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REFERENCES

1. T. J. Atherton, J. H. Suhrbier, and W. A. Jessiman. Use of Disaggregate Travel Demand Models to Analyze Car-Pooling Policy Incentives. TRB, Transportation Research Record 599, 1976, pp. 35-40.
2. Sensitivity Analysis of Selected Transportation Control Measures: Potential Reductions in Regional Vehicle Miles of Travel. Barton-Aschman Associates and Metropolitan Transportation Commission, Berkeley, CA, July-Aug. 1977.
3. M. Ben-Akiva and T. J. Atherton. Methodology for Short-Range Travel Demand Predictions: Analysis of Car Pooling Incentives. Journal of Transport Economics and Policy, Jan. 1977.
4. J. M. Bruggerman, R. B. Rubin, and F. Griffiths. Findings of a Study to Estimate the Effectiveness of Proposed Car-Pool-Incentive Policies. TRB, Transportation Research Record 650, 1977, pp. 36-42.
5. MTCFCAST Travel Demand Forecasting System. Comsis Corporation, Cambridge Systematics, and Barton-Aschman Associates; Metropolitan Transportation Commission, Berkeley, CA, Aug. 1977.
6. T. A. Domencich, G. Kraft, and J. P. Valette. Estimation of Urban Passenger Travel Behavior: An Economic Demand Model. HRB, Highway Research Record 238, 1968, pp. 64-78.
7. G. K. Ingram. Reductions in Automobile Use in Four Major Cities as a Result of Car Pooling and Improved Transit. TRB, Transportation Research Record 650, 1977, pp. 59-65.
8. J. B. Margolin, M. R. Misch, and R. D. Dobson. Incentives and Disincentives to Ride-Sharing Behavior: A Progress Report. TRB, Transportation Research Record 592, 1976, pp. 41-44.
9. W. T. Mikolowsky, W. L. Stanley, and B. F. Goeller. Effectiveness of Near-Term Tactics in Reducing Vehicle Miles (Kilometers) of Travel: Case Study of Los Angeles Region. TRB, Transportation Research Record 574, 1976, pp. 1-14.

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Evaluation of Road and Transit System Requirements for Alternative Urban Forms

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Research was performed for the purpose of evaluating the road and transit system requirements of a range of cities that have different density and spatial patterns and thereby assessing the effects of varying urban forms on transportation investment and service measures. The assessment is conducted in the context of a proposed policy evaluation framework that uses the end-state transportation and land-use plan for policy guidance and the time stream of benefits and costs as the object of evaluation. For the analysis of the transportation implications of a number of urban forms, a two-mode network generation model is developed and applied to six hypothetical city types of 2 million population. The comparison of the transportation requirements for these urban forms indicates a range of transit use among the city types of from 8 to 34 percent and wide differences in the need for high-capacity service routes. In terms of person hours of travel and mean trip length, the multicentered city in particular and the centrally oriented cities in general have the lowest requirements. These conclusions have important implications for the use of horizon-year transportation and land-use plans within the proposed framework of dynamic evaluation.

The current emphasis in urban planning on a more comprehensive and open process and an orientation to strategic choices among a wider range of alternative policies has placed new demands on the transportation planner. In spite of the ability of the transportation planner to simulate travel demands on a complex multimodal network, there is a notable lack of success in responding to currently relevant planning issues and alternatives. In general, existing transportation planning models are expensive and cumbersome to use and difficult to interpret, and their attention to the detail of system performance is too restrictive in scope (1, 2).

Perhaps the best way to exemplify the deficiencies of current transportation modeling is to define a comprehensive three-level hierarchical structure of the planning process against which present achievements can be compared (3, 4). The three components of the structure are defined as follows:

1. Policy planning—Policy planning is a political exercise concerned with the broad issues of urban development and the authority and constraints relating to the resolution of these issues within a public forum. This process provides the contextual setting within within which transportation system alternatives may then be assessed.
2. Systems planning—For transportation planners, this process is concerned with the analysis and evaluation of multimodal networks that consist of major transportation facilities and associated terminals from the point of view of location, operation, and regulation.
3. Project planning and programming—The third level of the structure involves those activities required to design and implement a particular component or link of the system plan and includes engineering design, right-of-way acquisition, and capital programming and budgeting.

The recent primary efforts of the transportation researcher have been to refine the planning model programs and packages available at the second level, presumably to improve the reliability of the model output for subsequent use in design at the third level. As a consequence, the linkage between the second and third level is very satisfactory, but the linkage upward to the highest level is almost totally neglected. Transportation system models are unresponsive to policy issues that relate to alternatives for land-use development, environmental and socioeconomic impacts, energy consumption, and effects of income distribution. This results in a relation between policy and systems planning that tends to be so ad hoc that systems planning often completely fails to reflect political and public views.

In summary, there is a need for analytical procedures or models at the policy planning level that can both provide a set of appropriate constraints for input to the systems planning process and in return accept corresponding system performance measures. Such a policy model would have to be easy to use and interpret, have the ability to accept a comprehensive set of development alternatives, and be capable of estimating a broad set of interrelated measures and indicators.

