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THE LAND USE FORECAST IN
URBAN TRANSPORTATION STUDIES

A THESIS

Presented to

The Faculty of the Graduate Division

by

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In Partial Fulfillment

of the Requirements for the Degree

Master of City Planning

Georgia Institute of Technology

October, 1968

THE LAND USE FORECAST IN

URBAN TRANSPORTATION STUDIES

Approved:

Date Approved by Chairman: 12/12/68

FOREWORD

The urban transportation problem is one of the most serious problems facing cities today. Urban transportation systems are failing to perform their function of providing for the efficient movement of people, goods, and services throughout cities. It is possible that the problems of traffic congestion in cities, unless solved, may lead to the economic decline of city centers.

To help solve the problems of urban transportation, transportation studies are being made or have been completed in hundreds of cities. These studies range in size from the Chicago Area Transportation Study, which spanned five years (1955-60), to studies for small cities, which can be completed in a few months.

Transportation planning is a major concern of the city planner. It is a specialized but integral part of city planning. City planners become involved with transportation studies in two ways: (1) they attempt to implement the final results of a transportation study in a city; and (2) they work with transportation planners in forecasting future urban land use as a part of the transportation study. Therefore, it is essential that city planners understand transportation studies.

The purpose of this thesis is to describe and evaluate the various techniques which are being used to forecast future land use in urban transportation studies and to make recommendations pertaining to the use of these techniques in transportation studies. The thesis should make the city planner aware of the importance of land use forecasts in urban transportation studies and help the city planner to understand the basic principles and strengths and weaknesses of various land use forecasting techniques.

Chapter I of the thesis presents some background information; Chapter II describes and evaluates some nonmodeling techniques of land use forecasting which have been used in transportation studies; and Chapter III describes and evaluates some modeling techniques. Chapter IV pertains to conclusions about the use of land use forecasting techniques in urban transportation studies.

The author wishes to thank the members of his thesis committee who have advised him in the preparation of this thesis. Special acknowledgement is due Professor Anthony J. Catanese who has served as thesis advisor and chairman of the thesis committee.

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SUMMARY

The purpose of this thesis is to describe and evaluate the land use forecasting techniques which have been used in urban transportation studies. In preparing this thesis the author investigated published literature in the fields of transportation planning and city planning.

It was found that the non-modeling techniques of intuitive judgment and land use accounting, accessibility models, linear programming models, simulation models and models derived through multiple regression techniques have all been used to forecast future land use in urban transportation studies. The thesis describes the procedures followed by transportation planners in utilizing the above techniques and evaluates the use of each technique to forecast future land use.

It was found that the following conclusions can be made pertaining to all of the techniques discussed in the thesis: (1) the large volumes of land use data required for urban transportation studies of large metropolitan areas and the complex nature of forces interacting in the urban land development process require the use of mathematical models to forecast future land use; (2) few significant tests have been made comparing the use of various land use forecasting techniques in the same city; (3) the use of mathematical models to forecast land use does not exclude the use of human judgment from the land use forecasting process; (4) the collection and analysis of land use data is an important part of any land use forecasting technique; and (5) the developmental process in an urban area should be thoroughly studied before the choice among land use forecasting techniques is made.

CHAPTER I

THE TRANSPORTATION STUDY AND THE GRAVITY MODEL

This chapter briefly presents background information necessary to an understanding of a discussion of land use forecasting in urban transportation studies. The urban transportation study is described and the relation of land use to the gravity model as used in urban transportation studies is discussed.

The Transportation Study

The following section describes the purpose and history of urban transportation studies. It also briefly discusses the procedures involved in urban transportation studies.

Purpose

Urban transportation systems perform the function of providing for the efficient movement of people, goods, and services in an urban area. Elements of these systems consist of urban freeways, arterial streets, collector streets, local streets, urban bus systems, and other forms of mass transit, such as rapid transit. The efficiency and effectiveness of an urban transportation system are measured by the ability of its elements to accommodate all of the desires to make trips which are generated in an urban area.

The purpose of urban transportation studies is to determine present and future demands, in terms of trip desires, for transportation services in an urban area and to analyze the existing urban transportation system in terms of these demands. Transportation studies propose changes in existing transportation systems or entirely new systems to meet the present and future transportation demands of urban areas.

History

Transportation planning in America has gone through three periods in the Twentieth Century (1). These periods involved the development of statistical techniques utilizing traffic counts, the development of origin-destination studies, and the development of traffic models.

In the 1920's, procedures relating to traffic counting techniques and to statistical methods of projecting traffic counts were devised. As the field of transportation planning developed it was recognized that traffic counts alone could not accurately predict future travel desires. Thus, origin-destination surveys were initiated in the 1930's.

Origin-destination surveys, which consist of roadside, post card, or telephone interviews of drivers to determine daily origins and destinations of trips, measure existing urban travel patterns. However, they do not provide information about future changes in travel patterns (2). Changes in urban transportation systems and changes in land use as the metropolitan area grows result in similar changes in travel patterns. Since World War II transportation planners have experimented with a number of techniques to forecast traffic generation and distribution in urban transportation studies.

Therefore, in the 1950's mathematical models aimed at overcoming the deficiencies in older methods of traffic forecasting were formulated. Traffic models have been developed and successfully applied for transportation planning purposes in a number of large urban areas during the last decade (3). Traffic models are mathematical formulas or sets of formulas used to calculate a dependent variable, such as the number of trips between zones, based on its relationships to other variables, such as the distance between zones. These models carry out what is essentially a simulation of traffic flow throughout the urban area under study during a typical twenty-four period at one or more future target years (4). Estimates of the distribution of population, employment, and other land use activities in question are required as inputs to the traffic models (5).

Procedures

Modern urban transportation studies utilizing traffic models involve: (1) transportation study zones; (2) inventories; (3) analyses of existing conditions and calibrations of forecasting techniques; (4) forecasts; and (5) a systems analysis (6). Figure 1 presents a block diagram of the procedures of an urban transportation study. These procedures are discussed below.

Transportation Study Zones. One of the first and most important steps in an urban transportation study is the division of the urban study area into a number of zones. These zones form the basis for all of the work of the urban transportation study. They provide workable study areas for the collection and analysis of data such as the location of origins and destinations of trips and the location of potential areas of growth in the urban area.

Study zones also serve as locational bases for the description of travel patterns in the urban area. Trip desires in an urban area must be located geographically in order to plan future urban transportation

