Models of Urban Development in the Analysis of Transportation Investment: North Central Texas

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This article reports on the theoretical foundations and structure of a model of urban development and its application to North Central Texas. The model has been used to examine the spatial urban development consequences of five alternative regional ground transportation systems that embody varied amounts and mixes of highway and transit investment. The objective is to select and adopt a preferred multimodal system for the period to 1990. The urban development forecasts provided by the model formed the basic socioeconomic inputs to the transportation analysis procedure, and certain of the impact measures that the model produces were used in the evaluation of the alternative systems. This article provides a summary of the work performed in Texas and the conclusions that can be drawn from it in a form that will be of value to urban analysts and policy makers.

STUDY CONTEXT

On February 26, 1974, the Regional Transportation Policy Advisory Committee was established for the North Central Texas Region. The committee's goal was to determine a multimodal transportation policy that would be suited to the requirements of the regional community for the period to 1990.

Four multimodal ground transportation system concepts and the do nothing case were considered. The four multimodal alternatives included tests of the extreme situations whereby investment would be channeled entirely into either highways or transit and two tests of different investment mixes of highway and transit. Each alternative was developed to serve the intensive study area of North Central Texas (the Dallas-Fort Worth metropolitan region). These concepts were further defined in terms of regional transportation plans, and detailed descriptions were given of small regional analysis areas' (RAA) highway and transit routes and service levels.

Both predictive and evaluative techniques were needed to measure the performance of the alternatives. Predictive techniques described the future conditions in the region for each alternative in terms of the future intensity and location of urban activities, such as residential development, industry and commerce activities, and travel demands. Evaluative techniques assessed the impact of these future conditions on the well-being of the community in terms of the accessibility of urban resources to different groups and the quality of the environment. This predictive and evaluative process is illustrated by Figure 1. Two additional inputs were required at this stage of the process: (a) future regional control totals for population and employment and (b) land use policies and other major factors influencing regional development.

The estimates of regional population and employment growth were derived from an analysis of the current and predicted economic position of the region relative to that of the Southwest region and the United States as a whole. The basic assumption underlying these population and employment estimates was that the rate of regional population growth and the demand for services are functions of the rate of increase in growth-generating economic activity. Growth-generating activity is defined in terms of either the production of goods or services for export or the goods or services that would otherwise have to be imported into the region. The employment so generated

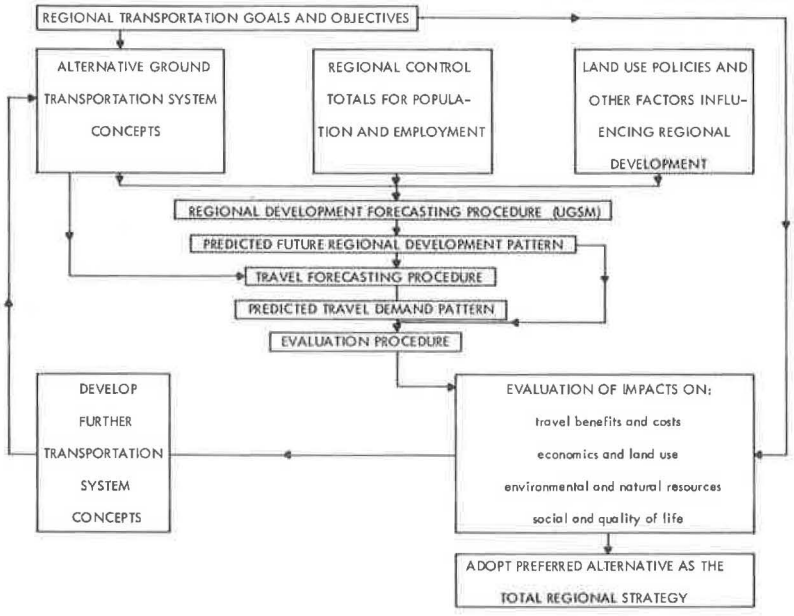


Figure 1. Simplified regional transportation predictive-evaluative process.

is defined as primary employment; all other types of employment that serve primary economic activity and residential population are defined as service employment.