It is the purpose of this paper to describe a proposed framework for policy planning and to present a series of analyses that represent an important initial component of this framework. The paper also briefly defines the proposed framework in abstract terms and then describes a numerical experiment to assess the effects of varying urban forms on transportation investment and service requirements. Finally, the relevance of the experiment to the policy framework is discussed.

PROPOSED FRAMEWORK

One of the essential differences between the policy planning and systems planning levels of the hierarchical structure already defined is the relevant time dimension. Although the transportation planner is concerned with a 20- to 25-year planning horizon, political decision makers at the policy level are primarily interested in short-term issues. The task of the urban transportation planner, then, might be defined as that of providing technical advice on short-range problems in such a way that consistency is maintained with regard to long-range intentions. Somehow the planner must understand the relation between immediate choices and evolving end-state alternatives. This relation then becomes a central element in establishing an appropriate linkage between policy and systems planning and a central element of the policy framework to be proposed.

A second characteristic that influences the proposed framework has to do with the approach the transportation planner follows in determining the most appropriate end-state plan. Typically, a static comparison is made of a series of horizon-year plans, and a "best" plan is chosen on the basis of the accommodation of future travel demand at an acceptable level of service. This is a rather limited perspective, however, since the interrelationship between transportation service and land use (an important policy issue) is a very dynamic one. Whether particular route links are built early or late in the planning period has much to do with the location and rate of urban growth, and whether the improvement of the road network is emphasized before or after the transit system is completed influences both travel demand and automobile ownership levels as well as location of residence and employment.

The implications for both policy and systems planning, then, lie in the requirement for a process that makes the time stream of benefits and costs rather than the end-state condition achieved the object of evaluation (5, 6, 7). The end-state transportation plan may serve as a general policy guide, but it is evaluated only in the light of the sequence of actions that it takes to achieve that state (if, in fact, the state is achievable or feasible).

Interestingly enough, this need for a dynamic evaluation structure parallels and satisfies the first requirement for a linkage between short-range decisions and long-range alternatives (1). To define this proposed structure or framework, let us assume initially that a statement of objectives is available so that the basis for the policy evaluation structure is given. These objectives may be translated into a list of measures of effectiveness that may be defined as x_i, where i is an index $i = 1, 2, \ldots, r$. Since the time stream of these r measures is of central interest, a vector X^t must be defined at any time t:

$$x^t = (x_i^t) \quad i = 1,2,\ldots,r \tag{1}$$

and a matrix X must be defined for the full planning period:

$$X = (x_i^t) \quad i = 1,2,\ldots,r \text{ and } t = 1,2,\ldots,T$$

$$= \begin{bmatrix} x_1^1 & x_1^2 & \cdots & x_1^T \\ x_2^1 & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ x_r^1 & \cdots & \cdots & x_r^T \end{bmatrix} \tag{2}$$

In essence, this matrix becomes the focus for the dynamic policy evaluation process. It is perhaps of some value at this point to compare this evaluation base with that typically used by transportation planners. Existing systems procedures that relate to both modeling and evaluation are concerned with the end-state condition:

$$X^T = \begin{bmatrix} x_1^T \\ x_2^T \\ \vdots \\ x_r^T \end{bmatrix} \tag{3}$$

and the comparison of the estimated measures of performance for a number of these conditions: $X^{T'}$, $X^{T''}$, $X^{T'''}$, and so on. These alternatives might represent a road-oriented network, a rail transit-oriented network, and a surface transit-oriented network, and the measures of effectiveness (x_i^T) might be average travel time by mode and socioeconomic group, average travel cost, and volume-capacity ratios by link. These measures are estimated as a function of socioeconomic variables, travel behavior parameters, and transportation system characteristics at time T, in accordance with the calibration of an identical function at the existing point in time.

The proposal for a policy evaluation process, on the other hand, requires that the full X matrix be estimated and evaluated. Since the number of measures of effectiveness may be expected to be greater, reflecting the increased scope of policy issues, the requirements for modeling will be both different and more demanding than those described for systems planning. Not only is it necessary to relate the performance and impact measures to socioeconomic factors, travel behavior, and transportation system variables but also the relations between the dependent measures, or x_i's (such as transportation service and land-use change) become very important. Thus, consideration of the requirements of the policy planning level in the hierarchical structure proposed above results in more than a simple extension of the techniques currently available at the systems planning level. Although the primary difference has to do with the incorporation of the time dimension, the implications of this change for both the type of forecasting model and the mode of application of the model are obviously substantial.

