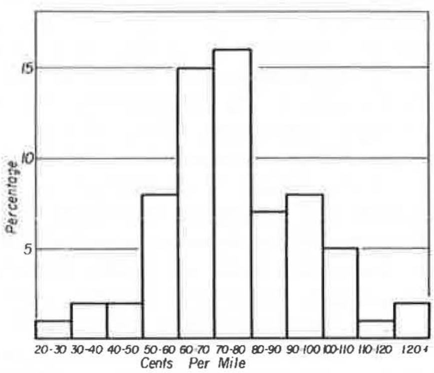

Table 4. Summary of reported data on slowness function (5).

Property	Date	Slowness (S_3)	Constant (B_1)
NYCTA 1969	Oct. 1969	19.38	5.28
Rapid busway	Nov. 1969	15.65	34.56
Bus 1967-1968	Nov. 1970	9.21	22.3
Bus 1970	Mar. 1971	18.15	30.83
San Francisco streetcars	Aug. 1971	11.9	85.10
San Francisco trolley bus	Aug. 1971	7.89	89.30
San Francisco diesel bus	Aug. 1971	11.61	56.50
Bus 1970	Aug. 1971	9.66	87.79

Another effort (9) to model bus costs is of interest for several reasons. First, it models total cost including depreciation and debt service. Second, it includes a variable that reflects prevailing wage rates. In addition, a dummy variable reflecting form of ownership (publicly owned or otherwise) is included because this influences capital costs. The model is of the following form: $\ell n C = a_1 + a_2 \ell n B + a_3 \ell n W + a_4 \ell n VEL + a_4 A + a_5 S + a_6 (PUB/a_7 s)$, where C = total cost, B = bus-miles, W = hourly wage rate of operating personnel, VEL = bus-miles per bus-hour attained by the firm, A = average age of fleet, S = average seats per bus, PUB = one for publicly owned firm and zero otherwise, and s = proportion of fleet purchased with capital grant.

These variables explained virtually all of the variation ($R^2 = 0.990$). Note that the VEL variable is the reciprocal of Holden's slowness variable. This variable was found to have a strong effect on costs, but a decrease in cost is slightly less than proportional to the increase in VEL. The dummy variable for ownership was significant. In fact, public agencies enjoyed total costs that were 10 percent lower than those of private firms (9). Fleet age, as in Miller's model, was only weakly significant. Possibly the same measurement problems he noted are the cause.

COMPARISON OF THE MODELS

Three distinct approaches to modeling costs have been presented (unit cost, four-variable regression, and slowness regression). To evaluate the relative merits of each, we assembled several sets of data and applied them to each model. Because it is not possible to check directly the predictive ability of the regression models, the criteria used to evaluate the model were (a) the degree to which the model explained variation in cost (R^2) and (b) the data requirements for estimating parameters and using the model.

Data from the D.C. Transit System, Inc., for the years 1962-1970 were used to compare the four-variable regression cost model with the slowness model. The resulting equations are as follows:

1. Four-variable model—$C = 28.095\ VH + 0.5488\ VM + 1.438\ DV - 183\ RP$ and $R^2 = 0.9966$, where VH = annual vehicle-hours in thousands, VM = annual vehicle-miles in thousands, PV = peak vehicles required, RP = annual revenue passengers in thousands, and C = annual operating cost.
2. Slowness function—$C/M = 0.9975 + 0.15\ S_3$ and $R^2 = 0.997$ (b for S_3 not significantly different from 0.0), where C/M = operating cost per mile, and S_3 = slowness expressed in minutes per mile.

Although the four-variable regression model explains variations in costs, when applied to future operating characteristics of D.C. Transit System, Inc., it underestimated costs by as much as 68.8 percent. It was thus rejected for the Washington study.

The slowness function cannot be calibrated from these data because the value of the coefficient assigned to S_3 is not significant. This is undoubtedly due to the nature of the data. Ten observations over time for the same company were used. If we assume that operating practices, technology, and operating environment remain constant, any variations in cost would be random or at least not explainable by a variable measuring speed of operation. These results are in contrast to Holden and Miller's analysis of the New York Transit operation. Using line-by-line data for the NYCTA (5), the following equation was determined: $C/M = 8.585 + 19.097\ S_3$ and $R^2 = 0.9888$. Apparently, because of the lack of change in transit systems over time, the slowness function can only be calibrated from data on individual routes of a single transit property at one point in time. The time series data were adjusted to a constant dollar; therefore, this should not be a source of variation.

On the basis of explanatory ability, the four-variable model is clearly superior for time-series data. For cross-sectional line-by-line data, the slowness function explains substantially the same amount of variation as the four-variable model. Neither model is especially suitable for explaining variations in costs when data from several properties are combined for regression analysis. Application of the four-variable model to the American Transit Association's sample of 69 firms yielded an R^2 of 0.52. The slowness function provided less explanatory capability.

The second criterion of data for evaluating the models is less important than the first. Size of data requirements is a factor only if a simpler model does an equally adequate job of prediction. In this case, the slowness function requires fewer pieces of input data but often does a poorer job of predicting. Using the Miami Transit Authority data presented by Ferreri, an R^2 of 0.45 was obtained with the slowness function, whereas using a two-variable cost function of the form C = a VM + b VH led to explanation of 99.5 percent of the variation in total cost. For the NYCTA data, the slowness function explained 99 percent of the variation. The four-variable cost function explained virtually 100 percent of the variation. For the Washington, D.C., data, the slowness function could not be used, whereas the four-variable function explained 99.66 percent of the variation. Annual mileage alone explains 65 percent of the variation.

The conclusion reached from this comparison is that the four-variable regression model is equal to, and usually superior to, the slowness function. Additional data requirements for the four-variable model are easily satisfied; therefore, there is no reason not to use the four-variable version.

To check the accuracy of the unit-cost model, data from the Pittsburgh Skybus and D.C. Transit System were used. The resulting equation for 1970 D.C. Transit System, Inc., data is C = 7.885 VH + 0.254 VM + 2,124 PV + 0.0121 RP. When the 1970 model was used to predict 1990 costs, the figure computed came within 5 percent of an estimate made in a detailed engineering cost study.

To further check the suitability of the unit-cost model for planning purposes, data from the Pittsburgh Skybus project were evaluated. Based on 1970 estimates, the following unit-cost model was determined (7): C = 0.496 VH + 0.148 VM + 0.008 RP + 10,321 PV. Applied in 1980 engineering estimates, this model predicted costs to within 3 percent of actual estimates of operating costs. The conclusion reached is that the unit-cost method of determining parameters appears to be an accurate method when used to predict future costs for the same system.

SUMMARY

The purpose of this comparative review of cost models for urban transit has been to identify a model, or models, that can estimate costs for alternative transit systems with sufficient accuracy for use in transportation planning. Five of the models estimate operating costs and are best suited for bus transit systems or other systems where operating costs constitute a substantial part of the total cost of operation. Capital costs, although difficult to model, are a relatively insignificant part of the total cost of operation for buses and are included in the sixth model. The simplest model in terms of data requirements is the slowness model; however, it is the least desirable for general application. The single independent variable only describes one of the cost determinants. It can only be used for cost estimation for additions to the property for which it was calibrated due to its stringent "ceteris paribus" requirements. The four-variable unit-cost model is much better suited to generalization even though it too does not encompass all factors influencing costs. The data requirements are not limiting. Recent experience of the authors using this model indicates that it is well suited for short-range planning purposes. As suggested by the Washington, D.C., study (1) described in this paper, the four-variable regression model is not as useful.

Efforts to formulate a general cost model, such as that by Miller, have been only partially successful. Further research is necessary to refine measurements of environmental variables such as urban density. Also, as Miller points out, better measure of fleet age and route structure might lead to a model better able to reflect cost variation from property to property.

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APPLICATION OF THE TIME-STAGED STRATEGIC APPROACH TO SYSTEM PLANNING

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This paper is concerned with an application of a time-staging approach to transport system planning when there are large uncertainties regarding demand and community acceptance of highway projects. A general strategic conditional approach is presented as one technique for handling the uncertainties associated with any long-range resource allocation problem. An example of the approach applied to a highway planning problem in Santa Barbara, California, is presented, and conclusions are drawn as to its general applicability to other transport planning problems, most notably when network constraints and regional budget constraints provide additional incentives to stage alternatives in a conditional way.

•THERE are three major factors that any planning process designed to be sensitive to community values and environmental concerns must recognize. First, change is endemic in the society in which we live. Community goals and planning objectives, transportation needs, and the impact of transportation facilities on the environment all change over time and require new responses in the planning of transportation systems.

In most states, these changes have been reflected in increasing and more vocal opposition to urban highways, growing pressure to develop mode options other than the private automobile by opening the highway trust funds (both national and state), and a renewed debate over the states' development goals and transportation requirements. The controversies generated by development plans for Mineral King Canyon near Los Angeles and the Boston transportation plan are illustrative of increasing public and private interest in the environment.

The second important factor that must be recognized is that public policy and investment decisions can strongly influence the patterns of change in a region. Though the long-run interaction between the transportation system and the myriad social and economic forces is not well understood, there is much evidence to suggest that the transportation system can encourage growth and development patterns that in turn may place new requirements for capacity on that system. Hence the need for transportation cannot be described in the abstract without consideration of the system proposed to meet that need.

Finally it must be recognized that changes in values, demand for service, and the influence of transportation improvements on these changes cannot be predicted with certainty. In addition to uncertainty in demand and factors influencing demand (e.g., population growth), the resources to be available in the future to meet these demands are also subject to change.

In California, the freeway and expressway system master plan will probably never be implemented in its entirety and certainly not on schedule. Had this been known or anticipated at the time of its conception, there may have been an intermediate system (in scale or location) that could have better served the state's transportation requirements in the 1970s and still provided adequate service in future years. For example, instead of building some major freeways in rural portions of the state, more moderate upgrading might have occurred over a larger segment of the highway system. There

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is currently some discussion within the California Division of Highways of the need to explore more thoroughly the opportunities for constructing interim improvements.

Thus transportation options must be developed with the knowledge that present decisions must be based on an imperfect understanding of the future of the region. Unforeseen changes may require new responses and adaptations that are impossible to fully evaluate at the present time.

Many of the problems currently facing state highway departments are directly related to the inability of the present system planning process to explicitly deal with uncertainty and effectively relate near-term programming decisions to longer range system plans. System planning must focus not only on desirable master plans but on implementation strategies as well.

DEVELOPING STAGING STRATEGIES

Historically, transportation studies have developed a number of candidate systems for some future target year and then chosen one of these plans to be implemented over the time horizon considered. The urban transportation studies done as a result of the 1962 Federal Highway Act focused almost exclusively on evaluating systems to be implemented by some target year. Usually, if alternative networks were even evaluated, there were only minor differences among them (4).

However, transportation plans are not implemented instantaneously in "one shot" but rather as a series of stages over time, and transportation planners ought to examine different strategies for implementing a plan. For example, the 20-year master plan might be divided into 5-year stages with alternative strategies consisting of different actions staged over this time period. Each stage of a particular strategy might include construction of a number of highway links or transit options as well as different studies. At the end of the first stage, the subsequent stages in a strategy could be revised or updated in light of new information or changes that have occurred.

A brief example will illustrate the concept of a time-staging strategy. The approach follows the general sequential decision model described in an earlier work by one of the authors (1). In Figure 1, A_1, B_1, and C_1 represent the potential first-period actions, and L_1 represents an uncertain variable (demand, community acceptance, etc.) that, at the end of the first stage, may affect the feasibility or desirability of particular actions. Associated with each value of L_1 is a probability $Pi(L_1)$. Second-stage decisions depend on both the first-period action and information gained on the L_1 during the first stage.

A staging strategy then represents a first-stage decision leading to a range of choices in later stages. Decisions in future stages are conditional on the impacts of previous decisions and the information gained in the interim. Although each first-stage decision leads to a range of choices available in the succeeding stages, as decisions are made, the number of choices and systems that can evolve during the specified period decreases because of budgetary and time constraints.

In most cases the agency has the option not only of immediate actions—particular transportation system changes—but also of deferring implementation of an action to acquire more information about the problem. For example, if there is a great deal of uncertainty about demand, it might be more efficient in the long run to delay construction of a new system for a period to collect sufficient information to reduce this uncertainty.

The time-staging approach recognizes that significant decisions on a system plan are in reality going to be postponed until environmental impact, corridor, and initial route studies are under way or complete. The mode, scale, specific alignment, and indeed existence of a particular facility may be determined in later phases of planning. Time-staged system plans recognize the possibility of a number of outcomes from these later studies.

By the time-staging actions on facility improvements, emphasis is placed on what choices are available over the planning time horizon and how present decisions affect the range of choices available in future stages. The different sequences can explicitly recognize uncertainty by evaluating the impacts of a number of outcomes from negotiations or impact studies. Thus, staging strategies provide a convenient framework for relating system and project planning by focusing on both short-term decisions and longer range plans.

With the staging approach, initially, no particular "end state" need be identified as a target system. By prematurely focusing on one future system, the master planning approach loses flexibility to revise plans in the future. In addition, by not considering implementation strategies, a master plan often represents an unrealistic goal that may distort near-term project decisions.

LEVELS OF STAGING STRATEGIES

In general, there will be a number of uncertainties present and a wide range of different sequences of actions possible over the planning horizon. Also, probabilities may be different at different stages, and a network simulation model may be required to evaluate alternatives at each stage. Thus, an agency could never expect to provide for all the possible contingencies in developing staging strategies.

Although the resources available for planning will restrict the number of sequences and uncertainties that can be considered, attention need not be limited to one sequence over time. Staging strategies cannot represent a statement of everything that may occur in the future but can represent what appears today to be the major choices facing the decision-making process. Research has been ongoing to develop practical techniques for treating transportation planning as a sequential decision process in the face of uncertainty (1).

To simplify the use of the staging approach, one can define different levels of strategies, each addressing different though related issues. Relating the staging approach to statewide transportation planning suggests the following three levels at which staging strategies for transportation facilities might be developed:

1. Project level—In this case, strategies would trace out alternative ways to improve transportation service in a specific location or alignment over time. The basic choice would be on the scale and timing of improvements. For example, the choices might be to build two lanes now and two later, four lanes now or four lanes later (6). Staging construction would allow expansion if future demand levels are high or delaying expansion if demand is low or improvements in other locations are more urgent.
2. Corridor level—A corridor will be defined as a subarea of the region in which project stagings cannot be considered separately because of network interdependencies. Corridor strategies might consider a number of projects that differ in location and mode as well as scale and timing.
3. Regional level—At this level, a staging strategy would trace out how resources might be shifted among all the investments proposed in the region. The essential trade-off at this level will be the allocation of funds to different corridors or projects based on the possible outcomes of studies and decisions made for staging strategies at these other levels. For example, given high demand in all corridors being studied in the region, large improvements could be funded in some areas with no improvement in others, or intermediate improvements might be funded in all corridors.

Thus a corridor strategy may include a number of project strategies, and, within a region, several independent corridor and project strategies may be developed. When particular projects or corridors are funded for study, any of a number of improvement sequences could develop because a staging strategy represents alternative decisions that may occur over time. At the regional level, all strategies will be related by the budget constraint on transportation improvements.

Figure 2 shows the relation between corridor and regional strategies. In each corridor, A and B, different strategies for improving transportation service could be studied separately. The alternatives implemented in one corridor will not affect the desirability of alternatives in the other, except in terms of restricting the resources available for improvements there. At the regional level, staging strategies trace out the combinations of improvements that can be funded over time in both corridors.

Figure 1. Staging strategy.

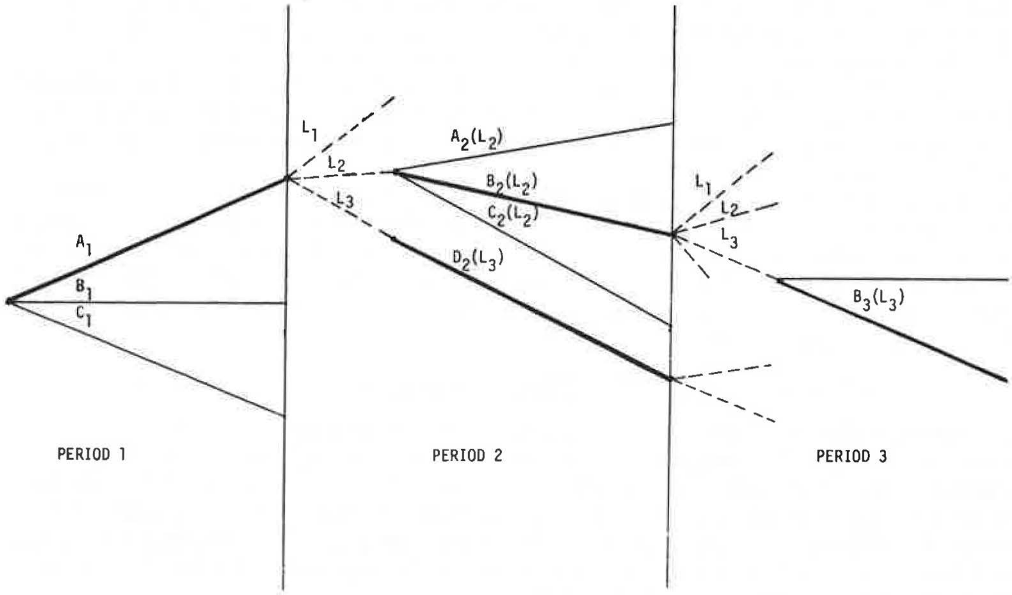
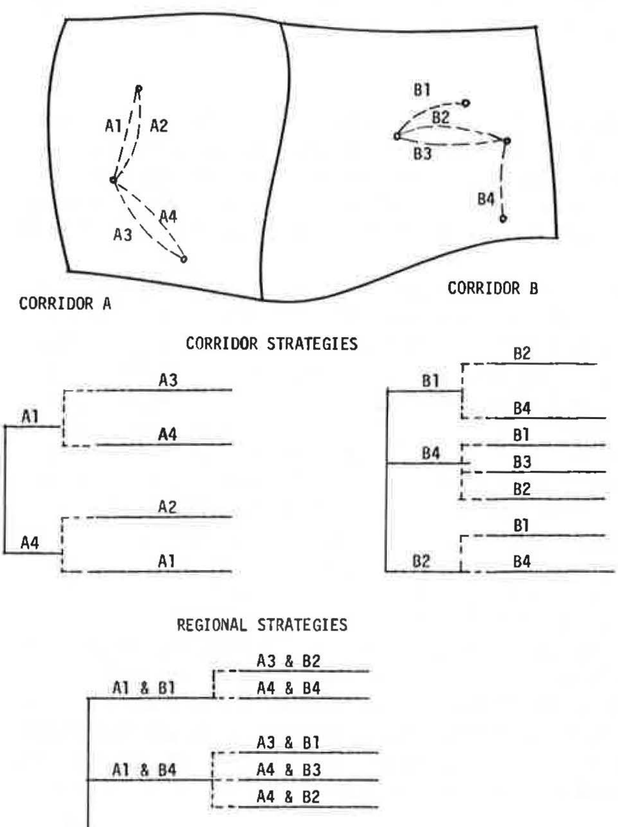


Figure 2. Regional staging strategy.