The land use policies of individual communities within the region were used to establish constraints on the amount and type of development that could occur within each small RAA. In addition, those factors (other than transportation) considered fundamental to the regional development process, such as the availability of land for development, sewer and water infrastructure, and the nature and intensity of existing development and possibilities for urban renewal, were examined on an RAA basis to identify areas for potential development during the period to 1990. Collectively these policies and factors were used to identify the set of fertile RAAs within which economic or residential development could take place.

The function of the regional development forecasting procedure was to distribute the projected regional increase in residential population and employment to each RAA, in response to the different regional accessibility surfaces created by each of the regional transportation system concepts, and subject to the above development constraints on infertile RAAs. The different regional development patterns and socioeconomic characteristics predicted under each transportation alternative and the service level characteristics of each system provided the basis for the subsequent prediction of future travel demands. In turn these development patterns, socioeconomic characteristics, and travel demands were used to evaluate the feasibility, desirability, and utilization of proposed transportation improvements, as well as their potential impact on land use patterns, the environment and natural resources, and accessibility.

This process led the steering committee of the policy advisory committee to select the primarily highway alternative (the mixed investment alternative that emphasized highways) for further refinement and analysis. As a result of that refinement and analysis, the steering committee recommended and the policy advisory committee approved the sixth alternative as the total transportation plan for the North Central Texas Region for 1990 (1).

REGIONAL DEVELOPMENT FORECASTING STUDIES

Our study objectives were considered fundamental to the overall process:

1. To simulate the interaction between the regional transportation system and the development process to provide a consistent description of the future pattern of regional development under each of the transportation system concepts tested and
2. To provide information that would be valuable to the assessment of the impact of each such system on the community.

The conventional transportation planning process fails to take sufficient account of the interaction between transportation and development. In a rapidly growing region such as North Central Texas, which is neither constrained by a lack of developable land nor by the historical investment in infrastructure, such an omission could be critical. Failure to take account of the different spatial development possibilities open to the region through alternative transportation concepts would result in an unrealistic set of future travel demands and impact measures and an inadequate basis for decision making. The urban development studies were, therefore, necessary to formulate and test relationships between the development process and transportation against an historical situation, and to apply the relationships so established to each of the transportation systems generated to predict the future pattern of development in the region.

The methodology of the studies assumes that the demand for travel is a function of the consumption of and interrelationship between different urban activities, such as working, shopping, leisure and recreation, and distributing goods. Within the urban region, consumers come into contact with the suppliers of urban activities through the communications and the ground transportation systems. Indeed, the present location and intensity of activities in the region is, to a considerable extent, a function of historical investment in the ground transportation system and the accessibility surface so created. Changes in either the total amount or mix of investment in the transportation system, therefore, affect the accessibility of production and consumption activities at different locations in the region. Such changes could affect one location's accessibility costs relative to others and cause changes in the amount of activity locating there, or the substitution of new activities for existing ones. Such changes could, in turn, affect the demand for travel between producers and consumers, which would manifest itself in the resulting regional patterns of travel.

The methodology on which the study was based, the urban growth simulation model (UGSM), simulates the interaction between the transportation system and urban development over time. The chronological development of this methodology is illustrated below.

- Theoretical Foundation
  - Lowery 1964
  - Centre for Environmental Studies 1967, 1970
  - Urban Land Market Theory 1961, 1970
  - Central Place Theory 1967
- Subregional Activity
  - Bristol Severnside Subregion England 1970, 1972
- Statewide Activity
  - Connecticut 1974
- Urban System
  - North Central Texas Regional Transportation Study 1972
  - Baltimore Regional Environmental Impact Study 1973
- Urban Growth Simulation
  - North Central Texas Continuing Transportation Program 1974, 1975

The structure of the UGSM is illustrated in Figure 2. The model is based on a conceptualization of the urban region as the culmination of a process by which physical stock (transportation areas, space, and public utilities) and activity centers (homes and places of employment) are distributed spatially (2). The hypothesis is that activity centers are distributed to locations as a function of their interrelationships with other activity centers and constraints imposed by the physical stock. Physical stock locates in response to the activity demands for stocks—for example, for transportation space and infrastructure. The model also incorporates the competition for physical stock among urban activities through an accounting framework that relates the distribution of activities to the availability of physical stock.

Specifically, the model distinguishes between growth-generating employment (primary), residential population, and service employment activities; and between floor space, transportation, and public utility physical stocks. The model simulates changes in the distribution of primary employment, residential population, and service

employment over time as a function of changes in intrinsic locational attractiveness and changes in the availability and quality of the physical stock.