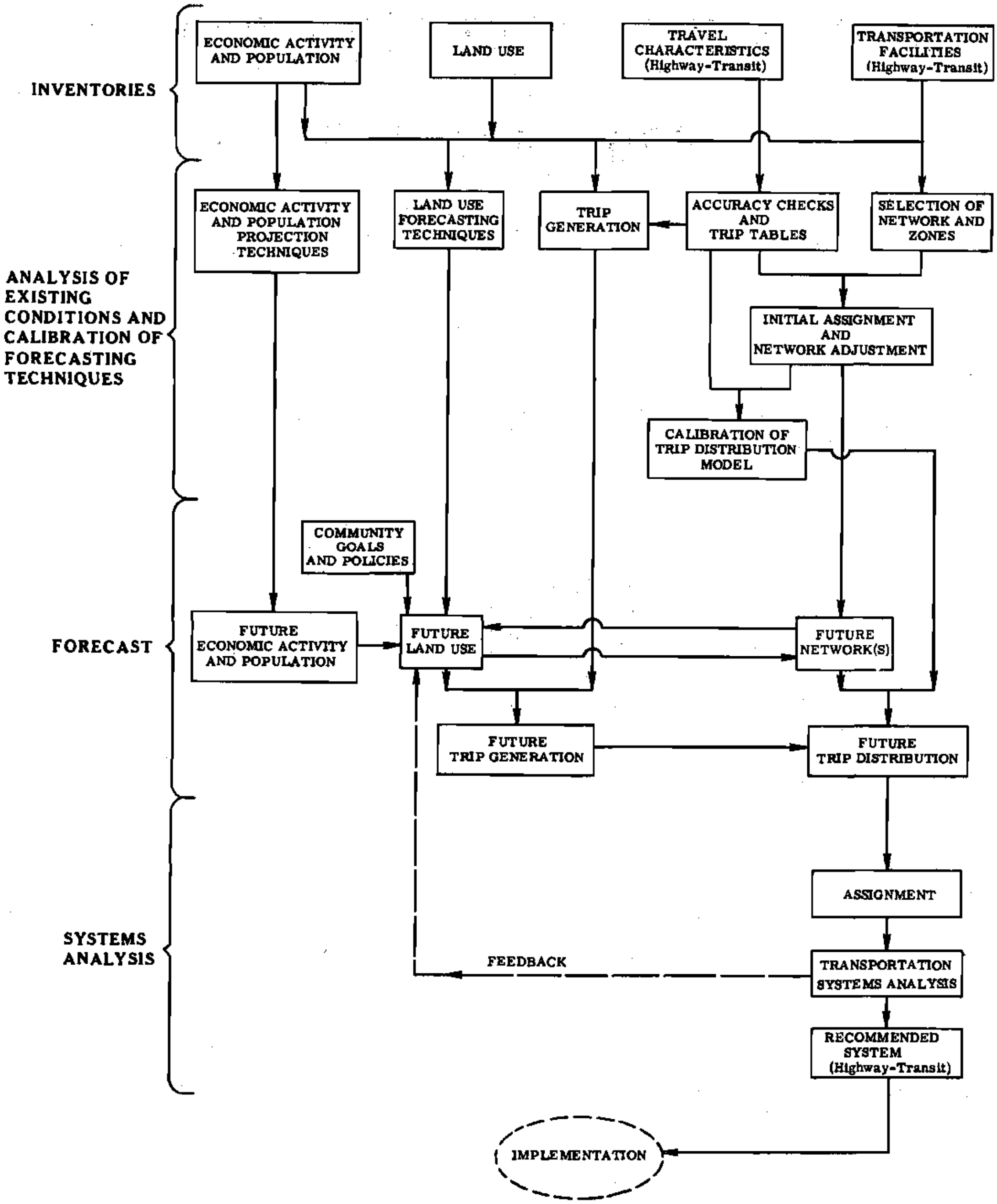

Figure 1. The Urban Transportation Study

Source: Bureau of Public Roads. Guidelines for Trip Generation Analysis. Washington: United States Government Printing Office, June, 1967, p. 3.

networks. For example, analysis of origin-destination data in a transportation study might locate 200 trips per day as being generated between a residential zone and a zone which contains a small industrial park.

Because study zones serve as a basis for data collection and trip descriptions in an urban transportation study, it is important for the transportation planner to understand how study zones are delineated. The following three rules are considered in designating the boundaries of zones in an urban transportation study:

(1) Zonal boundaries should correspond closely to boundaries of census tracts in order to facilitate the collection of data about population characteristics within zones (7).

(2) Zonal boundaries should be designated to include areas of homogeneous land use wherever feasible (8).

(3) Zones should be rectangular or circular in shape wherever feasible. Transportation studies assume that all traffic generated in a zone is generated at the zonal centroid. If zones are rectangular or circular in shape, the computations locating the zonal centroid are more easily made than if zones are irregularly shaped (9).

<u>Inventories</u>. The inventory phase of the urban transportation study involves the collection of data. Data about economic activities and population, land use, travel characteristics, and transportation facilities are gathered.

Data about transportation facilities provide the transportation planner with a complete description of the physical elements of an existing transportation system. Such data are obtained from inventory surveys which catalogue all existing urban street and highway locations and capacities as well as from surveys of existing mass transit services, showing the location of transit routes and the quality of services offered (10).

Data about travel characteristics are obtained from volume counts and from origin-destination surveys. Volume counts are made in order to determine the existing number of vehicles utilizing specific elements of the transportation system. Volume counts are made either manually or by mechanical devices on all of the major streets and highways of a transportation system. Origin-destination surveys are made in order to determine the origins and destinations of present trips being made in the urban area. Surveys are made by interviewing drivers of vehicles at interview stations placed along existing streets and highways, by mail interviews, or by telephone interviews. The interviews usually provide information such as location within the urban area at which a trip originates, location within the urban area for which the trip is destined, the purpose of the trip, the number of people in the vehicle, and the time of day of the trip.

Data about existing land use and existing economic activity and population in the urban area are obtained from inventory surveys. Often such data are available from city planning staffs in the urban area under study.

Analyses and Calibrations. The third phase of an urban transportation study involves the development and calibration of forecasting techniques to be used in determining future travel demands in terms of future trips. Population and employment projection techniques, land use forecasting techniques, and trip generation and distribution techniques are chosen and calibrated.

Forecasts. The fourth phase of an urban transportation study involves the application of the forecasting techniques developed in the third phase to the data collected in the second phase. Predictions of future population and employment are made and used as inputs to the technique used to forecast future land use. The land use forecast is used as an input to the forecasting technique used to predict future trip generations and distributions. The output of the fourth phase is a forecast of future trip patterns in the urban area.

Systems Analysis. The final phase of an urban transportation study is a systems analysis. The existing transportation system is analyzed in terms of its ability to accommodate the trip patterns forecast in the fourth phase, and a future system which will meet future demands is planned.

The urban transportation planning process should contain a feed-back step in which the effect of planned transportation systems on future land use is considered. New elements in urban transportation systems generate changes in urban land patterns which, in turn, generate future trips. Thus, the effect of planned systems on land use and trip generation must be considered.

The Gravity Model

Gravity models, intervening opportunity models, and competing opportunity models have been employed in the procedures of forecasting and distributing trips in recent urban transportation studies. Gravity models have been used in most urban transportation studies because the input requirements are relatively simple and because they can approximate within acceptable limits of accuracy, mass automobile movements (11). Also, the Bureau of Public Roads has published a number of manuals related to the use of gravity models in transportation studies, thus facilitating and encouraging the use of gravity models.

Theory

All gravity models are based on an analogy of the theory exhibited in Newton's formula for the attraction between two bodies. Objects are said to attract each other with a force directly proportional to the mass of the objects and inversely proportional to the distance between the objects.

In 1955, Alan Voorhees recognized the similarities between the Newtonian concept of the attraction between two bodies and the competition among zones in an urban area for the attraction of trips. He developed a traffic gravity model to describe the attraction of trips to zones in an urban area.

A gravity model applies the Newtonian concept of gravitational attraction by representing mass as the trip attracting and trip producing powers of zones and by representing distance as the travel time between zones. Thus, traffic between zones in an urban area is directly proportional to the trip producing and attracting powers of zones and inversely proportional to travel time between zones.

Sample Model

An example of a simple transportation gravity model is explained below.

$$T_{ab} = \frac{P_a \times A_b \times t_{ab}}{\Sigma (A_i \times t_{ai})}$$

Where T_{ab} = the total number of trips generated from zone "a" to zone "b";

P_a = a trip production index for zone "a", which is an indicator of the trip producing potential of that zone;

A_b = a trip attraction index for zone "b", which is an indicator of the trip attracting potential of that zone;

t_{ab} = a travel time factor indicating the difficulty of traveling from zone "a" to zone "b";

A_i = a trip attraction index for any zone "i"; and

t_{ai} = a travel time factor indicating the difficulty of traveling between zone "a" and any zone "i".