By considering a range of possible outcomes from the studies in each corridor, regional strategies recognize the budget dependencies between strategies in each corridor without initially restricting the range of solutions studied in either. If only small improvements are acceptable to the communities in B, then more major improvements could be funded in A. Likewise, if communities in both corridors wanted major improvements, then a compromise would have to be achieved with either intermediate improvements funded in both areas or all but minor improvements delayed in one of the corridors.

Because a regional level staging strategy must include decisions on both program selection (set of projects) and individual project development, it must explicitly address the interaction between system and project planning. That is, strategies must recognize that information acquired during more detailed route studies may affect both the schedule and the design of the improvements in that location and in turn affect the scale and timing of improvements in other locations.

APPLICATION OF THE STRATEGIC APPROACH IN CALIFORNIA

To illustrate the concepts involved in a time-staged strategic decision-making process, we developed a case study based on projects currently under way in the California Division of Highways Planning Program. The focal point for the example is the Crosstown Freeway project in the city of Santa Barbara located in District 5 in the state of California. Experience with the Crosstown project highlights many of the limitations of the present process for developing an investment program that the staging concepts can help to address more directly.

The case study makes use of decision analysis in evaluating the expected economic efficiency of different strategies for the Santa Barbara area. The examples demonstrate both the effect of considering the uncertainty of community acceptance of a proposal and the interdependence of projects caused by a budget constraint.

Project Background

The Crosstown Freeway project in Santa Barbara has been concerned with improving the transportation service into and through the city. In particular, the proposed Crosstown Freeway will upgrade the existing four-lane downtown section of US-101 to freeway standards. Currently the downtown section has four signalized intersections and is one of the few remaining segments of US-101 that is not at freeway or expressway standards.

Santa Barbara, a scenic coastal city, has traditionally placed a high value on aesthetics. The existing alignment of US-101 forms a border between the beach and recreational area and the main business district. Figure 3 shows a map of the area and the location of alternatives for the Crosstown Freeway and for two of the proposed bypass routes. During the past 17 years, the controversy surrounding the Crosstown project has been focused principally on the location and design of the freeway. Although many different interest groups within the city have felt some improvements are desirable, a number of nonfreeway alternatives have been proposed, and recently a group of citizens opposing any further improvements on the downtown highway system has emerged. Over the years the city council has steadfastly refused to accept a facility design felt to be detrimental to the city's visual and recreational assets. What began in 1954 as a 1-mile project with cost estimates around \$10 million is currently a 2.7-mile project with cost estimates ranging from \$38 million to \$55 million.

For the most part, the city has favored either a completely depressed freeway or a partially depressed, landscaped alternative. At first, the Division opposed all depressed alternatives because of their high cost and proposed a viaduct design and a number of at-grade alternatives. Subsequently, a groundwater study concluded that a depressed freeway on the existing alignment was unacceptable based on environmental grounds. As each impasse was reached, new alternatives were studied and compromises sought.

As a result of the difficulty with developing an acceptable improvement for the Santa Barbara corridor, the District 5 planning program has experienced a large amount

Figure 3. Santa Barbara corridor.

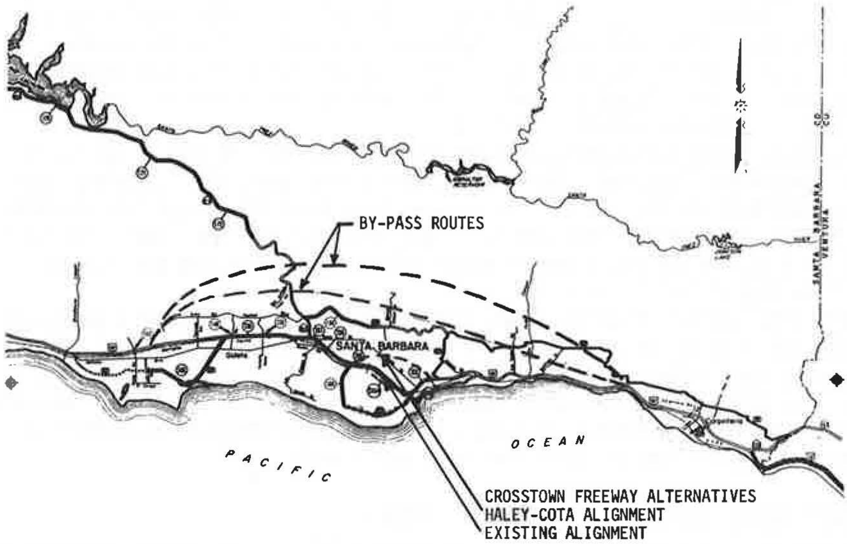
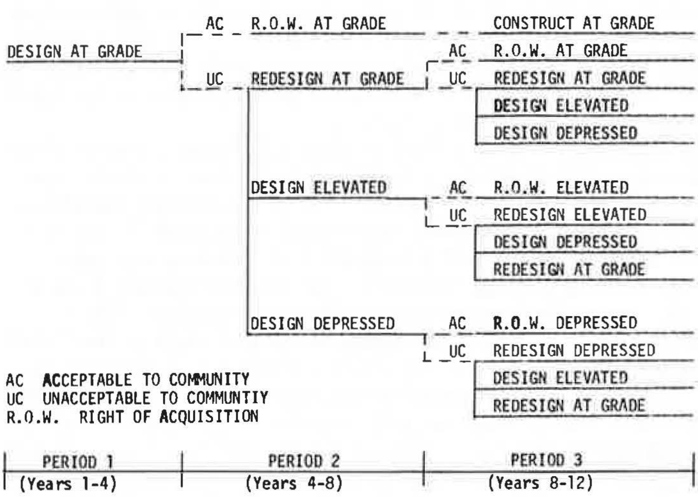


Figure 4. Staging strategy based on designing at-grade alternative in the first period.



of project schedule slippage and reordering of project priorities. Such fluctuations in planning program schedules have made it difficult for District 5 to effectively allocate its resources because the Crosstown project represents a large part of the southern half of District 5's total allocated budget. When the project was continually postponed, augmentation projects had to be found so that legislatively defined District 5 and Santa Barbara County budget minimums could both be met.

Over the years, it has become more and more difficult to find interim projects to substitute for the Crosstown Freeway. Some of these interim projects, advanced for early right-of-way acquisition and construction, have also run into delays and controversy during the necessary negotiations with the communities involved. More importantly, many of the substitute projects are of relatively low priority and are funded primarily to meet the legislated minimums.

One additional problem at the district level is that effective allocation of manpower resources has suffered as a result of delays to the Crosstown Freeway project. When a project is pushed ahead and scheduled for early right-of-way acquisition, personnel must be shifted to this new project and work hurriedly to meet a new deadline. Because District 5 is a relatively small district, it does not have a great deal of flexibility in reassigning personnel and moving projects ahead on short notice.

Project Level Alternatives in the Santa Barbara Corridor

The three freeway designs chosen to demonstrate the time-staged strategic approach at the project level were the depressed alternative on the Haley-Cota alignment, an elevated landscaped fill alternative on the existing alignment, and the at-grade alternative combined with relocating the Southern Pacific tracks along the existing US-101 alignment (Fig. 3).

The decision to be considered in developing staging strategies is which alternative should be advanced to final design in order to present a request for a freeway agreement to the city. Given the size of the District's staff, there are only enough manpower resources to do final design on one of the three alternatives, and therefore a decision must be made to do a final design on one of the alternatives.

The probability of obtaining an agreement on a final design will depend on the alternative chosen. Figure 4 shows one staging strategy based on the decision to do final design on the at-grade alternative. By the second period, if the community accepted the design and signed a freeway agreement, right-of-way acquisition could begin with construction taking place in the third period. If the proposed alternative was unacceptable to the community in the second period, however, the Division would have to redesign the at-grade alternative or do final design on another alternative. Then, depending again on whether or not the community accepted the new design in the third period, right-of-way acquisition could begin or a new design would again be needed.

Thus, assuming that these three freeway alternatives are available, the Division would continue to choose to redesign rather than drop all studies if no freeway agreement was obtained. Figure 4 shows the choices available over a span of three planning periods for one possible alternative. A similar staging strategy can be developed involving a first-period decision to design the depressed or elevated alternatives.

Once a first-period decision is made and the design proceeds, future decisions become conditional on both the previous decision to design a particular alternative and whether or not the design presented to the community was acceptable. A staging strategy then is represented by a first-period decision and a series of conditional future decisions that represent the choices left open over the current planning horizon. The desirability of a particular first-period decision would depend, to some extent, on the choices left open and the magnitude of the uncertainties present.

To simplify the example our attention is limited to the effect of uncertainty on the relative economic efficiency of the three designs, and a straightforward expected value decision analysis is performed. The method assumes that subjective probability estimates are appropriate for explicitly considering uncertainty. [Raiffa (7) discusses in detail decision analysis and the assumptions it makes.]

The cost figures for right-of-way and construction for this example were taken from the final environmental impact statement for this project. The economic efficiency benefits were calculated from the state's planning, programming, budgeting system (PPBS) indexes reported for the project in the 1972 planning program. The benefits for all three designs were assumed identical because each project is assumed to provide the same improvement in service.

The net present value of each alternative strategy is the evaluation technique used, which measures the net economic efficiency benefits of an alternative, given that implementation begins at some specified time. In describing the staging strategies based on doing final design on one of the alternatives during the first 4 years, however, explicit recognition was given to the fact that Santa Barbara may reject any or all of the proposals, and therefore the implementation time of each alternative was uncertain. To account for uncertainty, then, the economic value of an alternative must be weighted by the probability of obtaining community acceptance for that design for any particular period. By using expected values, we assume that the Division is not "risk adverse" (7).

Given the staging strategy shown in Figure 4, the Division can estimate the probability that the design of the at-grade freeway would be acceptable or unacceptable to the community at the beginning of the second 4-year period. Likewise, if the at-grade was unacceptable, one could estimate the probability that designs on any of the three alternatives could be acceptable at the start of the third 4-year period. Once the probability estimates are made, an expected net present value can be calculated for a staging strategy.

To calculate the expected value of a staging strategy, one must use the standard "average-out and folding-back" procedures. This involves working backward through the decision tree, calculating the expected value at each decision point (assuming you have reached this point in the tree), and discounting back until an expected net present value is obtained for each possible first-period decision. This backward search procedure is necessary because the actions in the last period cannot be evaluated until the history of actions and uncertain events up to that period is known.

Thus, one assumes a history of actions and events leading up to the last period and then calculates the expected value over all possible outcomes for each action at that time. The best decision for this point in time is then chosen as that action yielding the highest expected value. For example, we could assume that the at-grade freeway was designed and unacceptable to the communities in the first two periods. In the last period then final design could be done on any of the three alternatives, and an expected value for each could then be calculated.

Using the benefits and costs described previously, and the staging strategies developed as a result of doing final design on one of the three alternatives in the first period, we calculated the expected value of each strategy for a range of probability estimates. One example is shown in Figure 5. Here the probability of the community accepting the depressed alternative was assumed to be 100 percent and for the elevated and at-grade alternatives, 20 percent and 30 percent respectively.

The values shown at the end of the third period were obtained by assuming that, if the community remained opposed to the alternative presented, after the third period no further studies would take place. The $2.86 million net benefit shown for the decision to redesign the at-grade in the third period, then, represents the 30 percent probability of the community accepting the design times the net present value at the time of right-of-way acquisition ($14.3 million) plus the 70 percent probability of no acceptance with a return of zero (because studies are assumed to be dropped).

For the probabilities assumed in the figure, the strategy with the highest expected economic return is to design the at-grade alternative, the second branch of the tree (Fig. 5). If the community rejects the proposal in the second period, the strategy involves redesigning the at-grade facility and, if rejected again, designing the depressed in the third period. In reality, of course, the range of decisions in later stages, as well as the probability estimates, may also change.

The strategies shown were tested with a variety of different probability estimates each time but always assuming less than a 50 percent probability of acceptance for the at-grade and the elevated alternatives and more than a 50 percent probability of acceptance for the depressed alternative. In all cases, the decision to design the at-grade alternative in the first period had the highest expected net present value, whereas the second- and third-period decisions changed as the probabilities shifted.

Naturally, the expected net economic efficiency benefit is not the only criterion to be considered, just as the present PPBS indexes are not the sole consideration in placing projects in the planning program now. Accounting for uncertainty with respect to a quantitative criterion can be accomplished in the formal manner shown for economic efficiency. However, it is only illustrative of how considering uncertainty may affect decisions. In this case, the preservation of the visual connection between beach and downtown provided by the depressed alternative had to be weighed against its greater impact on the relocation of homes and business establishments.

Relating Santa Barbara Corridor Decisions to the Rest of District

Two types of relations may exist among different improvements considered in a planning program. First, within a given area there may be network effects (i.e., changes in traffic patterns of volume) that create dependencies among the scale and timing of proposed improvements. In the case of the Santa Barbara corridor, a number of improvements on US-101 outside the Crosstown section are contingent on a freeway being built. Unless the Crosstown Freeway is constructed, these improvements will also not be constructed.

The second and more general type of relation among improvements is that resulting from the budget constraint. With scarce resources, a decision on a particular improvement must be made in light of the alternative uses available for those resources. Thus, a decision to construct a freeway in Santa Barbara restricts a large amount of funds and manpower from being used elsewhere. We will not illustrate how the desirability of improvements in the Santa Barbara corridor may be affected by improvements being considered elsewhere in the district.

In California, the relation among projects due to the budget constraint has two dimensions because of the existence of budget minimums as well as maximums. In past years in District 5 when the Crosstown Freeway was delayed, substitution projects were needed to meet the District 5 and county minimums. The effect of the minimums was to constrain the geographic area in which substitution projects could be developed.

Before adverse environmental impact of a depressed alternative on the existing alignment was uncovered by a groundwater study, the Division had ruled it out as too costly. Before making such an assessment, however, one must consider both the uncertainty associated with the community accepting a particular design and the alternative uses for the funds if the Santa Barbara project is delayed.

The previous example will be modified by assuming that, now if the Crosstown Freeway is delayed, some funds would have to be spent on one or more substitution projects just to meet the district minimum. Furthermore, as before, the only improvement alternatives in the Santa Barbara corridor are the three designs considered earlier.

Given these conditions, two substitution programs were developed from projects identified in the 1972 Multi-year Financial Plan as candidate substitution projects if the Crosstown is delayed. The net present value of these substitution programs was negative, confirming the Division's judgment that many of the substitution projects were low-priority improvements whose schedules had been pushed forward prematurely just to meet the District 5 and county minimums.

Figure 6 shows how the decision to design a freeway alternative in the Santa Barbara corridor is related to the overall District 5 planning program. The decision to design a particular freeway alternative can again result in two outcomes. If the community accepts the design, right-of-way acquisition can begin in the second period, followed by construction in the third. If the design is unacceptable, a substitution program must be funded in the second period and a decision made to redesign the alternative rejected or design one of the other two freeway options.

Figure 5. Expected value of designing freeway alternatives.

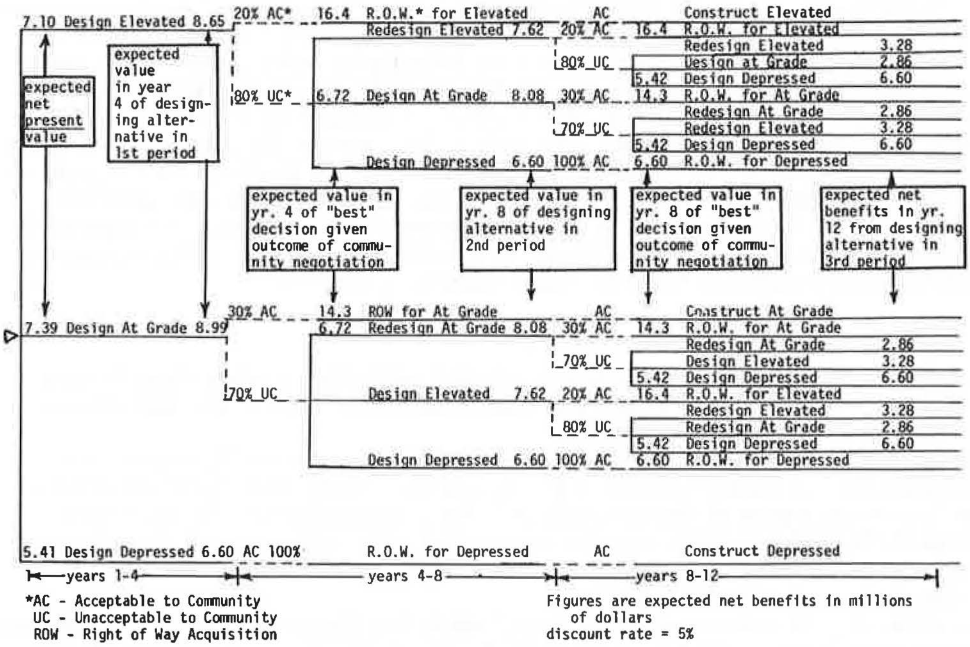
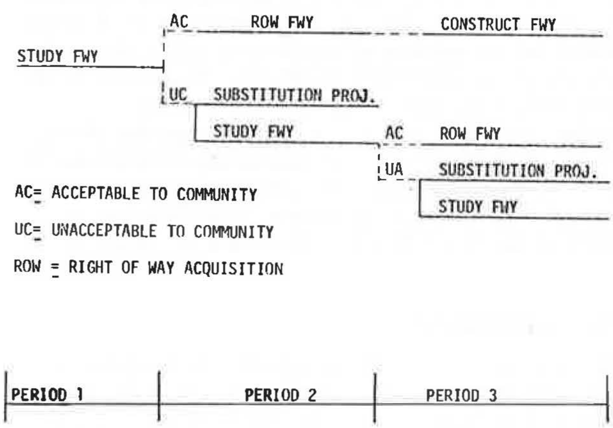


Figure 6. Staging strategy relating Santa Barbara corridor decision to planning program.