Lowry's contribution (3) is significant because he formalized and tested a stratification of metropolitan economic activity in terms of a basic residential population (export oriented) and a service sector (population serving). These were interrelated regionally through a series of activity rates and population serving ratios and interrelated spatially through a series of zonal activity distribution functions. The definition of the metropolitan economy in Lowry's terms leads to a number of inconsistencies—the most important is that all economic growth is assumed to be export oriented. No allowance is made for growth through either import saving or local market oriented employment. To overcome this problem, our model was designed so that both import saving and certain local market oriented activities (such as local government expenditure or investment in the housing market) could influence the regional economic growth rate (4). This is important because the separate identification of growth-generating economic activities in the study area allows the effects of differences in national economic growth to be traced. For example, changes in national demand as a result of changes in energy availability or price could cause changes in the structure and growth of the region's primary economic activities and in turn affect the demand generated within the region for service sector products. The second influence on the development of the model was the research of the Centre for Environmental Studies, London. This work established a general theoretical framework for the analysis of urban activity distributions (5).

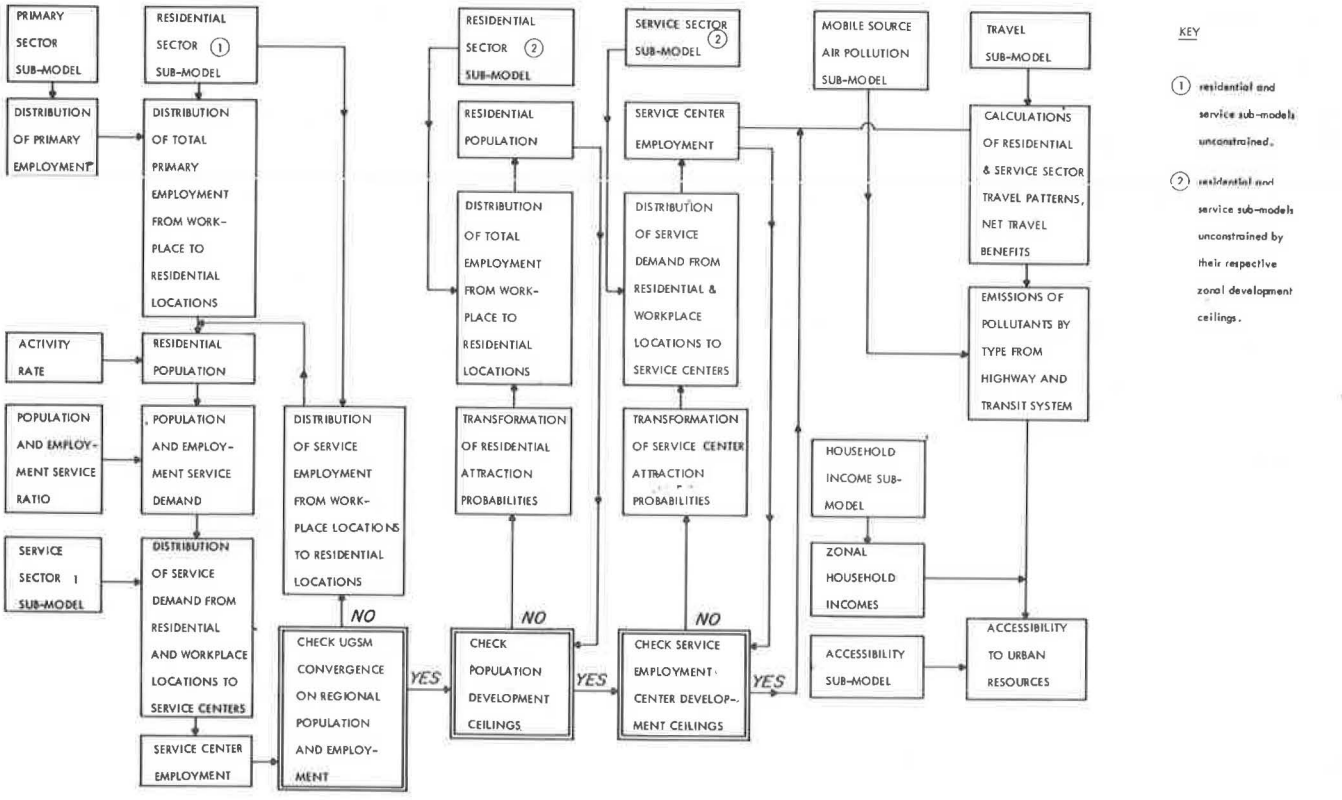
This theoretical derivation is important for the development of the UGSM residential and service employment submodels (Figure 2). The spatial distribution of residential and service employment activities is determined by submodels that distribute employees from work to home and distribute service demand from home and work to service centers, thereby maximizing the entropy of each activity system. This relationship is determined in the model by the amount of travel observed or projected for each activity.