In order to improve the accuracy of transportation studies, different trip types have been developed. Many studies classify trips by purpose, such as work trips, shopping trips, and social-recreational trips. Separate production and attraction indices are derived for each trip type for each zone, and the gravity model is then used to calculate the number of interzonal trips of each type.

<u>Trip Indices and Land Use</u>

As shown above in the sample model, the calculation of future travel patterns in an urban area, which is the output of the gravity model, is based on trip production and trip attraction indices for zones. This section describes how these indices came to be based on land use data and projections. It also describes types of land use information which have been used for trip indices in recent urban transportation studies.

Trends Towards Utilization of Land Use Data. Urban transportation studies have used a number of techniques to obtain the trip production and attraction indices used in the gravity model. In the past these techniques have consisted of the calculation of growth indices for zones. These growth indices for zones were then applied to existing trip productions and attractions for zones as estimated from origin and destination studies. Growth indices were calculated by techniques such as the ratio method in which the growth of zones was likened to that growth anticipated for the city or state; the three factor method which expressed zonal growth as proportional to anticipated population growth and increases in motor vehicle registrations in zones; and the driver population method which expressed zonal growth as proportional to driver population growth in zones.

However, as the number of urban transportation studies increased and analyses of urban transportation systems grew in number it became evident that trip generation and distribution in an urban area were a function of the land use pattern of the urban area. A study conducted by Shuldiner illustrated this fact by showing how trip generation rates varied in urban areas. Table 1 shows the results of Shuldiner's survey. In recent years urban transportation studies have found that three factors related to land use influence trip generation and distribution: (1) intensity; (2) character; and (3) location.

Intensity of land use is the amount of a given land use activity

Table 1. Summary of Trip Generation Rates for Ten Metropolitan Areas

Metropolitan Area	Residential A	Residential B	Commercial A	Commercial B	Industrial A	Industrial B
Tucson	18.2	13.0	134.3	112.6	3.9	4.3
Twin Cities	26.5	15.2	187.9	118.7	12.6	9.3
Corpus Christi	30.5	19.7	174.4	127.7	10.6	8.6
Pittsburg	23.9	14.6	157.8	110.6	24.6	21.7
Chicago	48.5	26.1	181.4	144.6	22.0	16.0
Detroit	29.1	--	271.2	--	37.2	--
Hutchinson	--	13.3	--	63.3	--	2.5
Ann Arbor	--	12.1	--	75.6	--	5.9
Flint	--	11.8	--	16.1	--	20.1
Baltimore	18.7	--	121.4	--	8.2	--

Metropolitan Area	Public & Quasi Public A	Public & Quasi Public B	Public Buildings A	Public Buildings B	Public Open Space A	Public Open Space B
Tucson	14.3	8.8	--	--	--	--
Twin Cities	17.4	7.5	--	--	3.5	1.5
Corpus Christi	35.3	22.0	--	--	--	--
Pittsburg	15.9	6.8	21.3	35.0	2.3	1.3
Chicago	12.4	6.0	8.6	10.2	4.2	3.1
Detroit	16.5	--	--	--	3.4	--
Hutchinson	--	9.8	--	0.9	--	--
Ann Arbor	--	28.1	--	--	--	--
Flint	--	1.6	--	--	--	--
Baltimore	9.4	--	--	--	--	--

A = person trips generated
B = vehicle trips generated

Source: Shuldiner, Paul, W. "Land Use, Activity, and Non-Residential Trip Generation," Origin and Destination. Highway Research Record 141. Washington; Highway Research Board, 1966, p. 75.

found in a given areal unit and is usually stated in terms of density variables such as dwelling units per acre. Variations in intensity of land use affect trip generation. For instance, residential areas with high population densities tend to generate fewer trips per dwelling unit than areas with low population densities.

Character of land use refers to the type of activity performed on a given areal unit of land. For instance, character could be reflected in variables such as manufacturing versus commercial employment or retail versus wholesale floor area. Again, Table 1 illustrates how trip generation rates in urban areas vary for different types of land use.

Location refers to the spatial distribution of land uses and land use activities within the urban study area. The location of residential land use activity in the urban area has a definite effect on the number of trips generated by residential areas. For instance, dwelling units on fringe areas of the urban area generate more trips per day than dwelling units adjacent to the central business district.

Because of the discovery that intensity, character, and location of land uses affect trip generation and distribution in urban areas, trip production and attraction indices based on land use data and projections were developed to replace the older trip indices based on simple growth formulas.

<u>Types of Indices</u>. Trip production and attraction indices utilizing many types of land use data projections have been developed. Table 2 shows types of land use data which have been recommended by Voorhees to calculate trip indices in gravity models. Gravity models in transportation studies have used many types of land use data other than those

Table 2. Land Use Data Used to Calculate Trip Indices

Purpose of Trip	Type of Land Use Data
Work	Number of Employees
Social	Number of Dwelling Units
Shopping	
Convenience	Retail Floor Area for Food & Drugs
Comparison	Retail Floor Area for Apparel Goods
Business	Business Floor Area
Recreation	Recreational Floor Area

Source: Voorhees, Alan M. "A General Theory of Traffic Movement," Proceedings of the Institute of Traffic Engineers. New Haven: The Institute, 1955, p. 54.

listed in Table 2 to calculate trip production and attraction indices. Appendix A lists some of those types of land use data.

A knowledge of the calculation of trip attraction and production indices is necessary to an understanding of the relationship between trip generation, as calculated by the gravity model, and land use data and projections. Many of the formulas used to calculate trip attraction and production indices are quite complex. However, Appendices B and C illustrate some relatively simple formulas based on land use forecasts which were used to calculate these indices in the Nashville Transportation Study and the Fort Worth Transportation Study.

Thus, in recent years the land use forecast has become an important part of the urban transportation study. Use of the gravity model depends on trip production and attraction indices which are based on land use data and projections of those data.

CHAPTER II

NON-MODELING METHODS OF LAND USE FORECASTING

This chapter discusses and evaluates two non-modeling methods of land use forecasting which have been used in urban transportation studies. The use of intuitive judgment to forecast land use and the land use accounting technique of forecasting are presented.

Intuitive Judgment

In many urban transportation studies for small or medium-sized cities, the land use forecast is based solely on planners' experience with and knowledge of an urban area. This method of land use forecasting is often referred to as intuitive judgment (12).

The Intuitive Process

In utilizing intuitive judgment to forecast land use, the transportation planner distributes forecasts of future population and employment for the entire city among the zones designated in the transportation study. The steps which the transportation planner follows in the intuitive process are described below.

Step 1. Forecasts are obtained of future population and employment for the entire urban area being studied. Such forecasts are usually obtained from local city planning staffs.

Step 2. A study is made of development policies which may affect the future land use pattern of the city. An analysis of land use plans, official maps, and zoning ordinances often reveals such policies. The effects of urban renewal, slum clearance, and central business district redevelopment, and of new residential, commercial, and industrial construction on existing land use patterns are also considered.

<u>Step 3</u>. A thorough familiarity with each zone in the study area is obtained in order to estimate the potential of each zone for attracting future development. This step often requires analyses of census tract data and windshield or on-foot surveys of each zone.

<u>Step 4</u>. Portions of the total urban area population and employment growth are assigned to each zone in the urban area on the basis of the analyses in Steps 1 and 2. For instance, zones which are undeveloped and designated for residential development in the land use plan might be large portions of the anticipated urban population growth based on density standards expressed in the zoning ordinance. Residential zones which are fully developed might be assigned minute portions of the anticipated urban population growth. Likewise, zones which are undeveloped and designated for commercial and industrial development might be assigned portions of the anticipated employment growth based on their accessibility to residential areas or on the topography of the land or the availability of utilities; and, commercial or industrial zones which are fully developed might be assigned portions of future employment based on the expansion plans of existing businesses and industries.