By evaluating the strategies considered in the previous project level example (but with the requirement now that a substitution program be funded if a design is unacceptable in a given period), the strategy with the highest expected net present value has changed from designing the at-grade alternative initially to designing the more costly depressed freeway. In fact, the strategy of designing the depressed freeway in the first period continued to have the highest expected net present value even when the probability of acceptance on the other alternatives increased to 50 percent. The implication is that the higher probability that the community will not accept the at-grade or elevated design, coupled with the need to fund premature and low benefit-producing substitution projects if the freeway is delayed, suggests that designing the depressed alternative in the first period may be a better decision with respect to increasing the expected economic efficiency from the entire planning program.

CONCLUSIONS

A broad application of the time-staging approach will allow system plans to both reflect and leave open a range of the choices available and at the same time restore more continuity to investment schedules.

When significant uncertainty exists, whether it involves community acceptance, demand forecasts, or another factor, a transportation agency should systematically examine the consequences of the uncertainty. One cannot eliminate the depressed alternative in the Santa Barbara case because of the $10 million cost differential without examining its probability of acceptance (or earlier acceptance) relative to other alternatives under consideration.

Even where significant uncertainties do not exist, the timing and design of projects in an investment program must be interrelated because of budget constraint. Transportation projects cannot be designed independently, but rather the design and timing of an improvement must reflect the alternative uses of those funds.

The role of system planning in the context of staged alternatives is to carefully anticipate the choice issues that must be resolved as planning continues and to devise tentative sequences of improvements based on potential outcomes from these choices. At the same time, it must be recognized that no amount of caution or effort can anticipate all the choice issues or recognize all the feasible alternatives. New options will be added at some later point and others will be dropped from consideration.

The time-staging approach is decisive, by requiring action on first-period plans, and realistic, by recognizing that it is neither desirable nor necessary to make tentative decisions over a long time horizon. While leaving future decisions open until more information is obtained, staging strategies take into account possible future options and events and are able to evaluate the most flexible direction for present decisions.

ACKNOWLEDGMENTS

The research reported in this paper was sponsored by the California Division of Highways, Department of Public Works, Transportation Agency, and the U.S. Department of Transportation, Federal Highway Administration. The authors wish to acknowledge the many individuals involved in contributing to this paper, both on the Transportation and Community Values Project at the Urban Systems Laboratory of M.I.T. and in the California Division of Highways and especially Mark Krejci of M.I.T., who assisted in the calculations. The opinions, findings, and conclusions expressed in this paper are those of the authors and not necessarily those of the state of California or the Federal Highway Administration.

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NEED AS A CRITERION FOR TRANSPORTATION PLANNING

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Transportation improvements are sometimes based on estimates of unfulfilled needs of particular groups. However, the concept of need (as distinct from that of travel demand) has not as yet been defined well. This paper analyzes various methods of computing how much transportation people need. The use of need is discussed in the context of health systems planning and other disciplines. An in-depth case study of the transportation needs of poverty groups in rural areas is discussed to illustrate methods of arriving at quantitative need estimates. Ways of defining necessary trips (by trip purpose) are discussed. The number of households needing transportation is calculated according to the transportation services available to the household and the transportation services that the household can afford. A scale of five levels of need is derived from transport service availability and affordability. Using travel behavior data collected through home interviews, the number of trips required for persons in several areas of rural poverty to meet the average U. S. travel standard is calculated. The amount of trip-making required to meet such a standard is so large that it was concluded that this means of calculating need was impractical. Another alternative, along the lines of demand and income-expenditure analyses, is proposed for future research.

•TRANSPORTATION is generally considered to be a service that is consumed not for its own merits but rather to achieve some secondary goal. Transportation is not an end in itself—it is a means to an end.

Ways of determining how much transportation service should be provided are relatively standardized. However, recent attention to the problems of poverty groups has shown that some persons, not by their own choice, use a great deal less transportation than others. This group (which also includes the elderly, the handicapped, the very young, suburban housewives, and others) is now known as the transportation disadvantaged. The members of this group are often thought of as using much less transportation service than they need. Therefore, according to this argument, they should be provided with more transportation. However, existing transportation planning models are not useful for specifying the additional transportation to be provided.

How much transportation does any person need? If someone needs more transportation than he now uses, should he be provided with all that he needs or with one-half of what he needs? How would increases in travel and mobility affect the lives of the transportation disadvantaged? It is important to distinguish between mobility and travel. Mobility represents the supply function of transportation services facing an individual (or group). If two people have access to the same transportation services at the same price, then they have equal mobility. Travel, on the other hand, refers to the actual behavior of an individual (or group) when he uses transportation services. An individual's travel is generally considered to be a function of several factors, including his mobility, income, personal tastes, employment status, age, sex, the supply functions for other goods, and his demand for other goods.

Sponsored by Committee on Social, Economic and Environmental Factors of Transportation.

PREVIOUS ESTIMATES OF TRANSPORTATION NEEDS

Although many analysts have argued that various groups of people should be provided with more transportation than they now use, very little has been written on precisely how many trips are needed by which persons. This is not surprising, given the complexity of the concept of need. The estimation of travel demand, based partially on the characteristics of the traveler and the travel facilities, still has some shortcomings despite the large amount of previous research (1). How then are we to estimate travel behavior if we are to say that the basic travel demand features (namely, personal and system characteristics) are inappropriate and ought to be changed for certain classes of riders?

One of the few significant contributions to the literature is Wickstrom's recent article (2) that evaluates transportation systems from the user's viewpoint in terms of available opportunities. Using data from the Washington, D. C., metropolitan area, he found that (averaging subareas within the SMSA) work trips that were made from subareas accessible to 75 percent of all SMSA work places within 45 minutes by automobile accounted for 90 percent of all work trips. He concluded that "areas which can reach 75 percent of regional employment in less than 45 minutes are better than the regional average and have superior access to employment (and vice versa)." (One should note that Wickstrom's definition of accessibility is stated only in terms of time and does not include cost or other considerations.)

Wickstrom found that "the highway system does and will continue to provide a higher level of access to regional opportunities to its users than to users of the transit system, either bus or future rapid rail." Because not all persons can use the highway-automobile system, he developed a balanced transportation measure for a region based on the sum of the products of the proportion of the population in each subarea times the ratio of actual to desired opportunities reached within a certain time.

The problem with this construct is that it is based on current actual behavior of persons who travel and does not consider why persons do not travel. Thus, an area with no public transportation is able to receive a perfect score on Wickstrom's index if the time constraint can be met by the highway-automobile system. The actual availability of transportation must enter into the calculations if transportation needs are to be accurately identified.

Other studies have discussed the travel needs of specific groups, potential demand, latent demand, and unmet needs (3), but none of these studies produced concrete measures of the number of trips required by specific groups of people. All in all, the previous attempts to define the need for transportation are incomplete, ambiguous, and arbitrary. Although there are many possible definitions of need, they usually depend on (a) the collective opinion of a body of experts as to the amount of travel people ought to undertake to meet some standard of living, (b) the actual amount of travel undertaken by some group whose travel behavior is taken as a norm, or (c) the target group's own perception of what it would like to have.

Well-intentioned as they are, these methods of establishing transportation needs are arbitrary in the context of actual impacts on the lives of the disadvantaged. The first criterion can be seen as a variety of professionalism, which too often ignores inputs from those actually being served. The second criterion seems to be the expression of an equalitarian principle embodying social and economic leveling. The presumption here is that everyone wants to (and should) travel as much as everyone else. These ways of defining need are flawed because either they ignore the autonomous behavior of the target groups or they make unwarranted assumptions about that behavior. The third criterion depends on the ability of the disadvantaged to imagine how they would use a service that they may never have had before. It has been found that the observed behavior of a group given a new transportation service may be quite different from behavior predicted in advance by the group itself. Therefore, each of these methods has serious flaws.

Efforts have been made in health and economics to make the concept of need workable in these disciplines. After considering what has been achieved in these fields, we will discuss a specific attempt to estimate transportation needs.

THE CONCEPT OF NEED IN OTHER DISCIPLINES

Although the use of a concept of need is widespread, very little has been done in the way of defining the concept. Two articles that work toward a definition are written in the context of medical care services, but their discussions are applicable to the provision of all social services. In the first of these (4) the population's health needs are defined as follows: "That quality of medical services which expert medical opinion believes ought to be consumed over a relevant time period in order for its members to remain or become as 'healthy' as is permitted by existing medical knowledge."

Other related concepts are defined in the article: The population's wants for health service are the quantity of services the population feels it ought to use. The population's demand for health services is a function relating the quantity of services that the population desires to consume, prices, financial resources, size, and psychological wants. A normative shortage is the amount at which needs exceed market equilibrium consumption. A market shortage is the amount by which market equilibrium consumption exceeds actual consumption. These definitions are given in Table 1 (4).

The concept of need described in the table is arbitrary because it ignores consumer behavior and it is vague about impacts of quality of life. The only connection between need and quality of life implied by this criterion is that the level of services represented by the need criterion is that which maintains a generally acceptable level of good health. The analog of good health in the field of transportation is not obvious because the consequences of varying amounts of travel are not obvious. Using travel as an analog to health status would be like using doctor visits or days in the hospital as measures of good health.

Boulding (5) describes differences between the concepts of need and demand, which we have already encountered: Need is an ideal determined by experts, whereas demand is what the consumer wants and buys. He notes that the expert-opinion criterion of need involves homeostasis—the maintenance of an organism (individual or society) in some generally acceptable state of being. He also points out that this definition leaves us with the problem of determining exactly which state of the organism is to be maintained. This is simply a restatement, in more abstract terms, of the arbitrariness to which we have already objected. Concerning the difference between demand and expert-opinion need, Boulding (5) says,

> All fields of life seem to feel the necessity of working out an uneasy compromise between the concepts of demand as defined by the consumer and need as defined by the professional. . . .Undiluted consumer sovereignty, whether in economics or politics, where it takes the form of the absolute sovereignty of the voter and the sovereignty of the nation, is ultimately intolerable and leads to corruption and disaster. On the other hand, total professionalization, in the case of the doctor, the economist, the sociologist, or the political scientist, is likewise intolerable; and the revolt against paternalism, no matter how benign, is an essential aspect of the human identity. Somewhere between the proposition that the customer is always right and the proposition that the public be damned must be an uneasy Aristotelian mean . . . .

Boulding goes on from the concept of expert-opinion need and considers the need of the poor due to financial constraints:

> One's need in this sense is not merely what some wise professional person thinks one ought to have, but what one cannot afford because he is poor. In this sense also, need is thought of as something which stands in contrast with demand, and the need for a concept of need arises because of certain deficiencies in demand as a principle of allocation. The concept of need as a criticism of demand here refers to the fact that effective demand is closely related to income and to the distribution of income. Need is an equalization concept.

This concept of need leads to what Boulding calls the grants economy in which governmental agencies manipulate the marketplace to achieve a more socially desirable pattern of consumption. Within the grants economy, two usually antipathetic schools exist: one advocating grants of money to the needy (showing a reliance on demand criteria) and the other advocating grants of goods and services (showing a reliance on expert-opinion need). The problem with both of these techniques is that, unless they are based on careful estimates of actual consumer behavior, they can produce market distortions leading to tremendous social loss. Boulding reports that the research to date on the need for medical care, for example, has produced quantitative estimates of need that are "absurdly inflated" because of their neglect of the problems of demand and price structure.

CASE STUDY OF TRANSPORTATION NEEDS

We have been involved in a number of research efforts (6, 7) where one of the specific objectives was to produce estimates of the need for transportation among specific groups of people. We have found that, to be useful, a definition of need must define which trips are needed and produce quantifiable estimates of the number of households and/or persons requiring additional transportation and the number of trips required.

Identification of Necessary Trips

Who needs to take a particular trip? This must be answered in terms of the attributes of the trip (e.g., purpose, frequency, cost, and destination) and of the person (e.g., age, family status, and employment). For example, grocery shopping (or other means of food-gathering) is an activity that is considered necessary for survival. However, it is not necessary to make one trip per day to the grocery store, whereas it is necessary for most people to make five round trips per week to work to get the money to buy the groceries. Therefore, we must first establish some overall estimate of the need (for trips as previously specified) and then subtract the amount of transportation now being obtained. The remainder will be the additional trips required. [When designing a new transportation system, the number of trips needed will figure in the calculations of trips generated by the new system, which must be added to the number of trips diverted from existing systems to arrive at a total required system capacity. Experience has shown that the diverted trips will be greater than the generated trips when new transportation systems are implemented to serve the rural poor (8).]

We have now produced what we feel to be a complete list of ways in which an overall level of need could be derived. These are as follows:

1. Optimize economic productivity by determining what level of transportation service would have the greatest effect on the regional economy through increases in employment and personal income.
2. Establish the level of transportation that you consider to be the moral right of a person through the political process.
3. Test a hypothetical range of transportation to determine at what point the benefits of providing the service outweigh the costs by the greatest amount.
4. Use what the poor have now in terms of frequency as the definition of the minimum amount of transportation required.
5. The minimum transportation required to achieve social goals is a possible alternative (experts in health, nutrition, employment and training, and other areas establish the minimum level of travel required for each).
6. Use the personal perceptions of the poor as the estimate of need.
7. Run a demonstration project to determine how people would actually behave when the system was actually there and see which of the preceding methods comes closest to predicting the actual use.

Whatever method is used, it is important to stratify trips into required and discretionary categories. Required trips are defined to be those that are highly income-inelastic; that is, they will be taken almost irrespective of their price. Discretionary trips are those that will be deferred as their cost rises. We found that, in an area of rural poverty where free bus transportation was introduced, income-production trips (work, welfare, and food stamps), grocery shopping, and health trips did not increase significantly in frequency in the face of drastic trip cost reductions, whereas trips for miscellaneous purposes, community action, visiting, and other shopping increased quite markedly when free transportation was available (8).

In a sense, we require a social-worthiness criterion for trips of various purposes. It would seem that health trips would be higher on a list of priorities than would trips to the pool hall. What portion of the gap between behavior and need might warrant social support? After all, when someone receives additional income through the welfare system, he gets only a minimally adequate level, not the national average.

Households Needing Additional Transportation

Having established which trips are needed, we can turn to the estimation of how many trips are required. There are two factors that interact to produce an unmet need for transportation service: the availability of some form of transportation and the constraints (financial, legal, and physical) on the options of the traveler. These items should also be calculated in light of the characteristics of a particular trip, namely, purpose, cost, destination (with respect to origin and other trip destinations), frequency, and other attributes. We could then say, on a trip-by-trip basis, whether or not a particular household needed additional transportation according to the procedure shown in Figure 1. This algorithm begins with the question of automobile ownership for the household. It then asks if the automobile is available for that trip (it may not be for the housewife in a one-car family), if the particular traveler in question can operate the automobile (persons that are too young, too old, or handicapped cannot operate it), and if the traveler can afford the cost of that particular trip (low-income persons may not travel in certain instances to save money for other trips). The availability and affordability questions are asked for each transportation mode to determine a residual number of persons without transportation meeting their requirements. They are those people who answer no to the last question on the list.

Estimating Procedure for the Number of Households in Need of Transportation Services

It has not been possible to date to disaggregate the trip characteristics as previously proposed. As of the present, one level of availability and affordability has been established for all trips. Four normative levels of need have also been established according to the availability of transportation and the ability of the individuals to afford it. These levels are as follows:

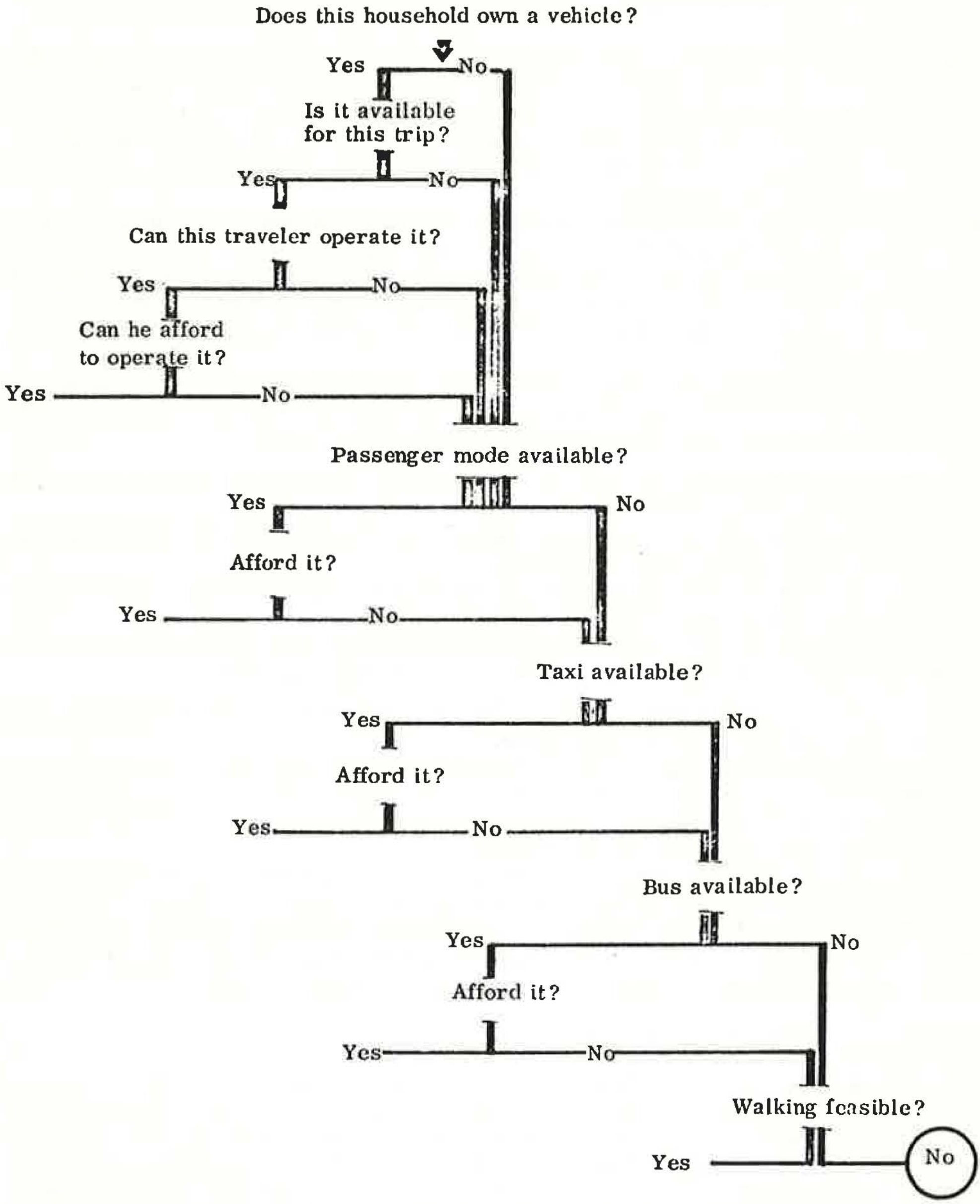
1. Dire need—little or no transportation available or little or no purchasing power;
2. Strong needs—restricted transportation available and restricted purchasing power;
3. Moderate needs—several transportation options available and moderate purchasing power; and
4. Slight needs—personal transportation available in good condition and moderate purchasing power.