In summary, policy planning is very much an exercise in evaluating alternative paths or time sequences of actions that lead to a desirable end-state condition. From an efficiency point of view, it is likely that the evaluation of planning actions through time will still require the definition of an end-state or boundary condition. As Rice and Nowlan (1, p. 102) have observed,

> It will always be computationally efficient to pre-select one or more specific terminal-year structural configurations, so that feasible paths of urban change will have a beginning point in the present structure and a terminal point or points in the pre-determined terminal-year structure. It is in general possible to optimize an objective function without specifying a terminal-year structure, but the increased computation . . . makes the exercise much messier. More importantly, however, the terminal-year structure, because it functions both as legacy and target, is interesting in its own right and worthy of separate analysis.

It is the primary purpose of the following section of this paper to initiate this type of separate analysis by assessing the two-mode transportation service and investment requirements of a series of alternative static terminal-year urban development conditions. This is very much a policy planning exercise since the terminal-year or end-state structure comes very close to representing a "policy statement." No attempt is made here to assess alternative plans or sequences of actions that would achieve this policy statement or target configuration (6). Instead, an approach for defining the general implications of alternative policy states is described (1, p. 103):

> Its purpose would be to make numerically specific the rather vague notions of policy that are part of current politics. Thus, different policy positions could be specified in quantitative terms. Such competing concepts as intensified central business district development versus nodal business district development, denser suburban populations versus stabilization at present densities, public transit transportation modes versus expressway development may all be defined by means of feasible terminal-year positions.

RESEARCH PROCEDURE AND ANALYSIS

The objective of the research described here is to define the notion of policy alternatives in terms of their transportation and land-use implications: That is, how might we determine the most effective combinations of road and transit systems to serve a defined number of cities that have different density and spatial patterns? Given the perspective offered in the literature (8, 9), it is apparent that any effort in this area should allow first for full modal interdependence, permitting shifts in travel mode with changes in land-use and socioeconomic characteristics as well as transportation level of service, and second for a greater number and broader type of output indicators. In essence, the estimation of modal travel demands for each urban form must be sensitive to both the level of service supplied and the space- and density-related pattern of land-use activities. To permit the investigation of transportation system characteristics for a range of urban patterns, there is a strong need for an analytical base that allows for the comparison of transportation measures between land-use plans. That is, the procedure for developing the transportation network and mode combination for each urban form must be consistent and not unduly bias any particular city patterns. This, in fact, is the central issue of the research procedure.

The description of the research method and results has been divided into three separate stages: The first deals with the definition of the range of hypothetical urban forms and the estimation of basic peak-hour travel demands, the second with the generation of optimal two-mode transportation networks to accommodate the estimated travel demands in each city, and the third with the comparative analysis of transportation system requirements by type of city.

Definition of Urban Form and Travel Demand Estimation

Because of the complexities associated with transportation and land-use interrelationships, hypothetical rather than actual urban forms were generated for testing in the research project. This process was quite complex and has been described in detail elsewhere (8, 9). Very simply, it was necessary that the range of hypothetical city types be defined so that they resulted in a significantly broad range of transportation conditions. In total, population and employment characteristics were developed for six different urban forms of 2 million population: (a) central core, (b) homogeneous (uniform density), (c) multicentered, (d) radial corridor, (e) linear, and (f) satellite. These forms were developed through the application of a series of realistic and empirically derived constraints on density variation, socioeconomic characteristics, and relative population and employment location. The six urban forms are shown in Figure 1, and their summary characteristics are given in Table 1.

Definition of the characteristics of urban form made it possible to estimate travel demands by trip purpose. The demand estimation procedure involved the use of the conventional four-stage process of applying zonal trip generation and attraction equations and the gravity model to produce origin-destination trip matrixes for each of the six urban forms. To permit the development and use of unique functions of travel impedance for each city type, reference was made to previous research that related the distribution of work opportunities to average trip length (10).

Finally, work-trip origin-destination matrixes were assigned to spider networks for each type of city. The rest of the analysis of the transportation implications of urban forms was restricted to the work trip on the basis that this trip purpose set the condition for the design of the transportation networks. The results of the spider, or desire-line, assignments for the work trip are given in Table 2. The advantage of the desire-line assignment is that the volume flow condition that has been estimated is not constrained by the form or characteristics (capacity and mode) of the spider network (Figure 2). It therefore provides a relatively objective and consistent base for deriving more comprehensive two-mode transportation networks.