<u>Step 5</u>. Estimates are made of specifically what changes in the land use pattern in each zone might take place due to the portion of the future population and employment growth of the city assigned to each zone. For instance, vacant land in each zone is analyzed to predict what its specific type of land use activity will be in the future (i.e. will a

vacant parcel be developed as a shopping center or as a service station). Also, built-up portions of zones are analyzed to determine whether they are likely to be redeveloped, and, if so, what the redeveloped land use activity will be.

Evaluation

The intuitive process is commonly used by transportation planners to forecast land use patterns in urban transportation studies for small or medium-sized cities (13). In small cities which are not part of metropolitan areas, changes over time intervals of five or ten years may not be very large. Perhaps, only one or two industries or one or two housing subdivisions will be added to a small city in a five year period. Because of the relatively stable land use patterns of these cities, the distribution of future population, employment, and land use activities among zones in an urban transportation study is most easily accomplished through the use of the intuitive process.

Also, urban transportation studies are carried out on limited budgets, especially in small cities. Because of the stable land use pattern existing in most of these cities, expenditures in transportation studies to develop sophisticated techniques for land use forecasting are not warranted. Thus, the use of the intuitive process to forecast land use in studies of these cities is favored.

The intuitive process is especially adaptable for use in transportation studies of cities in which a considerable amount of city planning has been done and which possess an experienced city planning staff. In such cities data, such as information about existing land uses in zones and the location of parcels of vacant land, and projections, such as total urban population and employment growth, can be obtained from the city planning staff for use in estimating future land uses in zones. Often, local city planning staffs have already carried out certain steps in the intuitive process, such as the estimation of total urban population and employment growth and analyses of existing developmental policies in areas of the city; and, transportation planners only have to carry out a few of the steps of the process, such as the analyses of vacant land in zones. In some cities local planning staffs have developed complete forecasts of future land use activities in zones in the urban area which can be easily adopted to the needs of the transportation study by the transportation planning staff.

The intuitive process should not be used to forecast land use in urban transportation studies of large urban areas. The factors which influence the growth and distribution of population, employment, and land use activities in large urban areas, such as public and private policy decisions, are so numerous and so complexly intermingled, that the intuitive process becomes difficult to apply. Also, in transportation studies of large cities, the study zones are numerous and the data pertaining to land use patterns which must be collected and analyzed are voluminous. For instance, in the Philadelphia metropolitan area there are over 800 transportation study zones and 250 districts; thus, there are over 60,000 possible interactions between pairs of such districts (14). Thus, no one group of planners can analyze all the parcels of vacant land in a large city and accurately predict the specific type of development which would take place on each parcel.

The calculations of trip attraction and production indices for gravity models in transportation studies of large urban areas require detailed forms of land use data and projections. For instance, Appendix A shows that population densities, dwelling unit densities, and commercial employment are some of the data required to calculate trip indices in various urban transportation studies. The use of the intuitive process can supply forecasts of population and employment growth in zones; but the use of intuitive judgment alone cannot produce these detailed forms of land use projections.

Land Use Accounting

Land use accounting is a technique of land use forecasting which was used in the Chicago Area Transportation Study and in the Pittsburg Area Transportation Study. Basically, it is a trend projection technique.

Theory

In using the land use accounting technique past patterns and trends of land use in an urban area are studied and principles governing land development for the urban area are developed. Future land use patterns are forecast by applying these developed principles to the existing land use pattern.

Land use accounting techniques have been used in cities where the following principles of land development have existed (15):

(1) A decline in density of land development as distance from the central business district increases;

(2) A decline in the proportion of land in use as distance from the central business district increases; and

(3) A stability over time in the proportions of land devoted to

each type of land use.

Procedures

The steps followed in the land use accounting technique of forecasting future residential land use are described below (16).

Step 1. The metropolitan area is portioned into a set of concentric rings (usually of one mile radii). Zones are established within the boundaries of the rings.

Step 2. An estimate is made of the amount of vacant residential land in each zone of the study area. This estimate can be made from analyses of existing land use inventories or from actual surveys of land use in the zones.

Step 3. Future densities for each zone are predicted. These predictions are usually based on existing land use and zoning policies.

Step 4. A residential capacity for each zone is calculated. A zonal residential capacity is defined as the existing number of residents in the zone plus the product of future residential density of the zone times the amount of vacant land zoned residential in the zone. Examples of calculations of zonal capacities are given in Appendices D and E.

Step 5. The data about existing residential development and zonal capacities are analyzed and existing residential saturations for each zone are calculated. A residential saturation curve is plotted showing percentage residential saturation versus distance from the central business district. An example of the form of a typical residential saturation curve is given in Figure 2.

Step 6. A residential saturation curve is derived for the future study year by projecting the present density gradient for the urban area

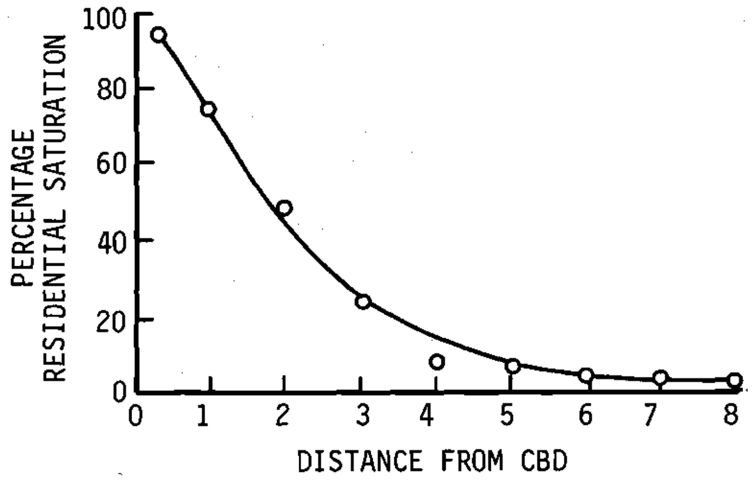

Figure 2. Existing Residential Saturation Curve.

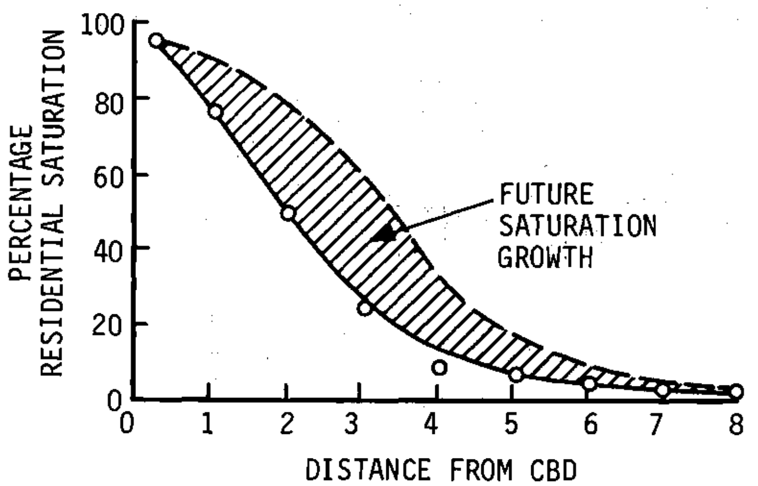

Figure 3. Future Residential Saturation Curve.

SOURCE: Swerdloff, Carl, N. and Stowers, Joseph, R. "A Test of Some First Generation Residential Land Use Models," Land Use Forecasting Techniques. Highway Research Record 126. Washington: Highway Research Board, 1966, p. 42.

into the future. The only restraint on this projection is that the area between the present and future saturation curves must equal the total projected population growth for the urban area. Figure 3 shows an example of a future residential saturation curve.