In addition, there is an implicit fifth level that may be called "do not need additional personal transportation." Persons in this group have two cars available or one car plus another mode that they can afford to use.

Transportation Availability—We have found that individuals with no transportation resources whatsoever are so few that they are not worth mentioning (6, 7, 9). (This conclusion applies to the most rural and poorest areas of our country.) The problem becomes one of measuring how much is available, not if it is available. Obviously, a person who does not own an automobile does not have as much transportation available as one who owns an undependable automobile, who does not in turn have as much as a person who owns a dependable automobile. Degrees of availability are distinct here, if difficult to quantify. The following situations represent important measures of the lack of transportation:

1. When the family does not own a car,
2. When no taxicab service can be called to pick up a person,
3. When no bus service is available nearby,
4. When friends or neighbors cannot or will not supply transportation, and
5. When walking is not feasible.

Figure 1. Algorithm: households needing transportation.



When none of these situations occurs, the availability of transportation is very good; when all occur, it is extremely poor. Several levels of availability are possible between these extremes.

We have developed a ranking scale based on the availability of transportation. This scale is as follows: bus stops nearby, 1 point; taxi service available, 2 points; vehicles owned, 7 points apiece; vehicle in poor condition, subtract 1 point; and vehicle not running, subtract 6 points. (If bus service is available frequently, it could be scored on an equal basis as a taxicab. However, in many rural areas only one round trip per day is possible on existing bus systems.)

It should be noted that availability, as used in our calculations, is based on the perception of the individual and not of the analyst. It is common for the poor in rural and urban areas to be unaware of the transportation services actually available to them. We would argue that these people are in need because the ultimate effect is restriction of their travel. However, the solution to their need is relatively simple: an information and education program.

Transportation Affordability—When a household cannot afford to travel on existing modes of transportation (including its own car), that household has unmet travel needs. We have used the following criteria to form our definition of need:

1. Income less than $2,500 per year—household cannot afford to travel by car (subtract 1 point if automobile available);
2. Income less than $3,100—household cannot affort to travel by bus (if income is $3,101 or more, add 1 point if bus available);
3. Income less than $3,800—household cannot afford to travel by taxicab (if income is $3,801 or more, add 1 point if taxicab available); and
4. Income exceeds $7,401—household has comparatively little difficulty traveling (add 1 point for such households if any transportation mode available).

These figures are for nonfarm households. The corresponding incomes for farm households are $2,500, $3,000, $3,500, and $6,500.

The somewhat arbitrary nature of these definitions is recognized. A more satisfactory procedure would be to contrast annual household income with trip cost and perform the calculations on a per trip basis. However, the proposed procedure is felt to be an adequate approximation of needs for the moment.

Composite Levels of Need—The points generated from information pertaining to each household according to the availability and affordability criteria are added. The levels of need previously described are defined to represent the following scores: dire needs, 0 to 1 point; strong needs, 2 to 3 points; moderate needs, 4 to 6 points; slight needs, 7 to 9 points; and no additional transportation needed, 10 points or more.

Estimated Number of Households Needing Transportation

The foregoing procedure was tested in five areas of rural poverty. Table 2 gives the number of households in need in each of the five study areas. Several conclusions are apparent from this table. First, in these five states few households have all the transportation they need, but the percentage not needing additional transportation is remarkably similar among states. The percentage of households in dire need of additional transportation varies substantially from state to state. North Carolina and South Carolina have the highest proportion of persons in the first need category and in the second as well. Minnesota has the lowest percentage of the rural poor population in these critical categories.

Estimated Number of Trips Required

An implicit objective of the research project previously described was to bring the rural poor up to some national level of transportation adequacy. Therefore, we tested the implications of the gap analysis method as the basis for an estimate of the amount of transportation required by households in need.

The number of trips by households in need, using a gap analysis, may be calculated by comparing the number of trips now taken by those households with an accepted norm of travel behavior. If the present travel frequency of those in the study group falls below the given norm, then the difference is the number of trips needed by the study group. The total number of trips needed per area is then the total number of households in need times the number of trips needed.

The norm of travel behavior chosen is the average number of trips made by all persons more than 5 years of age in the United States. This figure, according to the Nationwide Personal Transportation Survey of the Federal Highway Administration, is 807 trips per person per year or 67.25 trips per person per month. A trip is defined by this survey as "anytime you went from one place to another by motor vehicle or some form of public transportation."

Table 3 gives the number of trips required by households in need in each of the five study areas. As one can easily see, the number of trips required by the rural poor to bring them up to the average trip-making behavior of the entire nation is phenomenal. Our figures show that a poor person in the five study areas only travels one-sixth to one-fifth as much as the average American. The number of additional trips he should be making to be consistent with the national average is almost two per day.

Applying the numbers of trips required to the total number of persons in need produces an estimate of the number of trips required to satisfy the various levels of need in each of the five study areas. The impossibility of providing anything resembling a national standard of transportation for the rural poor should be immediately obvious from the table. If standards are to be used, they must instead focus on local areas and/or specific population groups to avoid arbitrary and unreasonable measures of need (such as that of the national average).

DIRECTIONS FOR FUTURE RESEARCH

The arbitrariness of a concept of need based on average travel behavior is readily apparent from the previous section. Although this may be the only viable approach at the moment, there are more promising avenues that should be explored.

Future research should focus on a concept of need that refers to transportation services that would be used (instead of those that should be used). Needs must be based on actual behavior (or estimates of actual behavior), not on some idea of what people ought to do. This forces the use of the values of the target group rather than the values of planners.

One reason, already mentioned in the quotes from Boulding, for the evaluation of a concept of need in contrast to demand is the feeling that the use of demand disenfranchises those who cannot afford the market price of the commodity in question. This feeling is completely erroneous. This form of disenfranchisement is a result of the way in which demand is used, not the result of the concept itself. The economist's concept of demand is simply a description of consumption behavior under a variety of conditions. It has no normative aspect; it is purely descriptive. This concept leads to economic disenfranchisement of the poor only when it is coupled with the idea that all transactions must occur in a free, competitive market. That idea is strongly normative (it is certainly far from descriptive of most real markets) and is responsible for producing a situation in which the economic votes of the poor are largely ignored because they cannot meet the market price.

Of course, it is not at all necessary to use the norm of a free market in conjunction with the descriptive concept of demand. It is perfectly acceptable to ask how people would behave if the price of transportation were X without addressing the question of how the price X would come about. In fact the approach that we now recommend to determine the transportation needs of the disadvantaged is to estimate the impacts that would actually occur under various hypothetical supplies of transportation, without asking how these supplies might come about (except that we would limit our hypotheses by technological feasibility). Some examples are as follows:

1. What would happen if free door-to-door transportation to work were provided to the disadvantaged?
2. What would happen if they could use the existing public transportation services at zero cost?

Table 1. Concepts of demand and need.

Concept	Related Phenomenon	Relation
Need for medical services	Biological and psychological health states as perceived by expert medical opinion.	Unique quantity comparable to total quantity of medical services wanted and to the quantity demanded, given determinants of demand.
Wants for medical services	Biological and psychological health states as individuals perceive them and as related to cultural, educational, and social status.	Unique quantity comparable to total quantity of medical services wanted and to the quantity demanded, given determinants of demand.
Demand for medical services	Market behavior as related to consumer wants, prices of medical services, prices of other good, and financial resources.	As a concept refers to no unique quantity of services, but rather refers to a functional market behavioral relation between quantities of medical services that will be demanded, given levels of the determinants of demand.
Quantity of medical services demanded	Consumption of medical services given values of determinants of demand.	A unique quantity of medical services comparable to both quantity needed and quantity wanted.
Market shortage of medical services	Excess demand: at existing prices, quantity demanded exceeds quantity supplied.	A unique quantity of medical services comparable to quantity needed, a normative shortage, etc.
Normative shortage of medical services	Extent to which quantity of medical service needed exceeds quantity of medical services demanded at existing prices.	A unique quantity of medical services comparable to quantity needed, a market shortage, etc.
Total shortage of medical services	Extent to which quantity of medical services needs exceeds quantity of medical services supplied at existing prices.	A unique quantity equal to the sum of market and normative shortages at a given price.

Table 2. Level of need of households requiring additional transportation.

	Arizona		Minnesota		Missouri		North Carolina		South Carolina	
Transportation Need	Number of Households	Percentage[a]	Number of Households	Percentage[a]	Number of Households	Percentage[a]	Number of Households	Percentage[a]	Number of Households	Percentage[a]
Dire	1,552	28	1,500	17	4,470	27	4,680	44	13,000	41
Strong	269	5	0	0	1,636	10	1,008	10	1,868	6
Moderate	911	17	4,210	48	4,070	25	1,652	16	8,450	27
Slight	2,268	42	2,425	28	4,470	27	2,820	27	7,380	23
Total households in need	5,000	92	8,135	93	14,646	89	10,160	97	30,698	97
Households not requiring additional transportation	435	8	612	7	1,910	11	314	3	949	3

[a]Percentages based on estimated rural poor population in each study area.

Table 3. Calculations of required trips.

State	Trips per Household per Month[a]	Persons per Household	Trips per Person per Month	Additional Trips Required to Meet National Standard[b]	Percentage of National Standard Now Obtained	Number of Trips per Month Required by Persons of Dire Need to Meet Standard
Arizona	52.1	4.58	11.4	55.9	17.0	389,662
Minnesota	26.4	2.81	9.4	57.9	14.0	244,050
Missouri	43.9	3.64	12.1	55.2	18.0	898,157
North Carolina	31.8	3.02	10.5	56.7	15.6	801,356
South Carolina	48.9	4.82	10.1	57.1	15.0	3,577,800

[a]Trips reported by respondents to survey (8) adjusted for comparison with national figures.

[b]Compared to national standards of 67.25 trips per month per person, according to FHWA's Nationwide Personal Transportation Survey.

3. In the case of the handicapped, what would happen if they were given transportation?
4. What would happen if the cost were nonzero in the three preceding cases?

You can see that our approach is one that asks why these groups travel less and seeks the answer by estimating how they would travel if one thing at a time were changed. This is what economists do when they conduct demand analyses. There are also some interesting parallels with marketing research, which is also trying to describe consumption behavior, but marketing researchers usually feel constrained to operate within the limits of the currently existing type of market. They usually do not consider situations that would require manipulation of the market to achieve socially desirable results. (A companion effort should ask the following types of questions: Must the transportation system be self-supporting through fares, or can permanent subsidies be accepted? Can transportation stamps be used, or should a cash grant be used instead? Can other social service agencies, like Social Security, be induced to subsidize increased travel for their clients?)

The use to which transportation is put is closely tied to the price that will be paid. That is, the answer to "how much transportation would be used at a given price?" is related to the answer to "for what purposes would transportation be used at a given price?" We want to know what the demand for transportation is among the disadvantaged, as a function of trip purpose as well as the usual variables in demand analysis. [The implication of the finding that demand elasticities for travel evidently vary substantially according to trip purpose is that increased mobility can substantially change the lives of the transportation disadvantaged through a significant increase in (a) the variety of activities in which they participate and (b) their frequency of participation.] Then we can attempt to quantify the impacts of increased use of transportation services.

ACKNOWLEDGMENT

Some of the material reported herein was developed pursuant to a contract with the Office of Economic Opportunity, Executive Office of the President. The opinions expressed are those of the author and should not be construed as representing the opinions or policy of any agency of the United States government.

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AN APPROACH TO MODELING URBAN GROWTH AND SPATIAL STRUCTURE

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The approach to urban modeling presented here seeks to extend the focus of model building activity from a product to a process orientation. By embedding model building in a dynamic feedback process, it is hoped that the resulting models will change and adapt to the needs of users over time. Thus a continuum develops beginning with model design and ending with public involvement and implementation, which in turn feed back to model design to form a loop. Model building is the subject of the process, and the model presented here includes three principal submodels: population and demographic change, regional economic forecasting, and land use. Taken together, these three components form a module that in turn can be interfaced with a variety of other regional simulation models. This module is currently being designed to interface with models of regional transportation, air and water pollution, health care, site servicing costs, and local government finances. Both the module and the process have evolved with flexibility and maximum use as prime design criteria. An early version of the module is already programmed and operational. With widespread use, further additions and modifications will be made both in the components and in their interaction. The main thrust of the paper, however, is on use and dissemination of the process. The module, although worthwhile in its own right, is merely a phase in the process. The most critical element is public involvement in, and knowledge of, the models. An informed and cautious public is the key to the process and spells the difference between the present model building approach and those that have preceded it.

•THE transportation planning process has evolved quickly during the past two decades. However, there is increasing concern that the evolutionary forces are losing out to inertia and institutionalization of procedures. Writers have recently pointed out new directions in which they feel transportation planning might move (10, 28, 30).

The thread that seems to run through much of the concern about urban transportation planning is the relevance of the process to new and emerging problems that the planner is facing. The problems include public participation, a variety of environmental and nontransportation and noneconomic factors that relate to transportation, the impacts of transportation and land use on each other, the lack of in-house expertise, and the increasing sophistication and esoteric nature of transportation and other urban modeling techniques. Thus, Voorhees and Bellomo (38, p. 147) have stated the following:

> The selection of city structure and broader considerations relating to the environment and living preferences are the key decisions that must be made. Once city structure and environmental objectives are selected, care must be exercised by the planner to develop a transportation system that is directed towards that particular city structure and to assure that the broader environmental considerations are met.

Sponsored by Committee on Social, Economic and Environmental Factors of Transportation.

Kochanowski and Wickstrom (18, p. 12) raise questions about the spatial specificity and time horizon of current planning procedures. They have observed the following:

> The urban transportation planning process must be made more relevant to decision-making and implementation. Most transportation decisions are not made at the regional scale, but at the corridor and project levels. Much of today's transportation planning methodology can be applied at these finer degrees of planning, but new methods and techniques specifically tailored to these scales need to be developed as well. At the same time, much broader regional studies involving human values, as well as physical and economic considerations, should be undertaken. We badly need more specific, fine-grained tools for short-range planning, and also broader social and economic planning tools to apply at the regional level.

Finally, in another broad brush summary of needed new directions, Roberts (30, p. 44) has concluded:

> The challenge to urban transportation planning is a challenge to how effectively we can utilize the model building capability we are slowly acquiring, the computing power we have developed, and the understanding of the nature and purpose of planning we have discovered to explore the possibilities that the technology of the future holds for the city.

Each of these authors has stressed the kinds of problems summarized at the beginning of the section. These writers and others (10) in the transportation field have in particular begun to stress the need for larger scale human input either through inclusion of more and better behavioral aspects or through direct citizen participation in the transportation planning process.

The following describes an approach (a process) to modeling urban development that we feel is generally applicable to urban policy formulation, testing, and implementation. Although not oriented to transportation specifically, transportation planning is both a needed input to the process and a likely user of it.

APPROACH TO MODELING URBAN DEVELOPMENT

The principal focus of our work is the creation of a model building process, of which a set of models is a part. The models, however, are not seen as an end in themselves but rather a focus for, and means of, evolving the process. This work is being undertaken at the University of British Columbia in close conjunction with various levels of government and, most importantly, with a variety of citizen groups.

The two essential elements in the process relate to synthesis and usability. Figure 1 shows the kinds of syntheses we are attempting, and Figure 2 shows model development and use. The syntheses we are seeking begin in the university and extend out to other institutions and then to the body politic. Thus, first we have sought to integrate a variety of disciplines and methodologies that abound on a university campus and to focus this diversity of expertise on problems of modeling our urban environment. The work is therefore interdisciplinary. Next, it is necessary to move outside the confines of academe to various levels and departments of government. Thus, the synthesis is an interinstitutional one as well. Finally, it is necessary to proceed further still and integrate this interinstitutional synthesis with the general public. This last synthetic activity is more than public involvement in the usual sense; it is intended to reach citizen groups, private businesses, and, most generally, interested citizens as individuals.

The first two levels of synthesis have been achieved. A dozen disciplines are involved from the university, and we are currently working with all four levels of Canadian government. The hardest part, however, is yet to come; it involves reaching out to the general public. This task has just begun and is expected to last well past the planned 5-year duration of the project. (We are currently beginning our third year.)

These syntheses are not unrelated to questions of model development and use (Fig. 2). For us to construct a policy-testing model of any use and interest, a wide variety of individuals and institutions must be involved. Thus, interinstitutional and public involvement are seen as means of achieving the process, which in turn has as its goal use. Without open access and actual use, the models will undoubtedly take their place alongside numerous others that have been developed during the past decade only to be quietly shelved after a brief period of trial. The whole purpose of evolving a dynamic and ongoing process (as distinct from the product, the models) is to bring use directly into the model development framework. With continued use and reevaluation, there will exist continued need for refinement and redevelopment. The process will entail an ongoing evolution of the models such that use and development will blend as different elements in a modeling continuum—the model building process.

One other point should be made about the role of the public. This relates to questions of values, preferences, biases, and so forth. The module to be described is not value-free in the traditional sense. The policies that were initially designed to be tested by the module (though not the outcomes, which are hopefully functions of system dynamics and not our values) are certainly reflections of our biases, as are the very components that we have included in the basic module. However, we like to call the models "value-variable," acknowledging that values are important but that they are user-determined and subject to direct change through intervention. The module is programmed as a real-time interactive system to facilitate such user selection of value assumptions.

This highlights one of the most important functions of public use, i. e., public evaluation of simulation output. The models are intended to provide an "if-then" format for questioning. The user specifies an "if" question or assumption, and the models return the likely consequences of such a question. The consequences can be specified along a variety of dimensions from land use, to employment, to migration, and later to congestion, air and water pollution, and so on. These outputs really represent a series of social indicators. However, unlike other investigations that promote social indicators, we will not, by conscious decision, specify any system of weights that will allow these index elements to be added to yield indexes of quality of life, pleasantness, well-being, etc. Such indexes of livability can only be formulated by individuals. Individuals do need information to derive such a measure (the derivation itself being an extraordinarily complex synthesis). The simulation system is designed to provide such indicators. It explicitly fails to supply weights to combine these indicators into a single index, leaving this synthesis to the individual. Simulation provides an important vehicle, therefore, for putting individual values back into public decision-making and thus avoiding the need to create arbitrary or narrow weighting schemes to evaluate alternate outcomes. Computer technology provides us with the opportunity to communicate with people on a scale and level that have previously not been possible. Whether or not we take the opportunity is another question.