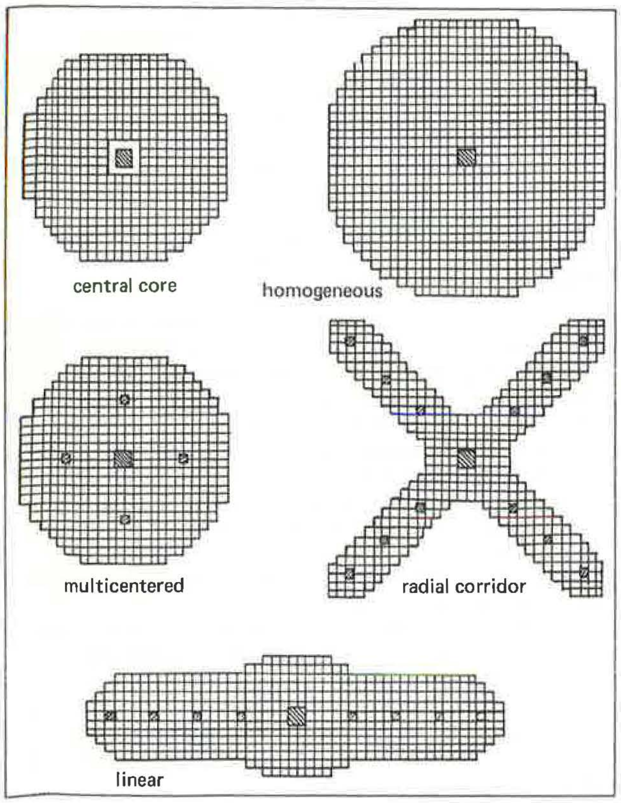
Generation of Two-Mode Network

As indicated earlier, the critical phase of the research requires that a procedure be developed for generating a unique, two-mode, capacity-restrained transportation network for each city type to permit a realistic and unbiased comparison of mode performance for the six urban forms. In basic terms, this procedure is dependent on a definition of modal balance, which might be stated as the condition in which both mode subsystems are used effectively in and of themselves and in such a manner as to produce collectively optimal total system performance.

The network generation procedure that was applied is a two-stage heuristic process that depends on an initial division of modal service for each network link (the supply equilibrium cycle) and the refinement of modal volumes in accordance with mode and route choice (the demand equilibrium cycle). This procedure is described in Figure 3 in the form of a flow chart.

The supply equilibrium phase starts with the desire-line volumes from the spider assignment for each type of city and defines an initial two-mode transportation network that can accommodate the expected demand.

Figure 1. Six selected urban forms.



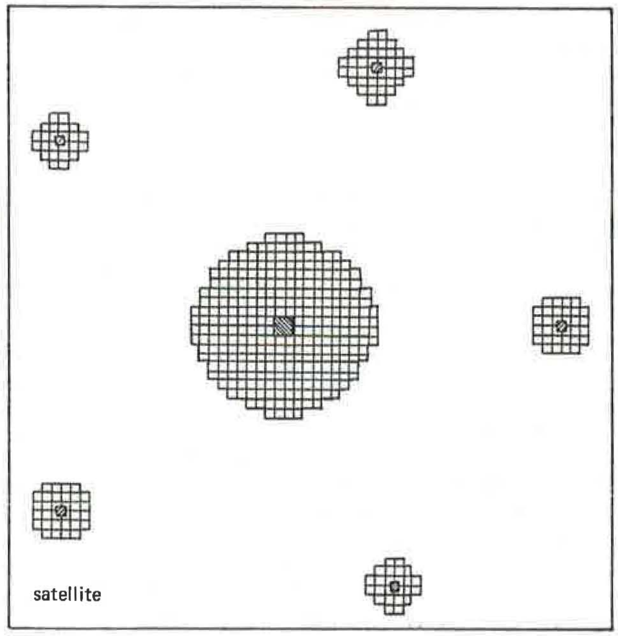


Table 1. General characteristics of urban forms.

Urban Form	Desig-nation	Employment	Developed Area (km^2)	Gross Population Density (persons/km^2)	Average Net Residential Density (persons/km^2)	Number of Dwelling Units	Average Number of Persons per Dwelling Unit
Central	1A	800 000	1240	1610	11 200	565 300	3.54
Homogeneous	1B	803 000	2190	910	5 200	534 300	3.74
Multicentered	2	804 700	1240	1610	12 000	567 000	3.52
Radial corridor	3	802 200	1045	1920	13 200	567 000	3.52
Linear	4	803 000	1270	1580	11 500	566 100	3.54
Satellite	5	800 300	1140	1760	12 600	567 300	3.53

Notes: 1 km^2 = 0.386 $mile^2$.
All urban forms are for population of 2 million.

Table 2. Desire-line assignment.

				Total Trips				Work Trips			
Urban Form	Total Length of Network (km)	Average Length of Links (km)	Number of Two-Way Links	Average Volume per Link	Maxi-mum Link Volume	Total Person Kilometers	Total Person Hours	Average Volume per Link	Maxi-mum Link Volume	Total Person Kilometers	Total Person Hours
1A	602.2	5.8	104	32 710	104 500	32 880 000	342 470	5465	34 600	5 440 000	56 700
1B	739.8	6.7	108	31 360	103 000	43 250 000	450 230	4900	24 000	6 640 000	69 200
2	610.2	5.1	120	29 390	80 100	32 530 000	338 000	4270	21 000	4 670 000	48 600
3	463.8	5.6	82	50 800	170 500	37 920 000	395 000	8530	47 100	5 970 000	62 200
4	604.2	5.3	114	37 970	169 000	41 650 000	433 760	6470	57 300	7 060 000	73 500
5	955.2	7.8	122	30 520	107 300	48 540 000	505 640	5130	28 800	9 180 000	95 700

Notes: 1 km = 0.62 mile.
For the desire-line analysis, a speed of 95 km/h (60 mph) was assumed.