Wilson's theoretical framework also incorporates a procedure to reconcile the demands of competing activities (population and service employment) with the available space at each location. This can be defined as a development ceiling on the location of both population and service employment, in terms of the amount of developable space, maximum density of development, or amount of activity. This procedure has been incorporated in both the residential and service employment submodels respectively, which provide unconstrained and constrained activity forecasts by RAA. Both submodels also incorporate a locational attraction index, in an attempt to represent, albeit crudely, the relative attractiveness of alternative residential and service locations.

Further assumed is that the perceived value of locational attractiveness lags behind its real value at a given point in time. The rationale for this assumed lag in the response of demand to the changing attractiveness of residential and service employment locations is a function of imperfect information and communication, habit, and inertia (6). For these reasons, the zonal attraction indexes used in the residential and service employment submodels are lagged behind their real values for existing and future points in time (7).

The residential sector trade-off decision between transportation cost and locational attractiveness, simulated in the form of a spatial distribution of population, is consistent with the urban land market theories of Wingo (8) and Alonso (9). Similarly, the service sector trade-off decision, simulated in the form of a spatial distribution of service employment centers, is consis-

Figure 2. UGSM structure.



tent with the spatial arrangement of service centers suggested by central place theory (10).

Model Application

The UGSM is based on the prediction of regional distributions of population and employment over time in response to changes in transportation, public utility, land use, and environmental policy variables. This approach (of recursive prediction) requires inputs by discrete time periods of 5 or 10 years from the base year to the end of the forecasting period. For each time period this involves changes in regional population, in primary and service employment, and to the zonal development ceilings or the regional transportation system to reflect policy changes. The model is then run for each time period to forecast a new regional distribution of activities. At the end of each time period, the inputs are revised and the model is run for the next forecast period.

The role of the UGSM was to examine the potential implications of five alternative 1990 regional transportation systems on the pattern of urban and regional development at that date and provide inputs to the travel model procedure.

An intermediate forecast for 1980 was made to provide the necessary inputs for the subsequent 1990 predictions. The specific alternatives tested for 1990 are described previously in this paper:

1. Do nothing,
2. Primarily transit,
3. Primarily highway,
4. All transit, and
5. All highway.

Table 1 summarizes the mean regional trip length results for the two extreme investment alternatives and compares them with the 1970 observations and 1980 estimates. The higher travel costs under the all transit alternative can be attributed to the concentrated pattern of economic activity that the regional rapid transit system would cause. Given the existing dispersed pattern of residential development in the region, this shift toward the concentration of economic activities causes a marginal increase in the work and a proportionately greater increase in the service travel cost.

It is useful to consider these results in relation to the two main factors that cause variance in the residential and service employment distributions within and across the five alternatives. These factors are the RAA development ceilings on population and employment (which, although constant across the alternatives, affect the distribution and intensity of development that would otherwise occur in a completely free market situation) and the five regional transportation system alternatives (which cause the regional accessibility surface to vary and have a differential effect on both the free market and constrained activity distributions within each alternative).

Table 1. UGSM mean regional generalized cost trip length comparison for 1970, 1980, and 1990.

Year	Mean Regional Work to Home Travel[a]	Mean Regional Home and Work to Service Travel[a]
1970	56.2	34.9
1980	56.8	34.9
% change 1970 to 1980	+1	—
1990-all highway	56.3	35.7
% change 1980 to 1990	-1	+2
1990-all transit	56.8	37.5
% change 1980 to 1990	—	+7.5

[a] Generalized cost (in units referred to as Utiles) is defined in terms of the composite highway and transit journey time multiplied by the perceived value of each element of the journey, and added to out-of-pocket expenditures.