The foregoing has set out the method. The following outlines its application and dwells on the basic simulation module or urban growth and spatial structure, which is the heart of the model building activity.

THE MODULE

The module consists of three separate simulation models that have been linked together. The component models are population, economic, and land use. The population model is a cohort-parity model of natural increase combined with a life-cycle model of migration. The availability of housing also plays a role in the migration component of the population model. The economic model is a synthesis of input-output techniques and simulation. A simulation model is used to generate a matrix of final demands, which are then distributed among the various sectors by the input-output model. The input-output model is in turn linked back to the simulation model with the population model.

The population and economic models are the driving forces behind urban growth. This growth is given spatial form through the land use models, which allocate population and employment to residences and work sites around the urban region. Thus, the land use models translate growth forces into changes in the spatial structure of the urban area. Spatial structure provides a natural focus for interfacing these components. Economic and population growth affect spatial form in the first instance, and spatial elements, such as density and agglomeration, in turn feed back on these two elements of regional growth.

POPULATION MODEL

This model is used to simulate the size and composition of the region's population (27, 14). The model operates on a simulated annual data base that utilizes a life-cycle classification system to describe the population (7, 21). The characteristics of the population considered, therefore, involve age, sex, marital status, age of spouse, and number and age of children. The various components of the model function sequentially to alter the composition of population over one iteration. The model (Fig. 3) is comprised of two major functional components: the natural increase (or more exactly the demographic change) submodel and the interregional migration submodel (16).

The natural increase submodel is further broken down into a number of subcomponents, here referred to as subroutines. The birth subroutine is an extension of the traditional cohort birth models. It is used to determine the effect of age on the probability that a female will give birth to a child and the effect of the number of children that a female of a given age has already borne (parity) (1). This subroutine uses an age and parity specific probability of a female giving birth to simulate the number of births and the age-size composition of families in the region. From the model, therefore, the family size, composition, and life cycle can be estimated, providing important inputs into housing, economic, and transportation models (2, 22, 23, 32). Policy interventions involve simulation of changing age, parity, and age and parity patterns of fertility.

The mortality subroutine accounts for deaths by altering the composition of the data base using the age-sex-marital status-specific probability of surviving to the next age group. Included in this subroutine is an accounting procedure that alters the characteristics of the surviving population on the basis of the change in marital status to widowed inherent in the demise of a spouse. Two other subroutines also result in changes in the marital status composition of the population. The marriage subroutine uses two age and present marital status probabilities of marriage, one for each sex, as inputs to a marriage market process. The separation and divorce subroutine simulates the effect on the composition of the population resultant from marital dissolution. Although divorce changes the marital status, separations were included to simulate the effect on the housing market of the functional, as compared to the legal, demise of the marriage. One further subroutine simulates the process by which non-nuclear-family households form for reasons not related to the housing market, such as cultural preference: This process is referred to as basic clustering. The formation of a household as a result of the cost and/or availability of housing, forced clustering, is included in the housing model (25).

The migration submodel simulates the size and composition of migration flows into and out of the region. Because the region is characterized by very dominant in-migration for reasons that are apparently more directly related to complex life cycle, life-style, and cultural factors than to economic factors, modeling interregional migration has proved to be very complex (6, 34). The migration model, as currently conceived, compares the characteristics of this region to those of other regions. Interregional migration is simulated using the results of this comparison and stage-in-life-cycle specific propensities to migrate (17, 41). The factors considered in the regional comparisons are included under the headings environmental (climate, recreation, and pollution), economic (wages, jobs, cost of living, and availability of housing) and cultural (diversity of activities). The migrants are characterized, where possible, by the same elements as are used in the data base. In terms of the population model, therefore, the out-migrants are subtracted from the data base, and then the in-migrants are added. But because of the very strong interconnection between migration and housing, the path by which this simple addition and subtraction takes place is in fact much more complex. First, when the out-migrants are removed from the population data base, an accounting procedure modifies the stock-occupancy matrix in the housing model to account for vacancies. Although the in-migrants are added directly to the

Figure 1. Framework for interinstitutional and public involvement.

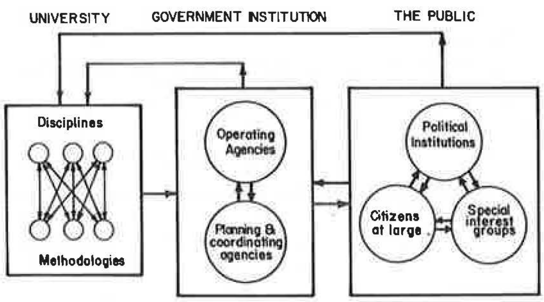


Figure 2. Framework for model refinement, policy evolution, and public involvement.

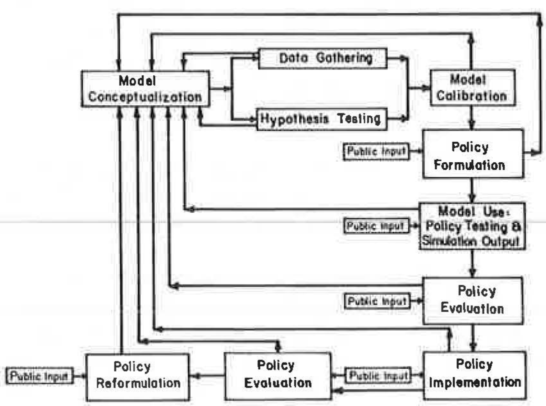
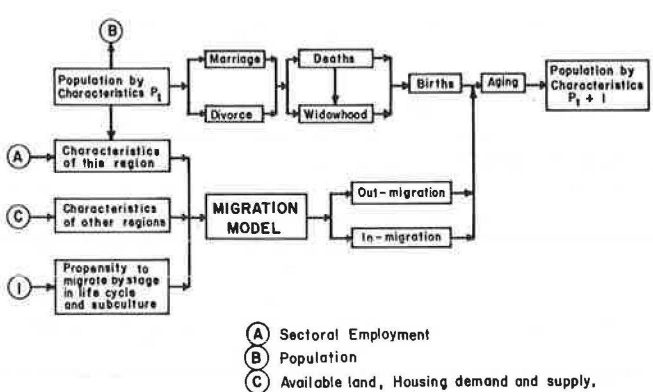


Figure 3. Population model.



population, the annual in-migration, by characteristics, is held for 1 year as an input to the next housing market. This is done to simulate the effects of the housing search characteristic of migrants (19). The final operation of the population model for each iteration is to age the population 1 year by adding one to each element of the age index in the data base.

ECONOMIC MODEL

The regional economy is being modeled with the use of two separate but closely linked models. Figure 4 shows the economic model, which includes an input-output component that calculates gross regional product. The input-output model also yields forecasts of employment in each of the 27 economic sectors into which the economy has been divided.

However, the input-output framework requires estimates of final demand by final demand category for each sector. These estimates are provided by a regional simulation model. The simulation model links the input-output model dynamically to the other components of the module.

Input-output analysis provides a systems approach to the economy (26). In the input-output model, all sectors of the economy are linked. Thus a change in any one sector affects not only itself and its immediate suppliers and buyers but potentially all of the other sectors as well. The input-output model developed here comprises 27 endogenous economic sectors and 9 exogenous or final demand sectors. The strength of the technique lies in the model's ability to link the sectors and their final demands. It is thus an ideal framework for evaluating the impact of changes in one or more sectors on the regional economy. Unfortunately, input-output models are less than ideal for forecasting purposes (4). To be useful for forecasting, an economic model should have reasonably stable parameters over time, or in lieu of stability there should be some satisfactory method for changing the parameters dynamically. Neither of these properties holds in input-output analysis. In addition, even if the model's parameters were stable over time, the model still requires forecasts of final demands to be supplied exogenously.

The simulation model shown in Figure 4 attempts to overcome these weaknesses of the input-output approach by providing first a means of calculating final demands into the future and second a framework for systematically changing the input-output coefficients dynamically.

A simple Keynesian model provides the conceptual basis for the simulation model. The Keynesian model encompasses all of the nine final demand categories. In the aggregate they appear in the familiar national or regional accounting form as $GRP = C + I + G + E$. The simulation model further disaggregates government expenditures into local, provincial, and federal and investment into residential construction and business expenditures on plant and equipment. The other final demand sectors are export categories that are classified according to designation into those related to the rest of British Columbia, the rest of Canada, the United states, and the rest of the world.

The simulation model in turn must generate 27 separate final demands for each final sector, one for each of the 27 economic sectors of the input-output model. The principal variables used to generate these final demand estimates are gross regional product from the previous period, disposable income, population and previous period consumption, investment, government spending, and exports. The resulting final demand forecasts are then supplied to the input-output model to yield gross total output for each of the 27 sectors.

These group outputs can be transformed into employment with the use of employment coefficients that measure man-hours of employment in a sector per dollar of gross output of that sector. Gross output changes that result from changes in final demands (or from any other source) can be converted into employment. It is these employment estimates that are of direct interest to the land use and population components of the module.

Finally, we are currently developing means of changing the input-output and simulation model coefficients dynamically. Phenomena such as new firm location in the region and the related correlate of import substitution are important factors in the change in the technical coefficients through time. The simulation model and the population and land use components can jointly provide some of the required information to model these phenomena and their impact on the input-output coefficients.

In a similar vein, changes can be anticipated in the simulation model coefficients. For example, in the simulation model equation for consumption, it is only reasonable to expect that the coefficient relating disposable income to consumption will change over time, most likely in response to changes in disposable income. Thus, as disposable income increases, the percentage spent on consumption is likely to decrease. In other words, the disposable income coefficient is likely to fall as disposable income rises. Similar dynamic mechanisms have been identified for a majority of the final demand simulation's parameters.

We believe that, by combining the input-output and simulation techniques, we will be in a position to develop more flexible and dynamic models than those constructed previously. In addition, by embedding these economic models in a broader, more powerful simulation module, we hope to create a more useful and realistic regional model for testing economic policy.

LAND USE AND HOUSING MODELS

The land use models are the principal means by which economic activities and population are located spatially in the module. The spatial unit used initially is a traffic zone. There are 82 such zones, each an aggregate of census tracts, covering the region. Figure 5 shows the elements of the land use models and their interaction. The principal components are discussed briefly in the following subsections.

Employment Location Submodels

Employment in each of 27 industry groups is allocated on the basis of the locational criteria of each industry. However, there are regularities in the way certain groups of employment choose locations within metropolitan areas; as a result, employment location was further broken down.

Manufacturing and Wholesaling—Employment activities involving manufacturing and wholesaling are disaggregated into major industrial sectors. Employment is allocated to a zone on the basis of its attractiveness to a given industry, where the attractiveness is given by a weighted sum of site factors. The site factors vary from zone to zone, whereas the weights vary from industry to industry. These attractiveness indexes, however, are only calculated for those zones with industrially zoned land and with certain essential factors that each industry must have, such as deep-water access for petroleum refining and railroad access for wholesaling, warehousing, and storage. The indexes are then normalized to allocate net increments to employment as well as employment that is being relocated within the region (29). The allocated employment is converted to land use via a land absorption coefficient (LAC) for each industry. If sufficient land is lacking, excesses are reallocated (8). An index of excess demand for land is calculated to provide a natural feedback link with the economic model.

Because the module is policy-oriented, a range of policies is testable in each submodel. In these initial manufacturing location models, policies available for testing are rezoning of land either to or from industrial use, exogenous removal or location of any desired number of employees of industry group, change in the rights for attractiveness indexes, change in the essential factors, and changes in the values of the site attributes. Each of these policies can be specified for a given time period and for a given traffic zone. This holds true for all of the policies in the study.

Retail Trade—Retail employment is allocated using either of two well-known approaches: the gravity model (13, 20) or the intervening-opportunities model (24, 38). Two alternatives are being estimated and experimented with to determine which is most easily used.

Both of these models generate measures of potential demand for retail trade in a zone. These potential demands are then compared with actual trade in each zone.

Excesses and deficits are not allocated instantly but rather phased in over time. Thus, if there is a large negative difference between potential demand and actual demand, only a part of this deficit is moved from the zone in each time period. This is intended to account for the lags and inertia that occur in practice.

As before, the newly allocated employment is converted to land use via the appropriate LAC. If too much land is found to be required, excess employment is reallocated to areas with adequate land supplies. An index of excess employment is also kept there to feed back to the economic component. Policy interventions analogous to those already mentioned are also an integral part of the retail location model.

Services—To date little work has been done in the area of service employment location. There is a paucity of work on office location (5, 12). Other services have been virtually ignored (36). In this absence of extant research, we are attempting to calibrate the gravity and intervening-opportunity models to provide estimates of service location. Thus, service allocations will be carried out in a manner analogous to retail trade as previously described.

Agriculture, Forestry, and Fishing—The primary activities have not been able to compete successfully for land with urban uses. As a result, these activities are seen as providing potential supplies of land for urban development on the urban fringe. Agriculture, forestry, and fishing are experiencing a decline in the region, and the assumption that these declines allow for conversion to urban land uses is consistent with the idea that they are a significant supply element for urban growth.

Housing Models

Housing policies are certainly among the most interesting, and the housing model can handle policies on renewal, rent subsidy, and receiving among others. To achieve this policy orientation, the present housing models allocate forecast increases in households (population) to each of the 82 traffic zones for each of 15 different types of housing (i. e., three structure types and five value classes). The structure types really correspond to densities and are roughly equivalent to single-family housing, row housing or garden apartments, and medium-rise and high-rise apartments. The value classes are class I, more than $400 per month rental equivalent; class II, $200 to $400; class III, $101 to $200; class IV, $51 to $100; and class V, less than $50.

The rental equivalent is intended to eliminate problems in tenure determination in the model and reduces all housing costs to a common base. The housing model proceeds by converting population into demand $D_j^{i,k}$ of structure type k, value class i, in subarea j. This demand is determined by using information from the population model on family size and the age structure of the population and information from the economic model on income distribution. Subarea attributes such as the types and quantities of housing already present in the zone, accessibility of the zone, and slope and amenity characteristics shape the spatial distribution of demand. Supply is determined in a similar manner. Initially, however, supply is constrained to be equal to demand at the regional level. Differences between $S_j^{i,k}$ and $D_j^{i,k}$ not only are permitted but in fact are the principal market forces underlying the housing location model. The zonal supply and its breakdown by structure type and value class are determined by zonal characteristics such as accessibility, availability of land, allowable and actual densities, and the excess supply from the previous iteration of the model. Most location models have lacked any model of the market mechanism (15, 31).

Supply and demand are reconciled through a simple market resolution process that cumulates excess demand in each zone and allocates it to zones with excess supply. Where housing of the wrong structure type and value class is all that remains, the number of units filled with potentially dissatisfied residents is noted and excess demand is allocated to these units. The index of dissatisfaction that results is a prime force in the market adjustment in future periods. Finally, the housing units are converted to land use, and the model begins its next iteration.

Recreation and Open-Space Models

At the present time, recreation and open-space determination is carried out in an extremely simplistic fashion. Two different kinds of parklands are identified: local and neighborhood parks and regional parks. For each there is a 5 by 3 matrix of parkland absorption coefficients, one for each value class and structure type of housing. These two land absorption matrices represent current planning practice and are subject to change for policy testing purposes. They are used to calculate the number of acres of local and regional parks required to serve the forecast increases in population. The required land is taken from each subarea (traffic zone) and from the urban periphery.

THE MODULE: THE COMPONENTS AND THEIR INTERACTION

The previous sections briefly described the component population, economic, and land use models. Figure 6 combines these models in a somewhat abbreviated form to illustrate the links among the models. The links described here are the simplest and most direct links. More complex links will be identified as the models are refined and take on greater complexity. The process of identifying, programming, refining, and extending links is identical to that followed for the model separately, and the module as a whole is discussed in the conclusion at greater length.

For expository purposes, the links will be summarized as those between population and economics, population and land use, and economics and land use.

Population and Economics

In each link, the interaction between the pair of models is two-way. In the present case, population supplies economics with the migration and total population information needed by the simulation portion of the economic model. Economic information on employment, income, and gross regional produce flows to the population component from the economic model. There is a one-period lag in these flows. Thus, population receives employment information in period t to calculate period t+1 total population. This population for t+1 is used to calculate final demands in t+1, which in turn is used for estimating t+1 employment.

Land Use and Population

Land use needs an estimate of the increase in the number of households each period. This information comes from population and directly affects the housing component of the land use model. Population increase in period t is used to calculate housing requirements and use in the same period. However, housing and land use relate to population for use in calculating migration in period t+1. Once again the flows are in two directions with a one-period lag.

Land Use and Economics

In order to forecast the location of economic activity in the future, the land use models require a regional forecast of activity by industry groups. The economic model has as its primary output forecasts of employment increases and decreases for the region for each of the 27 industry groups. The land use model then distributes these spatially. Employment forecasts for period t are used to generate employment location for period t. However, land use also provides the economic model with information on the availability of industrial and commercial land. This is used in the simulation model of final demands. Available land and density information for period t from the land use models is used by the economic model for its forecast of economic activity in period t+1, once more a two-way flow with a one-period lag.

These links, as noted earlier, are the simplest and represent the first stage in the evolution of more complex and realistic links among the component models. Thus, at a later date, information on recreation and open-space land along with estimates of land prices or scarcity may be incorporated into the migration model as more detailed information on regional characteristics. Similarly, information on agglomeration and spatial association might be included in the simulation model to change the input-output coefficients dynamically with changes in spatial links among sectors within the region. Other links will be identified and tested in the continuing process of evolution and refinement to which the models and the module are being subjected.

Figure 4. Economic model.

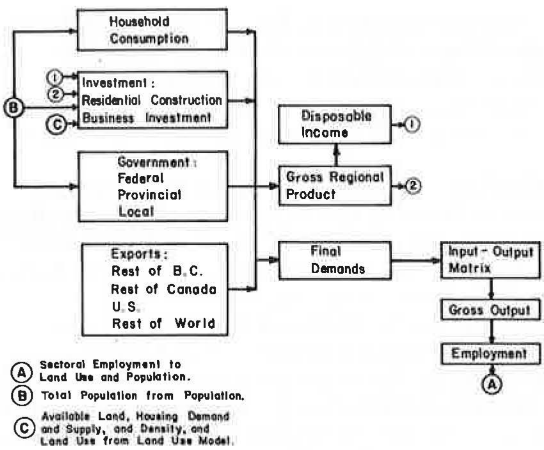


Figure 5. Land use model.