Figure 2. Spider network for satellite city.

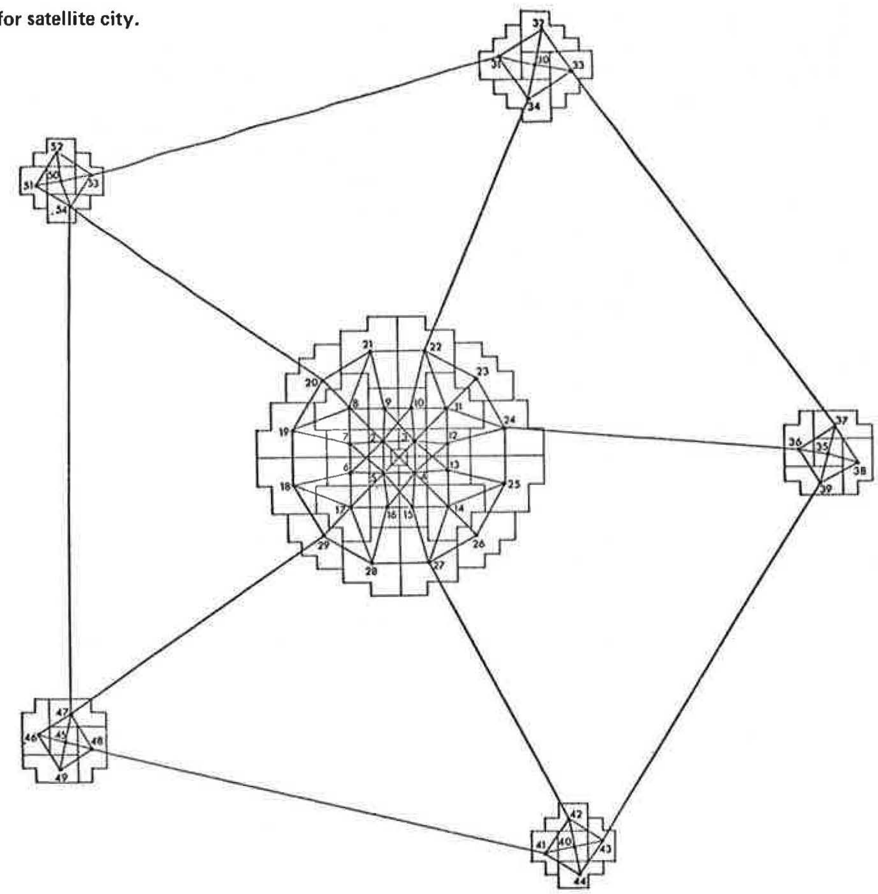
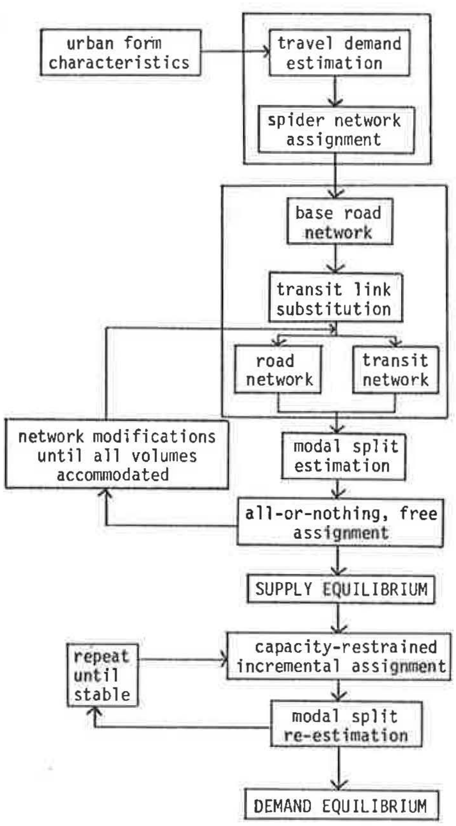


Figure 3. Procedure for two-mode network generation.



This was achieved by first designing a base road network with four possible link types in such a way that it would just carry the estimated desire-line volumes. Modifications were then made to this initial feasible solution by substituting one of eight levels of transit service on a link-by-link basis so that a trade-off function between the consumption of space for the transportation facilities and user travel time was always satisfied. This was achieved by calculating the ratio of the change in travel time to the change in transportation facility space for each feasible transit substitution per link. The transit service for which this benefit ratio was closest to the mean value of the ratios for all feasible substitutions for the link was chosen for implementation. This, in effect, means that the trade-off is directly related to total link volume and higher volumes are more willing to accept larger increases in travel time per unit of facility space gained. This seemed plausible, and a testing of the decision rule indicated that higher capacity transit service does replace road capacity on high-volume links.