Step 7. Future residential saturations for each concentric ring in the urban area are obtained from the future residential saturation curve.

Step 8. Projected growths for each ring are distributed to the zones within each ring in proportion to the residential capacities of each zone.

Chicago Area Transportation Study

A good example of the use of the above steps of the land use accounting technique to forecast land use in urban transportation studies is illustrated by the forecasting method used by the Chicago Area Transportation Study (CATS), which is one of the most publicized transportation studies. The technique used in the Chicago Area Transportation Study resulted in a forecast for 1980 of zonal populations and employments and of acreages devoted to each major land use in each zone. A description of the Chicago method of forecasting land use shows how the steps of the land use accounting technique are applied in urban transportation studies.

Input Data. The first step in the Chicago technique was the collection of data. The basic data required were descriptions of the base year land use patterns, information about existing zoning and development policies pertaining to the use of vacant land, and forecasts of the 1980 population and employment in the Chicago area (17).

Phases. After the collection of data the Chicago technique of land use accounting consisted of the following three phases (18):

(1) An examination of the stability of the existing land use pattern to determine which zones would probably remain stable in the future;

(2) A classification of vacant land in the study area according to its possible types of future development; and

(3) A distribution of future population, employment, and land uses through the calculation of zonal capacities and saturation curves as described above.

<u>Evaluation</u>

The land use accounting technique of forecasting is a trend projection method. It examines past trends in land development, assumes that these trends will continue in the future, and predicts future land use on the basis of these trends. The technique is insensitive to changes in public and private policies which may produce changes in past trends.

An example of the insensitiveness of the technique to changes in trends is illustrated by the calculation of residential zonal capacities, described above in Step 4. Residential zonal capacities, which are essential to this forecasting technique, are based on estimates of future population densities which are based on existing zoning policies. However, these zoning policies are subject to change. Thus, changes in past trends over the time span of a forecast may result in inaccurate forecasts.

The land use accounting technique requires the use of much judgment on the part of transportation planners, especially in the projection of saturation curves, described above in Step 6. For example, the projection of saturation curves in a land use accounting technique developed for forecasting land use in the Greensboro, North Carolina area involved the following assumptions on the part of the transportation planning staff (19):

(1) The bulk of residential growth would occur in the two, three, and four mile rings.

(2) The inner ring (core ring) would suffer a slight decline in residential population.

(3) The shape of the density gradient would tend to bow out in the one, two, and three mile rings.

(4) The sharp transition found in the existing saturation curve would be less abrupt in the projected curve.

(5) Areas five miles or further from the core would exhibit some growth, but the projected curve would be flat beyond five miles.

The land use accounting technique has some weaknesses. Like the intuitive judgment technique, it requires the analysts to become intimately familiar with the zones in a study area in order to calculate future zonal densities and capacities. This process of familiarization is time-consuming. Also, the output data from the technique is fairly general in form, consisting usually of estimates of zonal population, employment, and various land acreages. More detailed information about future land use, such as intensities of future development, cannot be obtained.

The land use accounting technique should only be used in cities which exhibit a fairly uniform decline in density of land development as distance from the central business district increases and a decline in the proportion of land in use as distance from the central business district increases. Declines in density and per cent capacity result from the operation of the competitive land market, a mechanism which might not exert the dominating influence upon spatial organization in all cities (20). The basis for the land use accounting technique of forecasting lies in the projection of saturation curves for future years based on the shape of saturation curves from past years, as is explained above in Steps 5 and 6. If saturation curves from past years do not exhibit uniformity in shape, they cannot be accurately projected to the future.

The land use accounting technique of land use forecasting was used in some of the earlier metropolitan transportation studies, such as the Chicago Area Transportation Study, when the techniques of trip projection being used did not require detailed estimates of future land use activities. As shown earlier, in Table 1, the first gravity models relied only on such indicators of land use intensity as the number of employees in a zone or the number of dwelling units in a zone to calculate the number of work and social trips in an urban area. Land use accounting techniques can provide those types of projections. However, the development of gravity models requiring sophisticated calculations of trip attraction and production indices has required detailed forms of land use data, such as those listed in Appendix A. Existing land use accounting techniques do not produce these forms of projections.

CHAPTER III

MODELING METHODS OF LAND USE FORECASTING

This chapter describes and evaluates some of the mathematical modeling techniques which have been used to forecast land use in urban transportation studies. Accessibility models and the modeling methods of multiple regression, linear programming, and simulation are presented. The chapter begins by describing the development of land use models in the field of urban transportation planning.

The Development of Models

Mathematical models were developed to forecast land use in many transportation studies in order to avoid basing sophisticated transportation studies on inputs of land use data which had been produced by trend projection methods such as land use accounting (21). Trend projections, modified by judgment according to the expected impact of transportation and other public policies, are not easily reproducible, except by the same planning team (22). Also, the actual preparation of trend projections is time consuming, often spanning many calendar months (23).

Description of Models

Land use models are mathematical formulas or sets of formulas capable of forecasting detailed urban development patterns based on existing patterns of development and on changes in "policy variables" (such as transportation facilities, open land policies, zoning policies, and taxation policies) (24). Models use mathematical relationships to show how "located variables" (such as population, employment, and structures) are influenced in their locational patterns by "locator variables" (such as accessibility to various activities, zoning, quality of public utilities, taxes, and population densities) (25).

"Policy variables" are quantified descriptions of the various public policies which affect land development. Examples of policy variables are described as follows:

(1) Policy variables describing transportation policies might consist of data about the capacities of streets in a given zone or of data about capacities and frequencies of bus service to a zone.

(2) Policy variables describing zoning policies might consist of data about allowable densities of development in zones or of indices describing the types of development allowed in a zone.

(3) Policy variables describing public policies pertaining to extensions of utilities might consist of data about the cost to developers of having utilities supplied to a zone or of data about the capacities of existing water and sewer lines.

(4) Policy variables describing taxation policies might consist of data about the average property taxes in zones.

The purpose of policy variables is to describe the effects which various public policies have on a given zone. For instance, a change in zoning policy which increased the allowable densities in a residential zone would change the value of the zoning policy variable of the zone. This change in the zoning policy variable would reflect the increased potential of the zone for residential development.

"Locator variables" are quantified descriptions of existing elements in the land use pattern of zones which affect the potential of zones for future development. Some examples of locator variables are described as follows:

(1) The accessibility of a residential zone might be described by the capacities of transportation routes between the zone and the central business district or between the zone and industrial areas.

(2) The rail service to a potential industrial zone might be described by the miles of track which border vacant land.

(3) The drainage characteristics of certain zones might be described by coefficients of runoff or by the slope of the land.

(4) The amenities of a residential zone might be measured by the air pollution content found in the atmosphere or by the acreages of park land in the zone.

"Located variables" are the outputs of models. They are variables which are placed in future locations throughout the urban area. Located variables consist of all forms of information about intensities of population, employment, and land use in the zones of an urban area.

Advantages of Models

Mathematical models have many characteristics which have made their use advantages to the use of older forms of analysis and forecasting. Their greatest advantage is their adaptability to computers. Computers can analyze the tremendous amounts of data required by metropolitan, regional, and state transportation studies; apply those data to equations; and solve the equations in a matter of hours. Analyses by humans in similar situations are impossible. For example, a study by Traffic Research Corporation for the Boston Regional Planning Project developed five forecasting equations for each of five located variables (white collar population, blue collar population, retail-wholesale employees, manufacturing employees, all other employees) in each of 29 zones in Boston, or 145 forecasting equations (26). These equations were solved simultaneously on an IBM 7070 computer in one-half hour. A solution of these equations by a team of humans would have been nearly impossible.