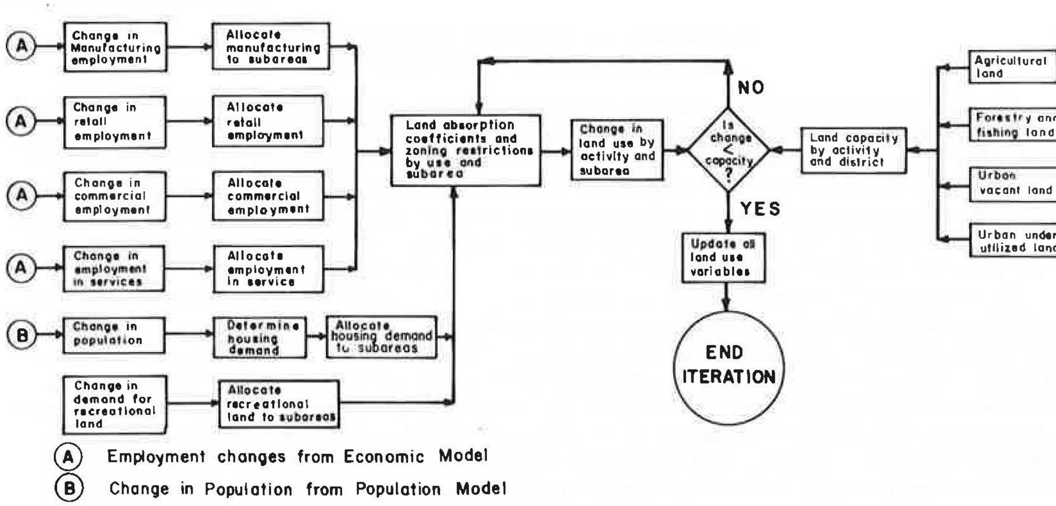
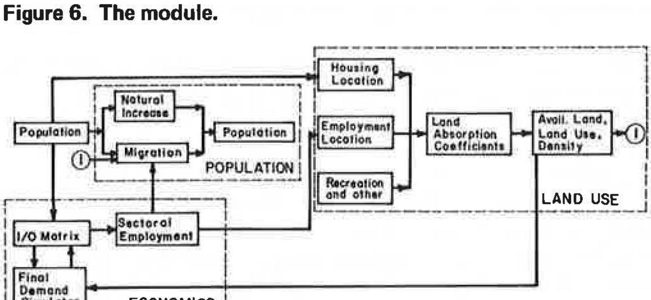


Figure 6. The module.



CURRENT PROGRESS

As of this writing, work is well along in the development of the module. The basic cohort-parity model is programmed and operational with a simple trend migration component. A more advanced version of the natural increase submodel and a much more complex migration model have been conceptualized. Much of the information has been gathered, and both submodels are in the process of being outlined (in flow charts) and programmed.

Work on the economic model is not so advanced. A sample of 3,800 firms has received input-output questionnaries. Based on returns from this sample an input-output table will be built, with a completion date of late summer 1973. The simulation model for the final demand matrix has been conceptualized and programmed. This also is expected to be completely debugged and calibrated by next summer.

Finally, the land use models as described here are fully operational. They currently receive inputs from the population model and from a simple trend economic model. Work is currently in progress to develop the feedback links from land use back to the population and economic components as described in the preceding section. Simple two-way feedbacks among these models are expected to be programmed and running by early spring 1973. By late 1973, the final versions of all these models should be fully operational with the completion of the input-output simulation model of the regional economy and the behavioral model of migration.

REFINING, APPLYING, UPDATING, AND EXTENDING THE MODULE

The foregoing provides a capsule description of the module that we are in the process of developing. Following is a sketch of the strategy for continued evolution of the module. Because a critical element in this evolutionary process is the application of the module, stress is placed on likely uses to which the module can and hopefully will be put. Only through a series of applications of this simulation framework do we see the means for updating the models and identifying their strengths and weaknesses so that they can be extended and refined to meet unfulfilled needs.

In the approach we are following, refinement, use, and extension of the module are not strictly separable. They are elements in the model development process that subsume continuous evolution and refinement of the module. Thus, each of the component models is conceptualized, programmed, calibrated, and refined separately, and where necessary whole subcomponents are replaced as more useful elements are developed. The three components are then interfaced to form the module, which is itself refined as an entity quite separate from its three components. Although this activity is occurring, new components are being developed to replace existing ones. Application of the module is continually kept in mind so that the module that evolves through changes in its parts and their interaction will have the broadest possible application and greatest ease of interfacing with other models, such as those dealing with transportation and pollution.

This brings us to questions of use. The greatest potential area for application is in urban transportation planning. Transportation planning has been responsible for creating some of the most useful computer simulation models of urban systems. In addition, the transportation models that are currently in operation have a substantial requirement for spatially disaggregated economic and population data. The module previously described is designed to provide such output. In addition, one of the principal outputs from transportation models is a matrix of time distances among spatial units in a region. This matrix, in turn, is one of the prime data needs of the land use component of the module. As a result, the module and transportation models have several natural feedback links. By linking the module with a transportation model, the effects of land use policies on transportation systems could be examined as well as the effects of transportation plans and policy on land use (39).

Just as there exist certain natural points for interfacing the module with a transportation model, so do there exist other natural interfaces with a variety of environmental models (3). It is pointless, without specific example, to go into the details of these other applications of the module. The procedure, however, is straightforward and would be as follows. The interfacing problem is reduced to one of bringing the module designers together with the designers of the using model. Interfacing therefore reduces to a bilateral negotiation between the supplying model and the receiving model. For some data the module will be the supplying element, whereas for others (as with the time distance noted previously) the module is the receiving element. In general, receiving elements desire greater detail and precision than applying elements can deliver. There is overlap, though, between the area of minimum detail acceptable to the receiving component and the maximum possible detail that the supplying model can provide. The final level of requested and supplied detail is the result of this bilateral discussion procedure. This bilateral procedure has already been followed with considerable success, and there is every reason to believe that both the procedure and the module have quite widespread applicability.

In the final analysis, however, usability is the ultimate criterion on which any simulation must be judged. The module must be useful, usable, and, above all, used. The usefulness of the module depends very much on the inclusion of those variables, parameters, and policies that are affected by and in turn affect real-world policy-makers and citizens. Cooperation from government officials and citizens is imperative for identifying those variables and policies that are of direct importance to governments and residents of the region being modeled. In Vancouver, we have direct ties to all levels of government as well as a variety of activities that are designed to provide citizen input to the work.

The module must also be usable. It must be economical of machine time, reasonably easy to understand, straightforward to operate, and, most importantly, accessible to all interested individuals.

Finally, in practice, to be useful and usable, models must be used. Use cannot be restricted to specialists in the planning field, but rather the module must be open to all. Looking at other modeling efforts, it seems clear that these use criteria have not been fulfilled or perhaps even sought.

CONCLUSIONS

The idea we have stressed throughout has been that of a model building process. The process is the essence of the approach, the product (the models) merely a means toward that end.

It is imperative that models and model building be subjugated to the process. The process is dynamic and open-ended. It is constantly changing its goals and objectives. Products on the other hand have in the past been institutionalized when successful. Enshrining our technology in institutions allows it to become static, to become an end in itself instead of a means to a more dynamic and global end, such as better planning for a more livable, diverse, and pleasant urban environment.

Success is to be feared more than failure. Failures vanish and cease to influence our society; successes live on. They grow and build on each other and become perpetuated, primarily because of past successes. Agencies like the Tennessee Valley Authority (originally a conservation agency) have lost sight of their initial broad objectives and have been carried away by a series of narrower achievements. In the TVA case, we find that agency currently one of the prinicpal users of strip-mined coal in the Appalachian region that it was originally created to protect.

The longest-surviving human societies have learned above all to live with success. They have succeeded where we have failed because of a skepticism about innovation for the sake of innovation (37). We are suggesting the same sort of critical assessment of our activities. The dangers of blind acceptance of simulation models (or any other technology) in our opinion outweigh the benefits. Models can too easily yield self-fulfilling forecasts. They can be put in a position of justifying actions rather than assessing likely consequences.

Direct public involvement holds promise of providing a way out of the positive feedback of self-serving success. Only through public communication can model builders and users jointly identify weaknesses and limitations of the models. The weaknesses are more importantly stressed than the strengths, as the strengths are usually sufficiently overwhelming as to jade the user's vision and lead to the dangerous state of blind acceptance.

The public is the key. Widespread diffusion of the model building process has the potential to keep models in perspective and above all in the service of people. The public is the ultimate safeguard against institutionalized, uncritical, and self-serving applications of models and model building to urban planning.

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PARAMETRIC ANALYSIS OF DUAL-MODE TRANSIT: PRELIMINARY CASE STUDY

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Greater understanding of the impact of different transit service configurations on system costs and benefits is needed, particularly in relation to new technologies. The purpose of this paper is to demonstrate a method for analyzing service trade-offs. Through a case study conducted in Milwaukee, the paper examines the sensitivity of four service characteristics for dual-mode transit, one of several promising technological innovations. The four service characteristics are main line speed, guideway spacing, vehicle size, and station spacing. Preliminary comparative analyses of these four features are conducted, in relation to nine output or system performance variables: annual operating costs, annual capital costs, total annual costs, average travel time, estimated ridership, required fares (operating costs), required fares (all costs), annual transport benefits, and benefit-cost ratio. Graphical techniques are explored for highlighting comparative sensitivities. The need to systematically examine different combinations of service features within different urban areas is stressed.

•AS increasing attention is given to the potentials for various innovative urban transit technologies, interest has grown in the relative importance of the different service parameters that such technologies offer. For example, several studies of the sensitivity of systems performance and desirability to various service parameters for dial-a-bus (1), multipurpose activity center systems (2), conventional bus transit (3), and dual-mode transit systems (4) have recently been completed. A general study of parametric service variations for generic urban transit systems has also been conducted (5), dealing with five different versions of a hypothetical, relatively extensive automated guideway transit system.

The notion of more carefully examining various combinations of service characteristics, in order to define and systematically characterize alternative transit systems, also seems to be influencing urban transit planning itself. For example, in a recent paper, it was observed that systematic choices of transport technologies will require that techniques for identifying subsystem trade-offs and local cost or performance optima be developed (6). In another example, a service specification model has been developed for screening candidate packages of service characteristics. The model converts the specific hardware characteristics and operating methods of any candidate system into a set of performance and user impacts (7). In a third example, a successive-approximations approach was used in the sensitivity analysis of alternative feeder and local transit systems in a suburban portion of the San Francisco BART service area. Under this approach, emphasis is placed on the early though approximate analysis of a wide range of service configurations to ensure that all reasonable alternatives receive adequate attention. Four successive and increasingly detailed rounds of analysis were conducted, with each round considering only the most promising configurations resulting from the previous rounds (8).

This paper presents an extension of the sensitivity analyses of dual-mode transit conducted in the study cited previously. It offers a framework for the sensitivity analysis

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of any area-wide express transit system, permitting direct trade-offs to be made among different service parameters. These trade-offs are expressed in terms of costs, performance levels, required fares, and transport-related benefits. Although many possible service parameters could be studied, four service characteristics that appear to be especially important are used to demonstrate the analytic approach. It is acknowledged that many other service parameters should also receive careful study. Some service characteristics, such as the maximum pickup time or the shape of the service area for dial-a-bus, or guideway configuration or vehicle headways for MAC systems, are more specialized in nature and deal with only a portion of metropolitan-wide urban transit systems.

Emphasis in the dual-mode transit sensitivity analysis was placed on service parameters derived from a simulation of peak-hour, door-to-door travel characteristics across the entire urban area. The four basic service characteristics studied—guideway spacing or guideway resolution (total miles of guideway within the fixed service area), station spacing (average distance between stations), vehicle size (number of passengers per bus), and main line speed (in mph)—appear to represent the most critical aspects of express urban transit service influencing attractiveness and ridership levels. These four variables then are the focus of this analysis and provide the inputs for the case study sensitivity evaluation.

Figure 1 shows the nine output characteristics of express transit service that were examined as a function of these service parameters.

CASE STUDY ASSUMPTIONS AND RESULTS

The dual-mode transit case study conducted in Milwaukee County involved the delineation of a hypothetical 110-mile, eight-corridor guideway network; a ridership forecast based on travel time and quality-of-service characteristics; a transit network assignment to determine system operating and performance characteristics; detailed operating and capital cost analyses; and preliminary analyses of transport and community impacts and benefits. Access to the hypothetical guideway system was provided at 40 different stations. Downtown distribution was accomplished via two separate downtown guideway tunnels, with six additional stations located along each tunnel. A constant speed of 55 mph along the main line guideway was assumed (with off-line acceleration and deceleration), together with an average operating speed in the downtown area of 13.5 mph (including time for station stops). An average of 6.6 neighborhood transit collection routes, conducted under manual driver operation, would emanate from each of the 40 outlying guideway access points (9, 10).

The equations and assumptions employed in the case study sensitivity analysis are defined in more detail in the Appendix. In general, these equations have been derived from data established for the peak-hour conditions of the case study system (e.g., ~110 miles of guideway, ~2,600 vehicles, ~40 stations, 55 mph, etc.). In some cases the relations examined are linear, and in other instances they are approximated by a few straight-line segments or a simple curve fit. Because each equation is based on simplifying assumptions, it must be recognized that the greater the departure of a given service characteristic from the design or simulated condition, the less likely or credible the result becomes.

Transport Supply

As noted previously, transport supply is represented in this analysis by four system output characteristics: annual operating costs, annual capital costs, total annual costs, and total travel time for the average trip. The impact of each of the four service characteristics (which, in a sense, could themselves be considered to be supply characteristics) on each of these output features will depend on a variety of unit costs and travel time components. Some costs and travel time segments will remain fixed, regardless of any change in a particular service characteristic. This section describes the assumptions and resulting equations from which the parametric curves presented later have been derived. (Total annual cost curves represent a linear combination of operating and capital cost curves and are not discussed further.)

Equations developed to estimate relative impact on operating costs, capital costs, and average travel time, for each of the four service characteristics, are shown in the Appendix (Tables 3, 5, 7, and 9). Accompanying each of these is a separate table (Tables 4, 6, 8, and 10) listing the assumptions on which each equation is based. These assumptions detail many of the results of the case study simulation, particularly in the areas of cost analysis, ridership forecasting, and transit network assignment.

These equations are illustrative only and should not be taken out of context. They suggest only how critical cost and travel time components can be singled out for analysis and how assumptions regarding their variability with various service characteristics must be made. Further studies of these variabilities appear warranted, especially as changes in service characteristics become more extreme. In general, halving and doubling of each service characteristic were taken as the range of interest. All equations and relations are consistently expressed in terms of proportional variations from simulated values (that is, as proportional multipliers of from 0.5 to 2.0). This form of normalization allows the efficiency or effectiveness of service characteristics measured in different units to be compared on a single scale.

The general form of each equation consists of (a) a constant representing those costs or portions of travel time not affected by the service variable at hand, (b) costs or travel time components that vary inversely with the service characteristic, and/or (c) costs or travel time components that vary directly. In some cases, separate technical analyses were conducted to account for additional cost variations that were over and above those resulting from the service characteristics alone. For example, annual capital costs for vehicles (Table 1), as a function of vehicle size, can vary both with the number of vehicles required (inverse relation) and with a per-unit change in cost as vehicle size changes (separate equation needed).

Transport Demand

Parametric analyses of demand can be no stronger than the mode split forecasting procedures utilized for the basic simulation. In the Milwaukee dual-mode case study, mode split was treated very simply, with subjective modifications of diversion curve (travel time ratios between highways and dual-mode transit) outputs made to reflect quality-of-service improvements. It was estimated that roughly 22 percent of daily peak-period travel would be attracted to dual-mode transit. The effects of variation in each of the four service characteristics on demand were estimated primarily through their impact on average trip travel time only. However, these previous adjustments to the diversion curve mode split, intended to reflect improved quality of service (e.g., all seated, arrival time certainty, and few transfers), were still carried forward.

A supplementary curve was derived to show the relation between travel time and ridership changes, adjusting for the comfort-convenience modifying factors. This curve was used to derive ridership impact estimates for each of the four service characteristics, according to their corresponding impact on travel time. It was found that forecasted ridership is relatively stable with regard to changes in average travel time. For example, if travel time were to increase as much as 18 percent, the system would still retain 90 percent of its estimated ridership. If travel time were to decrease 18 percent, ridership would gain only about 7 percent. Subsequent analyses also showed that, under more desirable service characteristics than those simulated, ridership would still vary only about 3 or 4 percent.

Required Fares

Consequently, in the analysis of required fares, depicted as ridership-cost ratios, the operating cost and total cost curves described earlier were utilized. Remember that these cost curves were based on fixed levels of ridership. However, further adjustments in costs due to the modest ridership changes previously mentioned would be relatively minor, and these adjustments were not made. The revenue-cost analyses were thereby simplified somewhat. They amounted to only a matching of ridership changes against associated cost changes for incremental fluctuations in each of the four service characteristics. No new data were introduced; rather, comparable points on the ridership and cost curves were matched and their ratios replotted.

Figure 1. General framework for sensitivity analysis.

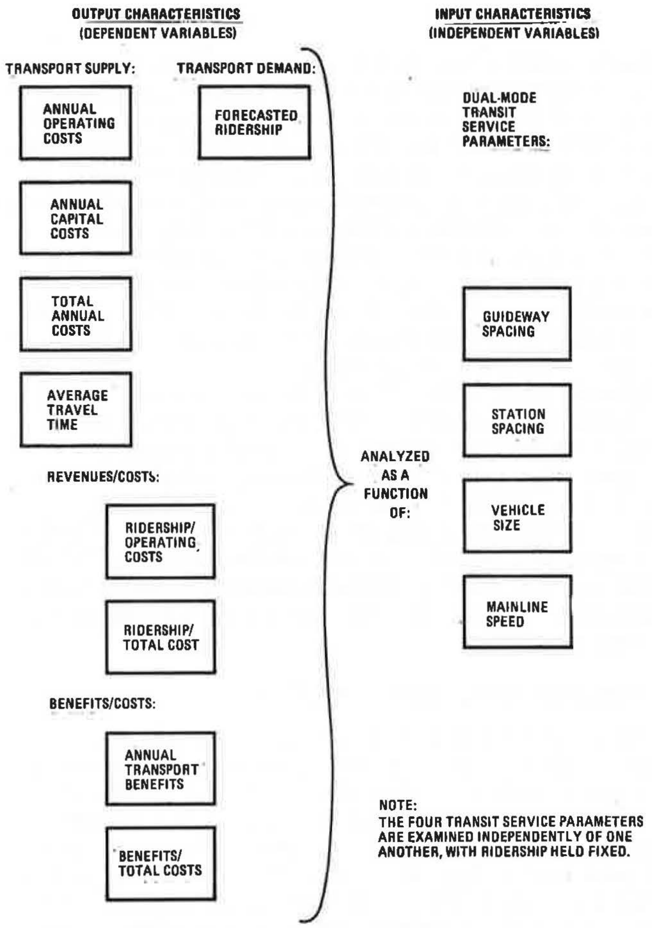

Table 1. Estimated impacts of revised service characteristics.