It is obvious that the introduction of transit service will have a substantial effect on both mode and route choice. It was necessary, therefore, to reestimate modal split and trip assignment after the initial round of transit substitution. When this was done, however, it was found that the new routes selected took advantage of the links with the higher level of service so that there was a natural aggregation of trip movements into specific modal corridors. In a similar manner, other links were deleted in trip volume; this modified the service available on these links in the next round of transit service substitution. In an iterative sequence, then, a process of network rationalization takes place that involves both the route and mode choices of the traveler so that natural corridors of travel demand build up in accordance with network geometry and demand orientation (11).

The process of network rationalization is most easily demonstrated by the diagrams shown in Figures 4 and 5, which represent the results for the road and transit networks of city type 1A (central core) for three phases of the iterative supply cycle. These figures represent only the high-capacity links in the modal networks, but it is apparent that the road network expands and the transit network contracts. This is obviously a function of the modal-split submodel, but this phenomenon did occur for all six urban forms.

The supply equilibrium cycle was repeated until no further changes were required in each of the modal network links to accommodate the travel volumes estimated in the previous iteration of the cycle. It should be noted that the trip-assignment component of the supply cycle is a free or desire-line assignment because the objective of the network synthesis is to develop a natural expression of the required transportation system. In other words, network rationalization must be unconstrained by physical limitations; modal capacity is simply provided in accordance with traveler demand. This resulted, therefore, in the need for the demand equilibrium cycle, which reestimates modal split and route assignment in an iterative sequence under assumptions of capacity-restrained flow on all links. This cycle is also indicated in the flow diagram shown in Figure 3 and completes the procedure of network generation.

Comparative Analysis

The results of the procedure of network generation are most easily demonstrated by the total system output measures given in Table 3 (the X^T vectors defined previously). The differences in travel conditions for the six cities are obviously quite significant. For two cities (the homogeneous and the multicentered), no rail transit links were generated. For both total person hours and mean trip length, urban forms 1A, 1B, and 2 have lower conditions than the other three forms. This is not a function of mode use because modal split varies from 8 to 34 percent and this variation occurs in both groups of cities.

The comparison of mode use for the range of cities

Figure 4. Transitional sequence for road network for central-core city.

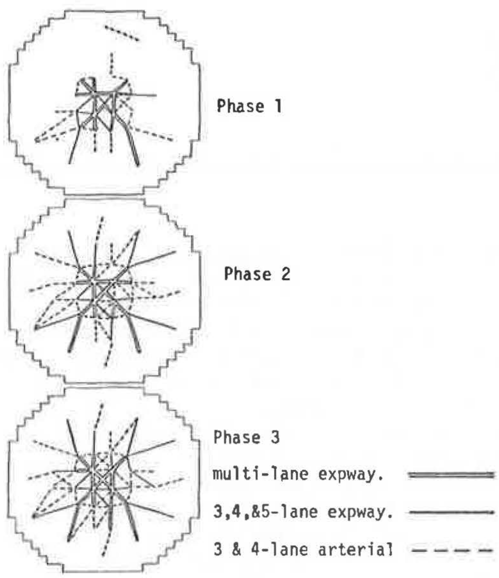


Figure 5. Transitional sequence for transit network for central-core city.

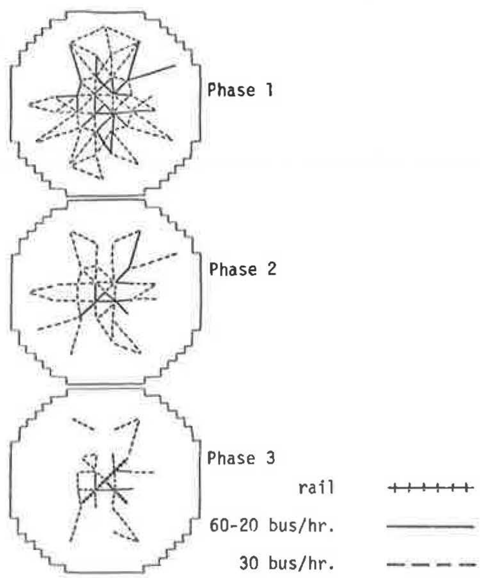


Table 3. Final characteristics of travel demand by urban form.

Output Measure	Urban Form 1A	1B	2	3	4	5
Total system						
Total work trips	346 500	341 380	326 900	334 700	375 100	387 950
Person hours	7.00×10^4	7.71×10^4	5.00×10^4	9.65×10^4	9.51×10^4	17.14×10^4
Mean trip length, min	11.68	13.1	9.07	17.01	14.49	26.0
Percentage transit	18.2	8.0	10.3	33.8	19.9	8.0
Road network						
Work trips	293 100	313 900	293 500	221 200	300 350	357 950
Percentage on expressway	63	55	59	85	75	90
Trip length, min						
Mean	11.78	12.16	8.30	17.2	13.58	26.66
Standard deviation	10.88	7.64	4.99	18.8	12.54	40.8
Transit network						
Work trips	53 400	27 480	33 400	113 500	74 750	30 550
Percentage on rail	30	0	0	51	37	26
Trip length, min						
Mean	11.22	24.06	15.82	16.62	18.82	18.39
Standard deviation	8.27	11.02	8.98	13.16	13.94	18.34