Another advantage of models is that through the use of computers they can receive changes in raw data over time and, accordingly, produce changes in output forecasts over the span of a transportation study. An urban transportation study may span many years, as the Chicago Area Transportation Study did (1955-1960), and factors affecting land use in urban areas are very likely to change over time. For instance, zoning policy variables may change between 1965 and 1970 due to political pressures, and located variables such as street capacities may change due to increases in traffic volumes over time. However, because models are adaptable to computers, models can be recycled through computers with sets of updated data pertaining to changes in policy and located variables, and updated forecasts will be produced. Thus, models allow forecasts to keep up with the dynamic patterns of urban development.

Modeling techniques have the advantage of assuring that the forecasting procedure is internally consistent (27). All projects involving comprehensive planning for any large area result in volumes of detailed work which rapidly become unmanageable (28). As a result, interrelations are overlooked, simplifying assumptions are made, and detailed consistency checks are abandoned in the interest of "getting the job done" (29). However, the use of modeling techniques assures that the same process and same set of formulas and assumptions will be followed in calculating similar located variables in different zones. There is no chance that a located variable, such as retail floor area, will be calculated one way in one zone and differently in another zone because the same weighted factors are applied in the same relationships in each calculation.

Also, modeling techniques of forecasting reduce omissions of factors affecting land use and mis-statements about land development by making necessary the explicit statement of all assumptions (30). Land use models must be structured by planners; and, model building requires that all assumptions about the effect of factors on land development be clearly defined in order to be included in the structure of a model.

Accessibility Models

Accessibility models are of historical significance because they were the first type of land use forecasting model developed. The National Capitol Transportation Agency and the Hartford Metropolitan Area Transportation Study developed models which related future land use development to accessibility. The following model, developed by Walter Hansen for the Washington, D.C. area, is typical of an accessibility model (31).

$$\frac{P_i}{P_t} = \frac{A_i^{2.7} O_i}{\Sigma A_j^{2.7} O_j}$$

Where: P_i = increase in residential population in zone "i",

P_t = total increase in metropolitan population,

A_i = an accessibility index for zone "i" based on its accessibility to future employment centers,

O_i = number of acres of developable land in zone "i",

and

$\Sigma A_j^{2.7} O_j$ = sum of the products of $A^{2.7}$ and O for all zones.

In the above model the exponent "2.7" was developed empirically from test data for the Washington area.

Accessibility models did not prove to be sufficiently accurate forecasters of land use. The above model was tested against data for the Washington area for 1948-55. Data describing vacant land in zones and accessibility of zones in 1948 were used as input for the model, and forecasts of population growth in zones for the period 1948-55 were obtained as output. These forecasts were compared with actual zonal population growths for the time period. It was found that the model forecast population increases for 40 per cent of the zones within ±30 per cent of the actual increases and that it forecast population increases for 70 per cent of the zones within ±60 per cent of the actual increases (32).

Multiple Regression

Multiple regression is a technique which is used to derive land use models. Basically, models derived from multiple regression techniques are trend projections. Multiple regression techniques were used to derive land use forecasting models in order to base these models on many locator variables, rather than on one or two locator variables, as in the accessibility model.

Theory

Multiple regression is a statistical technique. An example of the simplist form of regression is the use of the method of least squares to fit an equation to a set of data points about two different variables, thus establishing a mathematical relationship between the two variables. Multiple regression is an expansion of the techniques used in the method of least squares; and equation is developed through complex statistical techniques which fit the equation to data about a number of variables, rather than only two variables.

Through the use of computers which have been programmed to perform multiple regression techniques, data about factors which contribute to a certain type of variable to be forecast (such as white collar employment in a zone) are reviewed; the factors most clearly associated with white collar employment are selected; and, a forecasting equation relating those factors to white collar employment is developed.

Procedure

In utilizing multiple regression techniques to develop a land use model the steps listed below are followed.

Step 1. The variable to be forecast is chosen (located variable). For instance, a forecast of retail floor areas in all zones in 1980 may be desired.

Step 2. Those factors which contribute to the development of the located variable are selected. These factors are the locator variables. For instance, average family income, acres of vacant land, accessibility, and automobile ownership patterns may be selected as factors contributing to the amount of retail floor area in zones.

Step 3. Data about the changes in the located variable over a recent time period are gathered. For instance, data about the changes in retail floor area in all zones for the period of 1955-65 might be collected.

Step 4. Data about the changes in locator variables over the same time period are collected.

Step 5. All of the data about the located and locator variables are placed into a computer which has been programmed to perform multiple regression techniques.

Step 6. The computer performs the actual multiple regression procedures. It is programmed to proceed step-by-step through the several locator variables and determine the degrees of correlation of each locator variable to the located variable. It keeps track of the inter-related effects of all the locator variables on the located variables and develops a forecasting equation relating the variables.

Baltimore Model

In a study made by the Baltimore Regional Planning Council, multiple regression was used to derive models for forecasting land use. The models which were derived to forecast zonal population growth and zonal manufacturing growth are described below (33).

$$P = 0.5A + 9364B + 283C - 1.5D + 36{,}089E - 34{,}837$$

Where: P = growth in population of a zone,

A = acres of available vacant residential land in a zone,

B = an index describing accessibility of the zone,

C = the percentage of land in the zone with water and sewer facilities available,

D = the total value of residential structures in the zone, and

E = the relative income of the zone.

$$M = 1.7A + 0.8B + 31C - 1839D - 625E - 6493$$

Where: M = growth of manufacturing employment in a zone,

A = acres of available vacant industrial land in a zone,

B = the total value of industrial structures in the zone,

C = the percentage of land in the zone with water and sewer services available,

D = the miles of rail service per acre of industrially zoned land in the zone, and

E = the miles of deep water frontage on industrially zoned land in the zone.

The large regression constants (34,837 and -6493) found in the above equations are not unusual in equations derived from multiple regression (34). However, the analyst should recognize that difficulties arise in utilizing equations derived from multiple regression when large coefficients occur in equations in which the values of the other coefficients are relatively small (35). In the Baltimore models the values of the coefficients (A, B, C, D, and E) and of the dependent variables (P and M) were large enough to avoid difficulties due to the large regression constants.

Most models which have been developed by multiple regression techniques to forecast manufacturing growth have used locator variables similar to those used in the Baltimore Model. Appendix F gives an example of a model developed to forecast manufacturing growth in the Hartford Metropolitan Area Transportation Study. This model used highway and airport accessibility, tax rates, and promotional indices as locator variables, in addition to those variables used in the Baltimore Model.

It is important to understand the steps with which transportation planners become involved when developing models such as the Baltimore or Hartford Models. A description of the procedures followed by transportation planners from Traffic Research Corporation in developing land use models for the Boston Regional Planning Project gives an illustration of the application of the steps described above to the actual development of models.

<u>Boston Project</u>

In May of 1963, Traffic Research Corporation began a project of land use model development for the Boston Regional Planning Project. The purpose of the project was to develop models to predict the amounts of several urban land use activities in each zone at the end of a given forecast period. The procedures followed in developing the Boston Models are as follows:

(1) The Boston Region was divided into zones.

(2) The land use activities to be forecast were chosen (located variables).

(3) The factors whose location and intensity were related to land development were established (locator variables).

(4) The object of the multiple regression techniques was decided

upon. The model which was to be developed would predict zonal shares of land use activities proportional to the change in zonal share of all other land use activities, the change in share of locator variables, and the absolute value of locator variables in the zone.