Despite the other spatial growth differences observed across the alternatives, little difference was found in the distribution of residential population by functional area. This can be attributed to three factors.

1. Development ceilings were held constant across the alternatives, thus dampening the differences in intensity and location of activity that would otherwise have occurred,
2. The 20-year time period under consideration allows for minimal deviation for the already established residential development pattern and philosophy of urban activities within any given metropolitan area, and
3. The distribution of residential population in the region is already far more scattered than is the distribution of economic activity, thus less scope is provided for further significant spatial change.

The impact of the alternatives on economic activity was marked—significant shifts in the location of employment occurred as a function of the amount and mix of transportation investment. The basic finding is that large-scale investment in a regional transit system would cause the greatest increase in the amount and intensity of service economic activity in the central business districts. This concentration of activity is reflected in the transit alternative's denser pattern of economic development than that of their highway equivalents, resulting in a smaller overall developable land requirement.

Findings

The development model described formed an integral part of the process by which a preferred multimodal transportation investment strategy was adopted for the North Central Texas Region. The urban development forecasts made by the model provided the basis on which the future regional travel requirements were predicted under each of the transportation alternatives tested. In this respect, the patterns of regional development predicted by the model across the transportation alternatives were found to be consistent with and sensitive to the changes made in the level and mix of transportation investment and other major variables influencing the development process.

Several points must, however, be made about the limitations of such models.

1. This type of model is founded on regional rather than local behavioral concepts. Therefore, the accuracy of small area predictions will vary according to the relative influence of regional and local factors on the decisions made at particular locations.
2. The UGSM requires regional primary employment, residential population, and service employment control totals that have been determined independently as a basis for its forecasts; thus, the interrelationship between the predicted spatial development patterns and rate of regional growth are omitted. Consider, for example, the possibility of a particular development alternative so constraining growth in the central business district that primary sector growth in that area is discouraged from locating within the region. This would have ramifications for both the growth and location of population and services, and by definition for the policy alternatives being examined.
3. The model is not explicitly disaggregated by socioeconomic group, although it is disaggregated to some

extent by employment category (i.e., the primary and service employment sector breakdown). The issue is the familiar one of the trade-off between the increased accuracy and the value of disaggregated forecasts and the extra information, technical development, and financial cost that would be necessary for their derivation. The results of modeling exercises that have adopted a disaggregated approach to policy testing do not seem to justify the additional effort and investment required.

FURTHER RESEARCH

Several areas of research continue in regard to the UGSM and its application to the comprehensive regional planning process:

1. Policy design and evaluation;
2. Forecasting techniques for the development of regional control totals (i.e., population and employment) and the allocation of the primary employment activities are exogenous to the UGSM structure;
3. Sensitivity testing; and
4. Policy monitoring.

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Applications of Land Use Models to Strategic Transport Planning

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The nature of strategic land use and transportation planning in Ontario is discussed and the major phases of the typical study are outlined. The structure of a land use and transportation model that may be used in these strategic studies is described as well as two applications of the model. The first set of applications are described for a variety of regional planning problems in the Toronto-centered region of Ontario. These applications include the analysis of the probable impacts of various public sector investments on activity distributions and the analysis of the role of a new town. The second application is described for the Delhi region of India. A version of the model that is disaggregated by socioeconomic group is also outlined.

The metropolitan transportation planning process that emerged during the 1950s and early 1960s was directed primarily toward the formation of long-range capital investment programs for regional transportation facilities. Many cities throughout the world have abandoned transportation plans or critical elements of plans developed by this process. During the past decade two types of new transportation policy responses have been undertaken. Much of the recent effort in the United States has concentrated on programs for improving the efficiency of existing transportation facilities. The transportation system management program is geared to improving traffic flow, encouraging the use of high occupancy vehicles, and maintaining road and public transportation capacity.

In Canada, urban transportation policy responses also embraced the shorter run, but while also focusing on the longer run strategic planning of land use and transportation facilities. This longer run policy emphasis reflects the view that realistic and effective solutions to urban transportation problems may be achieved only through the formulation and implementation of good development plans. These development plans must embrace many of the public infrastructure sectors, including transportation.

PLANNING STUDIES IN ONTARIO

The emergence of strategic planning in Ontario may be traced to the creation of regional governments that have the power and finances to implement regional development plans. Strategic transportation planning studies