is shown in Figures 6 and 7. The percentage of trips that use transit corresponds closely with the number of train kilometers supplied except in the case of the satellite city where the existence of rail transit has little effect on the use of public transit. With regard to the percentage of person hours on high-speed service links (expressway and rail), the two corridor cities (3 and 4) and the satellite city (5) depend most on facilities that have high levels of service, as would be expected. Although the cost of transportation investment has not been estimated directly, it is possible to form some general conclusions on capital costs from the amount of high-service facilities required in each of the six city types. The two corridor plans and the satellite plan are dependent on high-service facilities for both modes and hence will require high capital investment. The satellite plan easily claims the position of the most expensive form even though its rail service requirements are not the largest. The radial-corridor plan is likely to be the cheapest of the corridor plans. The remaining three cities (central core, homogeneous, and multicentered) require the lowest transportation investment; the multicentered city requires the absolute minimum.

Finally, in order to measure the relative efficiencies of the high-service links in the modal networks, intercity comparisons were made between person hours per expressway lane kilometer and person hours per rail transit train kilometer. For expressway efficiency, the satellite city ranked highest, and the multicentered city and the linear city performed rather poorly. For rail transit, however, the networks of the radial-corridor city and the linear city performed well and those of the satellite city very poorly. With regard to the efficiency of the total networks, including all link types, it may generally be concluded that it is more difficult to achieve an efficient transit network than it is to achieve an efficient road network. The satellite form is the primary example of this disparity, but it is demonstrated in the other urban forms as well. In terms of overall efficiency, the radial-corridor city rates best overall. This might be expected, but the fact that the homogeneous city ranks second certainly is not. Even though the homogeneous city has minimal transit service, what is available is effectively used.

Figure 6. Use of automobile mode and expressway.

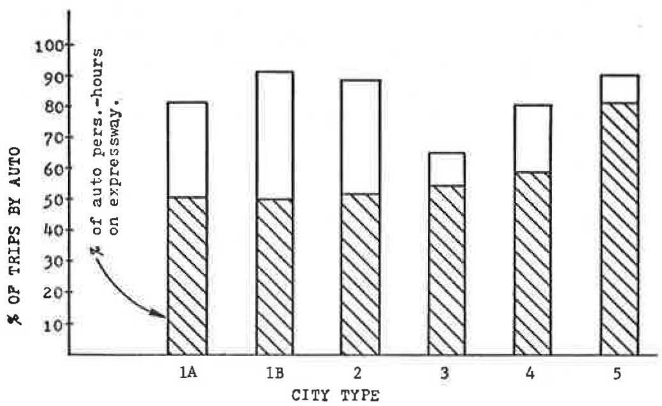
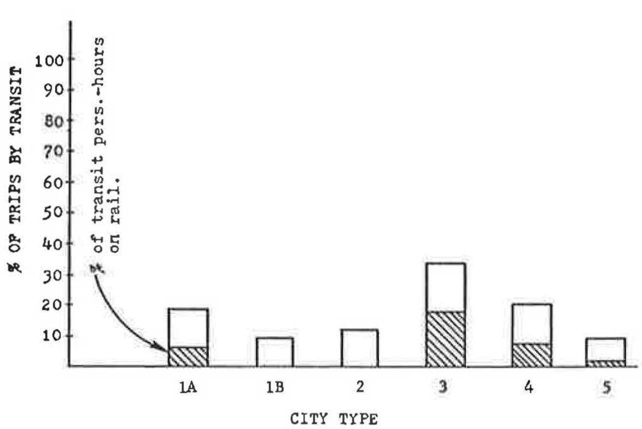


Figure 7. Use of transit mode and rail transit.



CONCLUSIONS

This paper has been concerned with refining the transportation planning process so that short-term policy issues might be incorporated more effectively. As part of the proposed framework of dynamic policy evaluation, an assessment of the importance and relevance of transportation and land-use alternatives was undertaken. Conclusions that relate to the framework and the static analysis can be summarized as follows:

1. Given the wide range of transportation service and investment requirements that resulted from the different urban forms, the horizon-year policy states are definitely essential inputs to the proposed dynamic evaluation framework. From this analysis, it would appear that their use within the framework will probably improve the computational efficiency of the method of selecting optimal time paths or plans for improvements through time, which is aimed at achieving the selected end-state condition.

2. The transportation requirements of any particular urban form are uniquely defined. The average work-trip lengths for the six cities that were analyzed differed by a factor of almost three. Also, the investment cost implications would appear to indicate the relative inexpensiveness of the centrally oriented city types (central core, homogeneous, and multicentered) relative to the two corridor plans and the satellite plan. This conclusion is verified by the requirement for a large percentage of high-service links in the satellite cities. This conclusion generally supports similar research by Balkus (12) but runs counter to the conclusions of Zupan (13) and Hemmens (14). With regard to specific urban forms, the research results are confirmed by Voorhees, Barnes, and Coleman (15), who conclude that the existence of subcenters reduces average trip lengths, but conflict with Jamieson and others (16), who contend that the linear form rather than the radial-corridor plan is most efficient. With regard to the Metropolitan Toronto Transportation Plan Review (17), the research supports the contention that a nucleated pattern is preferable to a single-core plan in terms of all transportation measures.