(5) One equation for each land use activity was established by computer multiple regression analysis of data from two past points in time (1950 and 1960).

(6) The equations were used to estimate future zonal shares of land use activity by substituting the present values of locator variables into the equations and solving them.

Evaluation

Multiple regression techniques of developing land use models have the advantages of being able to handle large inputs of data and of flexibility. Multiple regression techniques can take large amounts of data in raw form, analyze them, and produce a set of land use forecasting equations. These equations are flexible because the multiple regression technique can be re-run to include new data for the production of updated equations.

In reality, multiple regression techniques of developing models for land use forecasting are complex methods of trend projecting. Data from the past are analyzed by computers in order to establish a mathematical relation between locator and located variables. These mathematical relations based on past data are used to forecast future land use patterns.

If trends in land development change, forecasts based on multiple regression models will be inaccurate. For instance, the Hartford models, derived by multiple regression, did not adequately describe the distribution of growth in the Hartford area between 1950-58 due to changing trends (36). Much industrial development was not predicted in a certain traffic corridor, population growth tended to be underestimated in the suburbs, and, because of the development of large shopping centers, retail employment patterns did not correspond to the patterns of distribution predicted (37).

The main problem in the use of multiple regression techniques is the use of locator variables. It is difficult to identify and measure all of the factors which contribute to land development in a metropolitan area. Often certain factors affecting land development can be recognized but not easily quantified. For instance, it is known that the decision making process of families concerning household location definitely affects patterns of land use. However, it is difficult to measure this decision process in order to incorporate it into a model.

Thus, the selection of locator variables is the most important and most critical of the steps in deriving land use models by multiple regression. The accuracy of the forecast depends on the identification of the most important factors affecting the development of land use patterns. The following criteria govern the selection of locator variables for land use forecasting equations derived by multiple regression techniques (38):

(1) Variables should be functionally related to the type of development to be forecast.

(2) Variables should be directly and universally descriptive of the factors which they are describing so that relationships established

in one zone might be translated to other zones.

(3) Variables should be subject to prediction or projection within the desired planning range.

(4) Variables should show a strong and direct statistical association with land use.

(5) Data about variables should be relatively inexpensive to obtain.

Co-linearity of variables is another major problem associated with the use of multiple regression. Multiple regression techniques do not take into account the effect that one locator variable has on another locator variable in the forecasting equation. For instance, in the Baltimore Model presented above, the locator variable "D" (the miles of rail service per acre of industrially zoned land) might have some effect on the locator variable "C" (the percentage of land in the zone with water and sewer services available). Thus, a change in the variable "D" in the future would have effect on both "M" and "C". However, use of the forecasting equation would only show the change in "M" due to the change in "D" and would not show the change in "M" resulting from the change in "C" due to "D".

Difficulties with co-linearity of variables have caused inaccuracies in multiple regression land use models. No successful attempts have been made to determine the optical number of locator variables to include in a land use forecasting equation. However, in many studies it has been determined that the accuracy of models derived from multiple regression does not increase as more than three or four locator variables are used.

Also, the use of multiple regression techniques requires utilization of some built-in control to assure that the sum of forecasts of zonal growths does not exceed the total forecast of metropolitan growth. In many instances, zonal forecasts must be adjusted so that the sum of zonal forecasts does not exceed forecasts for the entire metropolitan area.

Linear Programming

Linear programming is another technique to modeling. The adaptability of linear programming models to land use forecasting has been experimented with in urban transportation studies, such as in the Penn-Jersey Transportation Study, in order to base land use forecasting on an understanding of the forces behind urban development rather than on statistical trend projections as in the use of multiple regression. Towards this end various types of land use forecasting linear programming models have been conceptualized.

Theory and Operation

Linear programming is a technique of modeling through which some objective, usually profit or cost, is optimized (maximized or minimized). Linear programming models allocate scarce resources within the framework of restrictions known as constraints in a manner which maximizes profits or minimizes costs. Linear programming models are most widely used in the field of industrial management to allocate scarce resources such as raw materials, labor, and services within the framework of constraints such as total availability or raw materials, wage scales, and production schedules in a manner which maximizes the total profits of firms.

The concepts of linear programming have been applied to the urban development process in which the allocation of a scarce resource, land, among various competing and, often, conflicting land use activities takes place. The application of linear programming models to land use forecasting is based on the theory that the urban development process results from a number of decisions by land developers, city officials, and heads of households to minimize certain costs, such as the costs of developing land, the costs of providing municipal services to areas, and the costs of owning a home. Thus, given a set of land use demands, development restrictions, land characteristics, and land development costs, a linear programming model forecasts a land use pattern which minimizes total costs related to land use (39).

Input Data. Input data for land use forecasting linear programming models generally consist of the following information:

(1) The costs of land acquisition and land development costs for each primary type of land use activity (These costs are usually obtained from engineering estimates or from statistical analyses of the costs of recent land development.);

(2) The demand for each land use activity (Demand is usually measured in terms of future population and employment forecasts.);

(3) Design standards reflecting the objectives of comprehensive planning in a city; and

(4) A land use inventory.

Constraints. Constraints are restrictions on land development which are placed in a linear programming model in the form of restricting equations. Constraints in land use forecasting linear programming models are generally of two types. Models contain restrictions, in terms of availability of land and zoning ordinances, on the maximal or minimal amounts of each land use activity which can be developed in a zone. Also, restrictions governing relationships between land use in a zone and external land uses, such as the need to provide school sites within walking distances of all neighborhoods, can be incorporated into models.

Output. The output of land use forecasting linear programming models consists of allocations of amounts of various land use activities to zones. These allocations result after computers carry out the complex linear programming technique.

Sample Model. A simple example of a linear programming model which might be used to forecast land use is presented below.

Minimize $C_t = c_1x_1 + c_2x_2 + c_3x_3$*

Subject to Constraints: $x_1 + x_2 + x_3 \leqq x_t$

$x_1 \leqq G_1$

$x_2 \leqq G_2$

$x_3 \leqq G_3$

Where: C_t = total cost of future land development in a zone,

x_1 = amount of new industrial land developed in a zone in a forecast period (output),

x_2 = amount of new commercial land developed in a zone in a forecast period (output),

x_3 = amount of new residential land developed in a zone in a forecast period (output),

c_1 = cost of developing industrial land (input),

*This model was constructed by the author.

c_2 = cost of developing commercial land (input),

c_3 = cost of developing residential land (input),

x_t = total amount of vacant land in a zone (input),

G_1 = amount of vacant land zoned industrial in a zone (input),

G_2 = amount of vacant land zoned commercial in a zone (input), and

G_3 = amount of vacant land zoned residential in a zone (input).

Penn-Jersey Model

The largest scale attempt to develop a linear programming model was developed to forecast residential development patterns based on the economic theory that individual households tend to maximize their locational advantage and that land is allocated to those households which can bid the highest price for it (40). The model attempts to maximize the rent-paying ability of households subject to the constraints that all households are located and that the total residential development allocated to each zone does not exceed the land available in each zone for residential use (41).

The following data was used as input for the Penn-Jersey Model (42):

1. Population locations and characteristics;
2. Inventory of structures;
3. Inventory of vacant land;
4. Accessibility of zones;
5. Public open space plans;

6. Public redevelopment plans; and

7. Public land development and public service extension policies.

Appendix G presents equations describing the Penn-Jersey Model.

Garrison Model

The use of linear programming models to forecast land use in urban transportation studies has much potential. An example of the future possibilities for these models is illustrated by a conceptual model developed by W. L. Garrison. In the Garrison Model the location of firms around interchanges is forecast by a linear programming model which minimizes total production costs of the firms and total transportation costs of the employees of the firms (43).