Characteristic	Reference Case[a]	Alternative Case 1: Vehicle Size, 19 to 38 Passengers	2: Guideway Miles, 110 to 165 Miles	3: Station Spacing, 2.75 to 1.65 Miles	4: Main Line Speed, 55 to 70 mph[b]
Annual costs (thousands of dollars)					
Operating	58,251	39,086	59,590	60,056	56,270
Capital	46,040	43,047	55,754	49,171	41,160
Total	104,291	82,133	115,344	109,227	97,430
Annual ridership (thousands)	97,000	90,300	100,200	98,900	100,200
Required fares (cents)					
Operating costs	60.0	43.3	59.5	60.7	56.2
Capital costs	47.5	47.7	55.6	49.7	41.0
Total costs	107.5	91.0	115.1	110.4	97.2
Annual transport benefits (thousands of dollars)	150,773	90,467	174,334	170,675	182,909
Benefit-cost ratio[c]	1.08	0.83	1.16	1.18	1.38

Note: These are illustrative and preliminary results only and should not be applied in other contexts without considerable further study.

[a]Full-scale dual-mode transit system as originally simulated in Milwaukee County.

[b]Highest average trip speed attainable would be desirable—70 mph used for illustrative purposes.

[c]Additional accident costs and travel time losses (for choice riders) were included in calculating the benefit-cost ratio.

Transport Benefits

The impacts of service characteristic changes on total transport benefits were also included in the parametric analysis. A limited benefit-cost analysis was conducted for the case study, where it was acknowledged that the seven benefits analyzed should not be construed as the full range of impacts that might be attributed to a dual-mode guideway network. Rather, they represent only those consequences that impact directly on users of the guideway system or indirectly on those persons continuing to use the street and freeway network. The seven benefit (or disbenefit) categories covered included transit travel time savings (for captive trips), transit travel time losses (for choice trips), accident costs avoided, transit accident costs incurred, private-vehicle operating costs avoided, CBD parking costs avoided, and highway travel time savings. Changes in total transport benefits were recalculated for a sampling of travel time and resultant ridership changes for each of the four service characteristics.

This entailed an interpolation, from previous calculation of benefits for all levels of dual-mode ridership, of the following transport benefits: highway travel time savings, accident costs avoided, private-vehicle operating costs avoided, CBD parking costs avoided, and transit accident costs incurred. For the two remaining categories of transport benefits, it was necessary to recalculate transit travel time savings and transit travel time losses according to the accompanying travel time changes. Finally, travel time losses for choice riders were also adjusted to account for the ridership increment or decrement that was involved. The results of these recalculations of transport benefits were then plotted graphically, and benefit-cost curves were replotted in the same manner as were revenue-cost curves.

ANALYSIS OF COMPARATIVE SENSITIVITIES

The basic results of the case study sensitivity analyses are shown in Figures 2 through 10 and are discussed briefly in this section. As noted earlier, the general approach used in analyzing these relations has been to match a proportional change in each of the four input service characteristics against a corresponding proportional change in each of the nine output characteristics previously defined. That is, a proportional change in each service characteristic may range from 0.5 to 0 to 2.0, with 0 representing no change, 2.0 representing a 100 percent increase (or a doubling), and 0.5 representing a reduction to 50 percent of the simulated value (or a halving). Similarly, corresponding changes in output characteristics are shown on a comparable scale.

Proper interpretation of these data is given in an example that refers to Figure 2. Figure 2 shows the sensitivity of annual operating costs to variations in service characteristics. It can be seen from the figure that vehicle size has the greatest effect on annual operating costs. (Vehicle size largely determines the vehicle fleet size as well as the driver force, the two largest single operating cost items.) Let us assume that we wish to examine the effect of increasing vehicle size by 50 percent on system operating cost. Referring to Figure 2, a value of 1.5 on the abscissa (vehicle size of 19 + 9.5 = 28.5, or 29) leads to a resultant value on the ordinate scale of 0.78. Thus, an increase in vehicle size of 50 percent results in a 22 percent reduction in total annual operating costs or in this instance a reduction from $58 million to approximately $45 million.

Table 2 gives the highlights of the relations depicted in Figures 2 through 10. It identifies the service characteristics that are most sensitive, as well as those that are least sensitive, in influencing the various system output characteristics. The table is based on an examination of the relative slopes at the design point (1.0, 1.0) of the various curves shown in Figures 2 through 10.

Table 2 shows, for example, that total annual costs are most sensitive to changes in vehicle size (as indicated by the absolute value of each slope). Ridership levels, on the other hand, are most sensitive to changes in main line speed and least sensitive to changes in station spacing. Expected revenues (or ridership-total annual cost ratio) are most sensitive to main line speed, meaning that increasing vehicle guideway speed represents the most profitable way to reduce required fares (although it is least sensitive to station spacing), which indicates that decreasing or increasing station spacing will have relatively little effect on required fares. Column as well as row comparisons

Figure 2. Operating cost sensitivities.

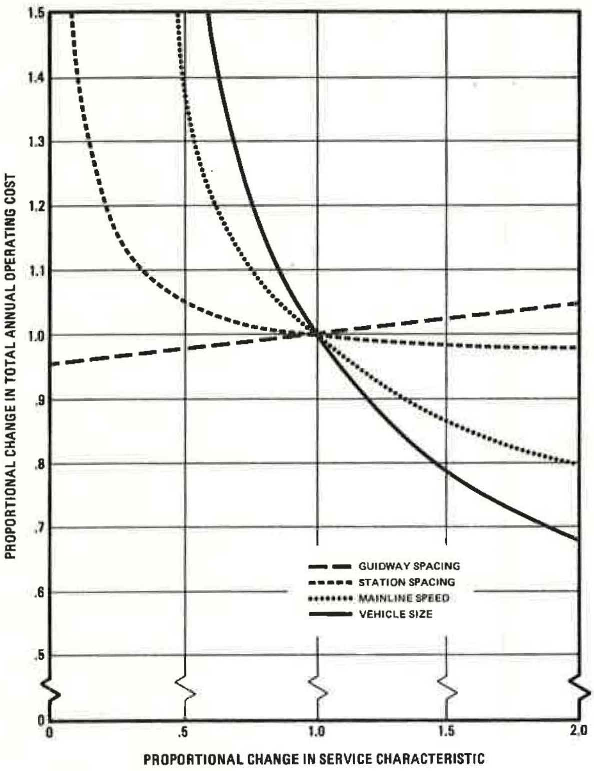

Figure 3. Capital cost sensitivities.

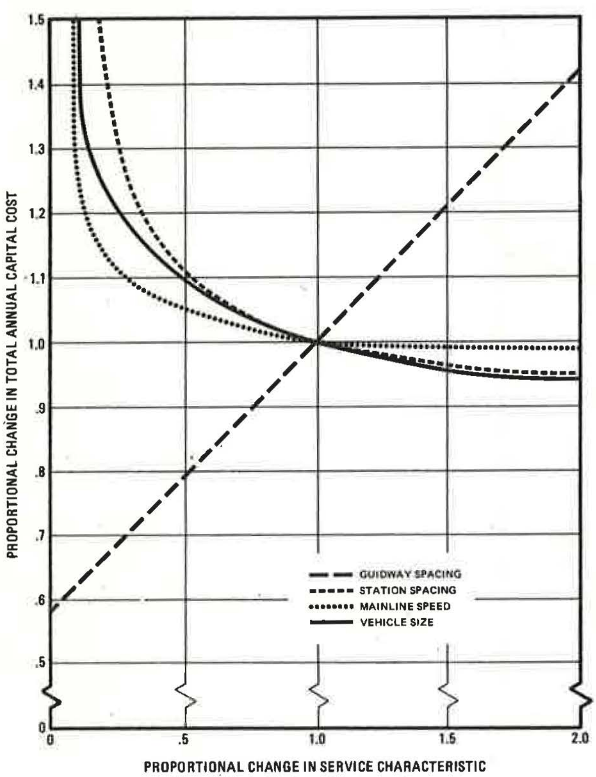

Figure 4. Total cost sensitivities.

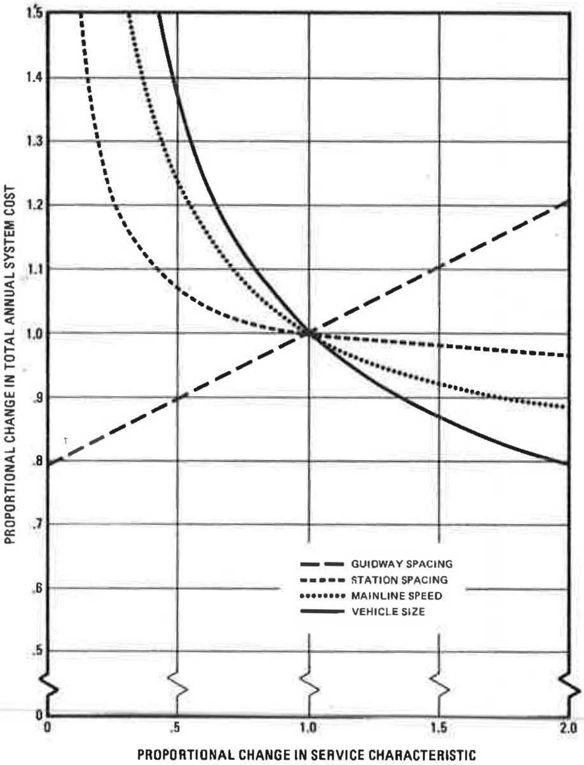

Figure 5. Travel time sensitivities.

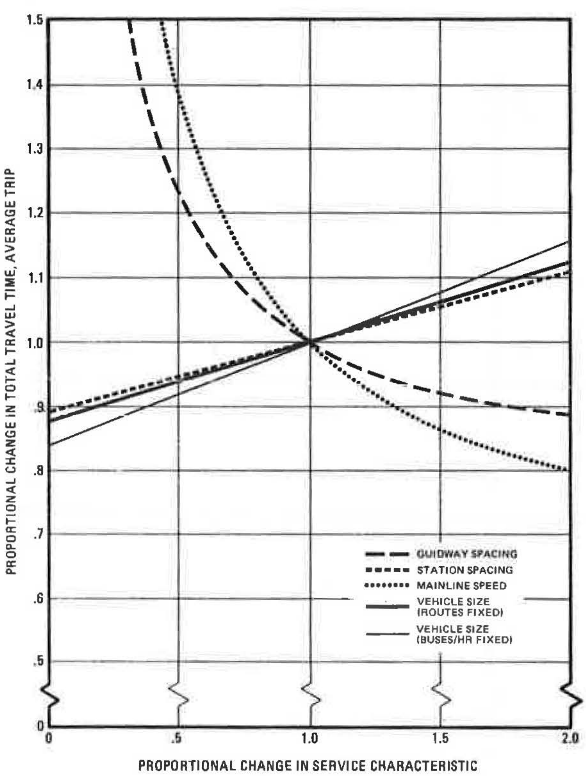

Figure 6. Ridership sensitivities.

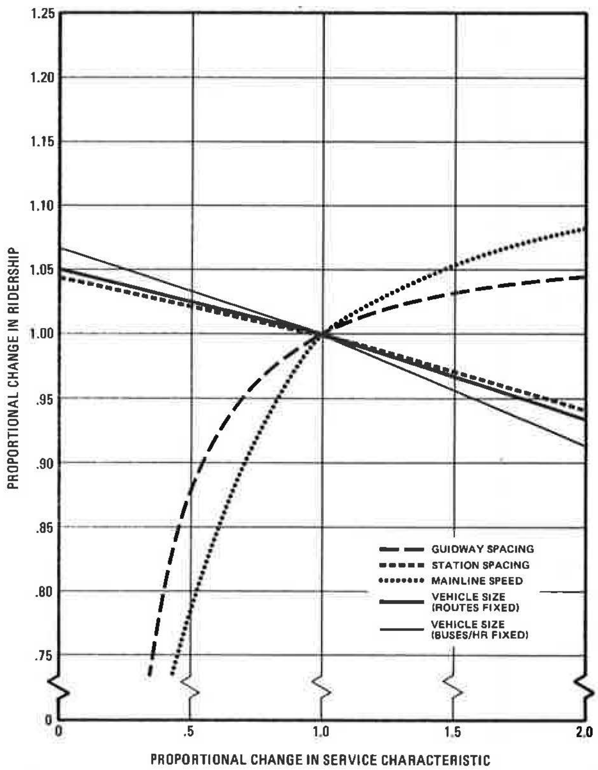

Figure 7. Operating fare sensitivities.

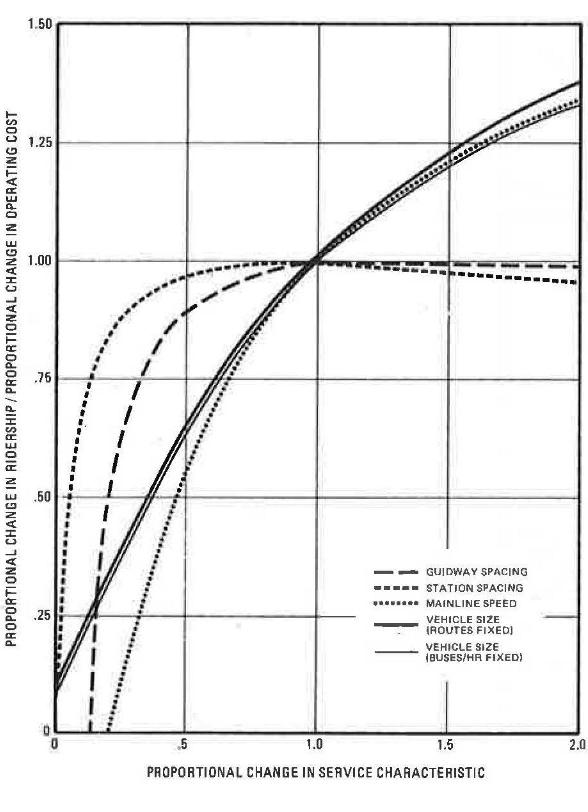

Figure 8. Overall fare sensitivities.

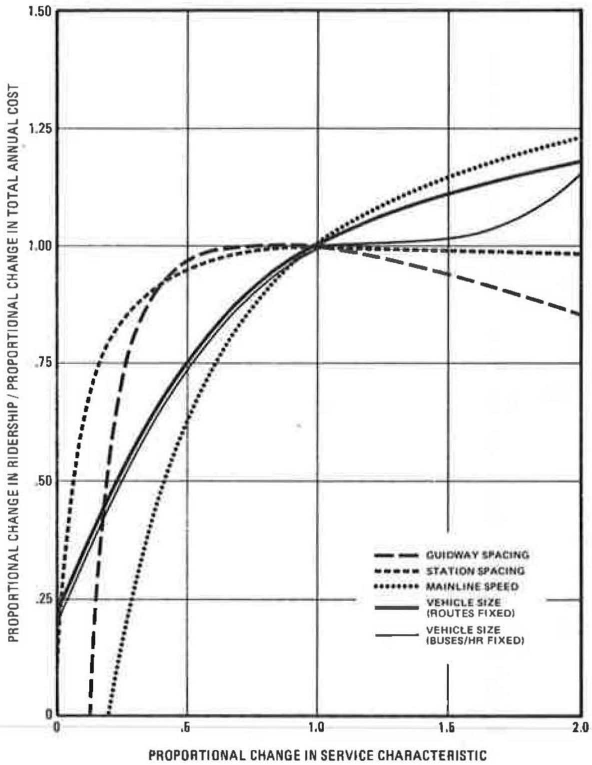

Figure 9. Transport benefit sensitivities.

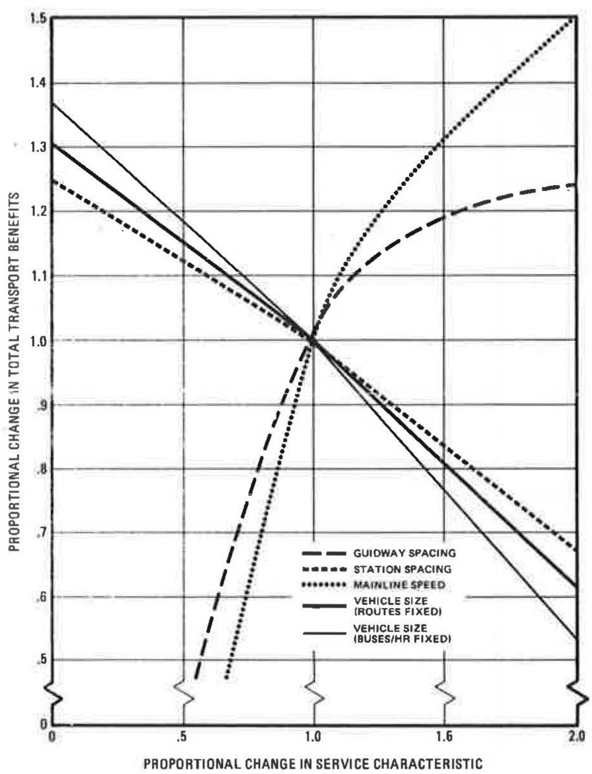

Figure 10. Benefit-cost sensitivities.

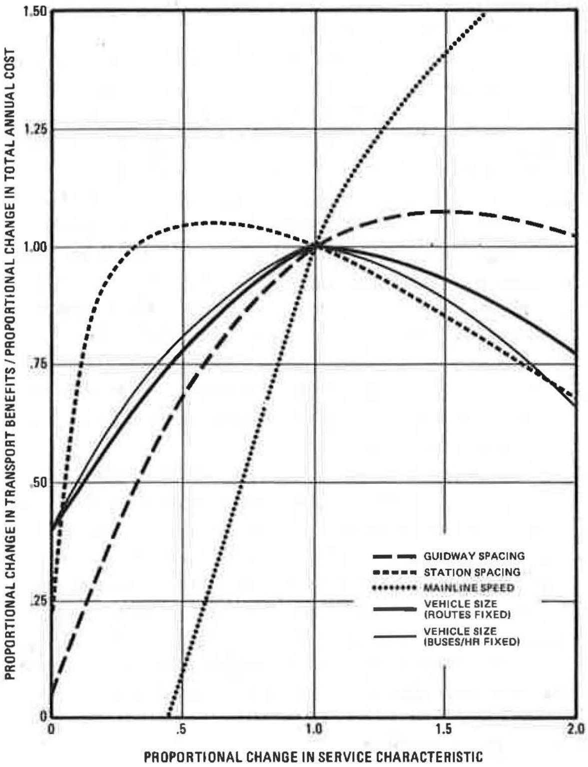

Table 2. Summary of relative sensitivities.