3. With regard to the effect that alternative urban forms have on specific modal requirements and use, the analyses indicate that substantial variability in mode use (8 to 34 percent for transit) may be expected among the six city types. In addition, the submode balance (rail-bus and expressway-arterial) is also dramatically different: Two urban forms—homogeneous and multicentered—have no rail service at all.

4. The implications of the modal differences for the urban forms may also be used to indicate differences in user travel costs and facility investment costs. Using either average trip length or number of person hours of travel as a proxy for user costs results in the following ordering of city types: multicentered, central core,

homogeneous, linear, radial corridor, and satellite. Using lane kilometers of high-service facilities as a measure of investment cost results in the same ordering from low to high cost for the first three urban forms and a reversal in order for the linear and radial-corridor plan in the last three cities. The consideration of transportation efficiency (output per unit of input, such as person hours per lane kilometer or per bus kilometer) is even more instructive, resulting in the choice of the radial-corridor plan as the most efficient plan in the use of capital funds, followed by the homogeneous and the multicentered forms.

The research results described here are preliminary in several respects. First, a number of internal modifications and checks should be applied to the transportation modeling procedure. These include the incorporation of transportation investment and user cost functions, the empirical verification of results, the inclusion of new transportation systems, and the application of the model procedure to cities of different population sizes. The most important direction, however, has to do with the further elaboration of the proposed policy evaluation framework and the construction of a policy model that will permit the evaluation of the most efficient path of investment over time in such a way that a desirable end-state plan may be achieved. Only in this way will the transportation system plan be relevant to policy issues.

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REFERENCES

1. R. G. Rice and D. M. Nowlan. Toward a Dynamic Framework for Urban Transportation and Land-Use Planning. Proc., 16th Annual Meeting, Canadian Transportation Research Forum; Transportation Research Forum, Vol. 16, No. 1, 1975, pp. 91-106.
2. F. C. Dunbar. Quick Policy Evaluation With Behavioral Demand Models. TRB, Transportation Research Record 610, 1976, pp. 47-49.
3. B. G. Hutchinson. Principles of Urban Transport Systems Planning. McGraw-Hill, New York, 1974.
4. L. A. Neumann and others. Integrating System and Project Planning for Effective Statewide Programming of Investments. TRB, Transportation Research Record 499, 1974, pp. 83-93.
5. K. V. Smith. A Mix-of-Modes Evaluation Model for Transportation Systems. Rand Corp., Santa Monica, CA, Rept. P-4059, May 1969.
6. R. G. Rice. Transportation Plan Evaluation as a Continuous Process: A Proposed Framework and Case Study. Paper prepared for Annual Conference of Roads and Transportation Association of Canada, Oct. 11-14, 1977.
7. L. A. Neumann and W. M. Pecknold. Application of the Time-Staged Strategic Approach to System Planning. HRB, Highway Research Record 435, 1973, pp. 20-31.
8. R. G. Rice. Performance Characteristics of Two-Mode Transportation Systems for Varying Urban Form. Department of Civil Engineering, Univ. of Toronto, PhD thesis, 1975.
9. R. G. Rice. The Effect of Alternative Urban Forms on Two-Mode Transportation System Requirements. Paper presented at World Conference on Transport Research, Rotterdam, the Netherlands, April 26-28, 1977.
10. Alan M. Voorhees and Associates. Factors and Trends in Trip Lengths. NCHRP, Rept. 48, 1968.
11. J. C. Rea. Designing Urban Transit Systems: An Approach to the Route-Technology Selection Problem. HRB, Highway Research Record 417, 1972, pp. 48-59.
12. K. Balkus. Transportation Implications of Alternative Sketch Plans. HRB, Highway Research Record 180, 1967, pp. 52-70.
13. J. M. Zupan. Social Implications of Land Use and Mode Choice. Transportation Engineering Journal, ASCE, Vol. 99, No. TE2, May 1973, pp. 383-391.
14. G. C. Hemmens. Experiments in Urban Form and Structure. HRB, Highway Research Record 207, 1967, pp. 32-41.
15. A. M. Voorhees, C. F. Barnes, and F. W. Coleman. Traffic Patterns and Land-Use Alternatives. HRB, Bulletin 347, 1962, pp. 1-9.
16. G. B. Jamieson and others. Transportation and Land-Use Structures. Urban Studies, Vol. 4, No. 3, Nov. 1967, pp. 201-217.
17. Development of Land Use and Transportation Alternatives. Metropolitan Toronto Transportation Plan Review, Rept. 62, Toronto, May 1974.

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