	Relative Sensitivity[a]			
System Output Variable	Speed	Vehicle Size	Miles of Guideway	Station Spacing
Annual costs				
Operating	-0.31	-0.59*	0.05	-0.05
Capital	-0.02	-0.09	0.42*	-0.10
Total	-0.18	-0.37*	0.21	-0.07
Performance				
Average travel time	-0.40*	0.16	-0.23	0.11
Ridership	0.16*	-0.06	0.09	-0.04
Revenues				
Ridership/operating cost	0.47	0.53*	0.05	0
Ridership/total cost	0.34*	0.31	-0.12	-0.03
Benefits				
Annual transport benefits	0.94*	-0.35	0.57	-0.29
Benefits/total cost	1.12*	0	0.36	-0.36

[a]These figures are the slopes at the design point of the curves shown in Figures 1 through 9. The most sensitive service variables have been asterisked.

also provide useful information. For example, by scanning the last column in Table 2, it is readily seen that, by a wide margin, the most sensitive output characteristics to station spacing changes are the benefit-cost ratio and transport benefits.

Perhaps most important, the data given in Table 2 also suggest that annual transport benefits and the transport benefit-total cost ratio for the system studied are themselves most sensitive to changes in main line speed. This means that the single most important service characteristic meriting further examination is guideway speed capability. Any incremental gains in average speed appear to be especially fruitful in relation to the other service characteristics. This conclusion, of course, pertains specifically to the demand-supply context for dual-mode transit simulated within the Milwaukee region.

Sensitivity analyses of the number of guideways, measured in terms of miles of route covering the same service area, show that this service characteristic has most influence on annual capital costs but least influence on annual operating costs. Its impact on total annual costs is thereby moderate. Because it can achieve relatively high benefits at only moderate incremental cost, the number of guideways (or guideway spacing) is also a significant factor to be considered in improving dual-mode transit service characteristics. Relative to the case study, the benefit-cost analysis shows that the number of guideways in the study area should be increased (Fig. 10).

Vehicle size is of greatest importance in affecting annual operating costs and total annual costs. It has a moderate influence on average travel time and expected level of ridership. Because it is relatively costly in relation to only modest incremental changes in transport benefits, vehicle size is of least importance in its influence on the overall benefit-cost ratio. It should be carefully determined in terms of expected demand characteristics. Sensitivity analysis of benefit-cost ratios indicates that an optimum vehicle size for the case study area is the 19-passenger vehicle that was simulated. If for other reasons this vehicle size were to be increased, it would be preferable to do so by also increasing headways, while holding the number and pattern of routes fixed.

PRELIMINARY CONCLUSIONS

It should be stressed that the primary purpose of this paper is not to form firm conclusions regarding dual-mode transit but rather to suggest how a method of parametric analysis might be carried forward. Emphasis should be placed on the method itself, not on the clearly preliminary case study results. Given this qualification, it is felt that the sensitivity analysis techniques discussed here, particularly in the graphical form shown in Figures 2 through 10, do warrant further development and exploration.

Perhaps the most important potential use of these techniques is in better defining optimum service conditions. To further illustrate this potential, the preliminary and illustrative results of the Milwaukee case study are further analyzed. These results also suggest some very tentative conclusions regarding dual-mode transit—the kinds of conclusions toward which new systems implementation efforts should be oriented.

The implications of the data shown in Figure 10 are especially significant here. They illustrate rather clearly the nonoptimization, relative to a maximum benefit-cost ratio, of the system parameters chosen for the dual-mode simulation. These curves suggested that the 19-passenger vehicle used in the case study is approximately the appropriate size. This is the only one of the four service characteristics, however, that achieves a maximum relative to the benefit-cost ratio.

Figure 10 shows that main line speed should be increased as much as possible to optimize the benefit-cost ratio; at the same time local optima for the two remaining characteristics, station spacing and guideway spacing, are also indicated. It must be remembered that these are independently derived optima; therefore, if two or more were to be pursued together, the location of these optimum points would change. It is stressed again that these independent optima are based on selected transport-related benefits only. Conceivably, other community impacts or indirect benefits may be of sufficient value to the community such that they may become more meaningful in determining appropriate system characteristics.

If emphasis is placed on the maximization of the benefit-cost ratio, determined on the basis of direct and indirect transport benefits, the data given in Figure 10 suggest the following changes in service characteristics:

1. Guideway miles—110 to 165 miles,
2. Station spacing—2.75 to 1.65 miles,
3. Main line speed—55 to 70 mph (or greater), and
4. Vehicle size—unchanged.

By factoring each of these suggested service characteristic changes independently into the equations that were used to support the sensitivity analysis, estimates of each of the resulting system output variables can be determined. These data, representing four alternative cases, where one of the characteristics is modified in each case (and subsequently restored in the next case), are given in Table 1. For comparison purposes, a 100 percent increase in vehicle size has also been entered. These data offer another example of how sensitivity analyses can be used to illuminate the importance of different transit service characteristics.

It should be noted that, depending on the service improvement selected, operating costs can be reduced by as much as 33 percent, total costs reduced by 21 percent, fares decreased by 28 percent, benefits increased by 21 percent, and benefit-cost ratio increased by approximately 30 percent. Interestingly, benefit-cost analysis for two service characteristics, guideway spacing and station spacing, suggests an increased investment in guideway facilities—but at a correspondingly increased fare requirement. This represents an aspect of economic feasibility that may argue against the potentially higher benefits to be achieved. In fact, the data shown in Figure 8 suggest that a more desirable revenue-cost ratio for guideway spacing may lie with a decrease in guideway miles to about 80 to 90 percent of simulated values—roughly, seven guideway corridors instead of eight, covering the same transit service region.

It was not suggested in the Milwaukee study that any of these alternative cases represents an acceptable system solution but rather that there are many trade-offs possible, such that a single best solution could not be fully explored within the scope of the case study. On the contrary, the Milwaukee County rapid transit plan system, with which the dual-mode system was repeatedly compared, represents the best of many conventional bus technology trade-offs already examined in that study. It represented the results of a much more intensive, 3-year planning effort. Comparable continuing effort would be required here to identify more preferred and yet locally realistic service configurations.

As a result, the great diversity in potential service configurations for dual-mode transit was emphasized. The sensitivity analyses previously described demonstrated that diversity quite clearly. Although a number of revised service characteristics (guideway spacing, station spacing, etc.) were examined, they are applicable to the Milwaukee area only. Even in this single case study, it was emphasized that further trade-off analyses will be necessary to identify preferred combinations of service features. In other urban areas, particularly those having different residential density patterns, additional studies and trade-off analyses of these same service characteristics will be required (11).

In other cities, both higher and lower service levels may well be indicated. For example, smaller cities, having lower residential densities and a smaller service area, might find a larger vehicle to be preferable. It was stressed that the quality of service simulated in the Milwaukee case study is not necessarily an inherent attribute of dual-mode transit. All of the four service characteristics could be varied to suit local conditions (as could other system features such as the proportion of captive vehicles). The operational flexibility of the dual-mode concept, as demonstrated by these sensitivity analyses, is consequently one of its greatest assets. The dual-mode transit approach closes few urban transportation options and opens up a host of new operating strategies that are not now options in conventional bus systems.

ACKNOWLEDGMENTS

This paper is based on research performed for the U. S. Urban Mass Transportation Administration (4). The advice and assistance of Paul S. Gurski, Joseph T. Warnemuende, and Ronald J. Fisher are gratefully acknowledged.

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APPENDIX

CASE STUDY EQUATIONS AND ASSUMPTIONS

The following tables are based on hypothetical data derived from a full-scale dual-mode simulation system (4, 9, 10). Cost and travel time data are based on simulation model outputs and preliminary unit operating and capital cost analyses.

Table 3. Main line speed analyses.

Independent Variable, x_1 = Proportion of Base Line Value, Main Line Speed (mph)

Dependent Variable	Estimating Equation	Comments
y_1 = Proportion of base line value, annual operating cost	$y_1 = .630 + .353/x_1 + .017(2.67x_1 - 1.671)$	x_1 increase
	.630: Proportion of operating costs unaffected by main line speed (63.0%); $.353/x_1$: Vehicle-based operating costs (35.3%); $.017(\ldots)$: Power consumption costs (1.7%). Sub-equation derived from technical studies	
	$y_1 = .630 + .353/x_1 + .017(1.69x_1 - .692)$	x_1 decrease
y_2 = Proportion of base line value, annual capital cost	$y_2 = .848 + .0949/(.735 + .265x_1) + .0096/x_1 + .047(.735 + .265x_1)$	x_1 increase
	.848: Proportion of capital costs unaffected by main line speed (84.8%); $.0949/(\ldots)$: Vehicle capital costs affected by speed capabilities (9.49%). Sub-equation derived from technical studies; $.0096/x_1$: Supporting facilities capital costs (.96%); $.047(\ldots)$: Power substation capital costs (4.7%)/. Sub-equation derived from technical studies	
	$y_2 = .848 + .0949/(.652 + .348x_1) + .0096/x_1 + .047(.652 + .348x_1)$	x_1 decrease
y_3 = Proportion of base line value, average travel time	$y_3 = .598 + .402/x_1$	
	.598: Non-guideway travel time (Neighborhood collection, walk, wait, ramps, enroute stops) (59.8%); $.402/x_1$: Guideway travel time, at main line speeds (40.2%)	

Table 4. Main line speed assumptions.

Operating Costs--	As main line speed is increased, it becomes possible to reduce the total number of vehicles required. 87.8% of total annual operating costs depend on the number of vehicles in the fleet (all vehicle-based operating costs, excluding guideway operation and maintenance). 40.2% of the travel time for the average transit vehicle is spent at main line speed. Consequently, 35.3% (40.2 x 87.8) of annual vehicle-based operating costs may be assumed to be variable with changes in main line speed. This is an inverse relationship. In addition, minor changes in power consumption costs will also occur.
Capital Costs--	Most annual capital costs--84.8%--will be unaffected by changes in main line speed. The same investments in right-of-way, guideway construction, guidance hardware, and stations will still be required. Adjustments in capital costs for vehicles and supporting garage facilities to reflect changes in fleet size (due to changes in main line speed) must be made. 40.2% of the average vehicle trip spent at main line speeds is used as a multiplier. 23.5% of total annual capital costs are required for vehicle purchase, but only 40.2% of these costs will be inversely variable with main line speed (40.2 x 23.5 = 9.49%). Separate technical studies also showed that per unit vehicle costs would increase slightly with greater speed capabilities (and vice versa), so that separate sub-equations were also estimated for inclusion in the inverse vehicle cost/speed relationships. Similar calculations for supporting facilities capital costs were also made (40.2 x 2.4 = .96%). Separate technical equations were also estimated to reflect changes in power substation capital costs (4.7% of total) due to greater guideway speed capabilities.
Average Travel Time--	59.8% of the average person trip will be spent off the guideway. The remaining 40.2% of overall average travel time will vary inversely with changes in main line guideway speed.

Table 5. Vehicle size analyses.

Independent Variable, x_2 = Proportion of Base Line Value, Number of Seats per Vehicle

Dependent Variable	Estimating Equation	Comments
y_1 = Proportion of base line value, annual operating cost	$y_1 = .105 + .475/x_2 + .403/(.71+.29x_2) + .017(.825+.175x_2)$	x_2 increase
	.105: Proportion of operating costs unaffected by vehicle size (10.5%); $.475/x_2$: Operator wages, superintendence and misc. vehicle-based costs (47.5%); $.403/(\ldots)$: Vehicle maintenance, fuel, and oil costs (40.3%). Sub-equation based on technical studies; $.017(\ldots)$: Power consumption costs (1.7%). Sub-equation based on technical studies	
	$y_1 = .105 + .475/x_2 + .403/(.54+.46x_2) + .017(.50+.50x_2)$	x_2 decrease
y_2 = Proportion of base line value, annual capital cost	$y_2 = .740 + .236/(.71+.29x_2) + .024/x_2$	x_2 increase
	.740: Proportion of capital costs unaffected by vehicle size (74.0%); $.236/(\ldots)$: Vehicle capital costs (23.6%). Sub-equation based on technical studies; $.024/x_2$: Supporting facilities capital costs (2.4%)	
	$y_2 = .740 + .236/(.54+.46x_2) + .024/x_2$	x_2 decrease
y_3 = Proportion of base line value, average travel time	$y_3 = .878 + .051x_2 + .071x_2$	Number of routes held fixed
	.878: Proportion of average travel time unaffected by vehicle size; $.051x_2$: Travel time spent at en route stops (5.1%); $.071x_2$: Average wait time (7.1%)	
	$y_3 = .842 + .051x_2 + .107x_2$	Number of buses/hour held fixed
	$.107x_2$: Average walk time (10.7%)	

Table 6. Vehicle size assumptions.

Operating Costs--	10.5% of total annual operating costs, those due to guideway operation and maintenance, will remain fixed. 47.5% of operating costs will vary inversely with the total number of buses (fleet size). These will include driver wages, driver superintendence, operating garage wages, insurance, and other miscellaneous operating costs. 40.3% of operating costs will vary inversely with vehicle size, including depreciation, maintenance, parts, tires and tubes, fuel and oil. The relationship of these costs to vehicle size is assumed to be the same as that for vehicle capital costs.
Capital Costs--	26% of annual capital costs will vary inversely with vehicle size, reflecting vehicle purchase, and construction of supporting facilities (operating garages, maintenance garages). Separate studies of the relationship of vehicle capital costs and vehicle size were conducted. The remaining 74% of capital costs will remain fixed, covering right-of-way purchase, guideway construction, guidance hardware, stations, and power distribution.
Average Travel Time--	When vehicle size is altered, either the number of buses per hour (headways) or the number of routes within a given neighborhood must be correspondingly adjusted to meet the assumed fixed demand. If the number of routes per neighborhood is altered, the walk time will be changed. If headways are varied instead, then the corresponding wait time will be altered. Vehicle size will also affect the dwell time spent at enroute stops along the line-haul portion of the average trip. All three of these time components were assumed to vary directly with vehicle size.

Table 7. Guideway spacing analyses.

Independent Variable, x_3 = Proportion of Base Line Value, Total Guideway Mileage

Dependent Variable	Estimating Equation		
y_1 = Proportion of base line value, annual operating cost	$y_1 = .954$	+	$.046x_3$
	Proportion of operating costs unaffected by guideway spacing (95.4%)		Guideway-based operating costs (excluding CBD) (4.6%)
y_2 = Proportion of base line value, annual capital cost	$y_2 = .578$	+	$.422x_3$
	Proportion of capital costs unaffected by guideway spacing (57.8%)		Guideway-based capital costs (excluding CBD) (42.2%)
y_3 = Proportion of base line value, average travel time	$y_3 = .771$	+	$.229/x_3$
	Walk, wait, and guideway travel time (77.1%).		Neighborhood collection/distribution travel time (22.9%)

Table 8. Guideway spacing assumptions.

Operating Costs--	Operating costs dependent upon total miles of guideway amount to only 4.6% of total annual operating costs. They do not include any costs relating to the total number of vehicles or vehicle miles, which are assumed to remain constant, and therefore include only guideway operation and maintenance cost items. Operation and maintenance cost for CBD guidway links and stations have, however, been excluded, since these facilities are assumed to remain fixed as well. Similarly, costs for power consumption and control complex maintenance have also been assumed to remain fixed.
Capital Costs--	Any increase in guidway mileage, for a fixed service area, was assumed to imply the construction of an additional segment in an additional service corridor, or a closer network spacing. A much higher percentage of total annual capital costs is related to the total miles of guideway in the system. 42.2% of total annual costs will vary directly with the number of miles of guideway. In fact, these will include all capital cost expenditure items except those for vehicles, supporting facilities, CBD tunnel, and CBD stations.
Average Travel Time--	Change in the number of guideways is assumed to have impact only upon the amount of travel time spent in neighborhood collection and/or distribution. That is, if the pattern of neighborhood routings is assumed to remain the same, as well as headways, there will be no effect upon walk or wait times, nor will there be any change in ramp or line-haul travel times. The assumed relationship is a reciprocal one. That is, if the number of guideways are doubled, the average collection time will be halved, since it will now be much easier to reach the nearest guideway from any neighborhood collection point. Nine minutes or 22.9% of the average dual-mode trip was spent in neighborhood collection.

Table 9. Station spacing analyses.

Independent Variable, x_4 = Proportion of Base Line Value, Average Mileage Between Stations

Dependent Variable	Estimating Equation		
y_1 = Proportion of base line value, annual operating cost	$y_1 = .954 + .046/x_4$		
	.954: Proportion of operating costs unaffected by station spacing (95.4%).	.046/x_4: Station-based operating costs (excluding CBD) (4.6%)	
y_2 = Proportion of base line value, annual capital cost	$y_2 = .898 + .102/x_4$		
	.898: Proportion of capital costs unaffected by station spacing (89.8%)	.102/x_4: Station-based capital costs (excluding CBD) (10.2%)	
y_3 = Proportion of base line value, average travel time	$y_3 = .369 + .229x_4 + .402(1.30-.30x_4)$		
	.369: Walk, wait, and ramp portions of average travel time (36.9%)	.229x_4: Neighborhood collection/ distribution travel time (22.9%)	.402(1.30-.30x_4): Main line guideway travel time (40.2%). Sub-equation separately derived

Table 10. Station spacing assumptions.

Operating Costs--	Annual operating costs dependent upon the number of stations in the system (excluding CBD stations, which are assumed to remain fixed) included the costs for station personnel, control complex maintenance, and 75.9% of control hardware maintenance costs (the latter reflecting the fact that most of the system control hardware will be located within station areas, where most of the merge, acceleration and deceleration activities will take place). Only 4.6% of total annual operating costs are represented in this variable relationship.
Capital Costs--	The annual capital costs for the 40 stations within the hypothetical guideway network (again excluding CBD stations) represented some 10.2% of total annual capital costs. These covered the costs for right-of-way, station facility, automation hardware, power hardware, and ramps within each station area. Changes in both operating and capital costs hold a reciprocal relationship with any change in the number of miles between stations. That is, as this mileage is doubled, related systems costs would halve, and vice versa.
Average Travel Time--	It was assumed that any change in station spacing would have no effect upon walk, wait or ramp times for the average dual-mode trip. However, in addition to a likely change in the neighborhood collection/distribution travel time, station spacing will also affect the amount of time spent in the line-haul portion of the average trip. That is, a trade-off between neighborhood and line-haul time will occur, for a given guideway configuration. As more stations appear in the system, less time for neighborhood collection will be required, due to more direct routings, correspondingly increasing the trip time spent on the guideway itself. A direct relationship with changes in both neighborhood collection/distribution time and main line guideway travel was assumed.

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