The model uses the following four constraints (44):

(1) Enough workers are employed in each industry to meet the total demand for its product;

(2) The number of workers drawn from each residential area of the city does not exceed the total labor force available in that area;

(3) The capacity of the connecting roads between residential areas and working areas is not exceeded; and

(4) The total amount of land used at each interchange does not exceed the amount available.

Appendix H presents some of the equations of the Garrison Model.

The Garrison Model is purely conceptual. The main problem in its application to forecasting future land use in urban transportation studies involves what are known as "dual" variables, which are variables representing resources and which are optimized by the linear programming technique. The dual variables in the Garrison Model involve the maximization of labor resources, and the resulting land use pattern forecast relies on this maximization. However, minimum wage controls and union restrictions involving labor are not accounted for in the model, thus the resulting maximization of labor resources is not a real-life situation. Also, the model assumes each residential area is connected to each work area by a street of a given capacity, thus not accounting for the joint use of streets for different purposes.

Evaluation

Utilization of linear programming models, like the utilization of models derived through multiple regression, provides for the analysis of large amounts of data quickly. For instance, a model for a region of about 30 transportation zones with 60 constraints and 400 variables could be solved on a larger IBM 7090 computer in about 30 minutes (45).

One big problem in the utilization of linear programming land use forecasting models involves the collection of data. Because these models are based on economic theory, the collection of land development cost data is necessary. However, the collection of this data is expensive, and, in many cases, data are difficult to obtain (46). Land developers are usually extremely reluctant to reveal their costs, and the cost data are of uneven quality since many developers do not maintain complete records of costs (47). The Penn-Jersey Transportation Study has switched from a linear programming model for land use forecasting to models derived through multiple regression because of difficulties arising from data collection (48).

One questionable property of the linear programming technique is that of maximizing or minimizing some aggregate function (such as total rent-paying ability of all residential locators). Given that economic theory holds that all individuals are trying to maximize their economic position, the linear programming technique assumes that this theory is reflected in the maximizing or minimizing of the aggregate economic position of all individuals. It is questionable whether such a relationship between the aggregate economic position and the individuals economic position actually exists (49). Thus, the ability of linear programming models to simulate locational behavior is doubtful, unless it can be shown that the sum of all actions to maximize individual economic positions is synonymous with a maximization of the aggregate economic position (50).

The weakpoint of linear programming models is that they are based on the assumption that decisions involving land development are based on the optimization of some economic objective. The theory of linear programming is that each individual is trying to maximize his economic position, and linear programming models exclude all factors which cannot be translated into economic terms. Thus, these models may exclude some non-economic factors which have a significant effect on urban development.

Numerous small decisions shape urban development, and many of these decisions are not economic. For instance, locational decisions of households are not always based solely on rational considerations, such as the Penn-Jersey Model assumes. As a family's income rises, factors such as aesthetics, socio-economic environment, and accessibility to schools and parks are all important factors in a family's decision on household location. However, these factors cannot be rated on an economic basis.

Also, the assumption that families attempt to maximize their rent paying ability may not be indicative of the decision making processes of household location. For example, the process of household location in an urban area involves decisions by land owners in all parts of the metropolitan area to place land on the market, decisions by real estate men, mortgage financiers, and developers on how to develop the land, and decisions by heads of households as to whether to rent, buy, or build a dwelling unit. Because of the inter-relationships among all of these decisions, it is difficult to say whether the maximization of rent paying ability is actually descriptive of the locational process (51).

Simulation Models

Like linear programming models, simulation models attempt to reproduce the factors causing the development of urban land use patterns. Opportunity models are the most common types of simulation models. However, other types of simulation models involving series of equations developed by multiple regression techniques have been derived.

Theory and Operation

Simulation models are based on the theory that the processes of urban development can be simulated through the use of mathematical equations based on theories about principles which guide urban development. By integrating the results of statistical and substantive analyses of data for a particular city or region with various theories concerning urban growth, decline, and/or development, it is assumed that mathematical equations for forecasting urban development can be devised (52). These equations produce an output describing future land use patterns.

Thus, two steps would be involved in the development of a simulation model to forecast land use. First, an analysis of data concerning urban growth, decline, and development in a city would be made in order to devise theories and concepts concerning urban growth in zones of that city. Next, mathematical equations describing these theories and concepts would be developed.

The equations developed act as a complete theoretical framework for simulating future development in the city. Input data describing existing land development patterns are placed into a computer which has been programmed to solve the equations, an an output describing future land use patterns is produced.

<u>Opportunity Models</u>

Opportunity models are a type of simulation model commonly used in urban transportation studies. They are based on expressing urban development patterns are placed into a computer which has been programmed to solve the equations, and an output describing future land use patterns is produced.

<u>Opportunity Models</u>

Opportunity models are a type of simulation model commonly used in urban transportation studies. They are based on expressing urban development through probability theory. In an urban area a probability exists that each parcel of vacant land will be either developed or remain vacant. Based on this probability an opportunity model, through the use of computers, analyzes data about vacant land in an urban area and simulates the urban development process by accepting or rejecting each parcel of land for future development. Parcels of land are investigated in rank order, outward from the central business district.

An example of a simple opportunity model is described below. In this model opportunities for development would be represented by parcels of vacant land zoned residential. Residential growth is simulated as being directly proportional to the number of opportunities for development in the zone (expressed as a ratio to the total number of opportunities in the urban area) times the probability that any given opportunity will be developed.

An example of a simple opportunity model is described below.

$$R = \frac{k(0_p)}{0}$$

Where: R = the number of new dwelling units built in a zone during time period "p",

0_p = the number of opportunities to build dwelling units existing in a zone during time period "p",

0 = the total number of opportunities to build dwelling units existing in the urban area during time interval "p", and

k = a constant of probability expressing the probability that an opportunity to build in a zone will be capitalized upon.

The above example is a relatively simple application of the theory of probability to urban development. Urban transportation studies have used more complex models to simulate urban development through the probability of accepting opportunities for development. Appendix I presents a more complicated example of an opportunity model used in the Niagara Frontier Area Transportation Study of the Buffalo, New York Region.

Pittsburg Model

The other type of simulation model which has been used to forecast land use is the type which consists of a series of equations derived through multiple regression techniques. These equations are based on theories concerning urban development. A model developed as part of the Pittsburgh Community Renewal Program illustrates this type of simulation model.

The Pittsburgh Model was based on assumptions relating urban growth to employment opportunities. The assumptions made in developing the Pittsburgh Model are as follows (53):

(1) Employment opportunities are directly responsible for all development decisions.

(2) Various types of "site-oriented" employment gravitate to specific areas of the city. This gravitation is based on criteria such as existing employment clusters, land use policies, accessibility, and taxation policies.

(3) Households tend to locate at prescribed distances from work.

(4) Commercial service employment tends to cluster at locations within prescribed distances from households.

(5) Racial, occupational, and economic characteristics of households tend to constrain household locations.

Equations were developed which expressed the above assumptions.

The first set of equations located employment centers in the urban region; the second set of equations located households, and the third set located commercial centers. Thus, the actual operation of the Pittsburg Model followed the following sequence of steps:

(1) Employment centers were located by equations derived from multiple regression.

(2) Based on the location of employment centers, households were located within specified distances of employment centers by another set of equations.

(3) A set of equations located service employment within specified distances of employment locations and household locations.

(4) The location of service employment generated new households which were located within specified distances of service employment centers.

(5) The location of households generated new service employment which was located.

(6) The above steps continued in a cycle until the model stabilized itself.

Evaluation

The main weakpoint of simulation models lies in their attempt to describe urban development as some orderly, structured process. This weakpoint occurs in both opportunity models and models consisting of a series of equations derived through multiple regression.

Opportunity models describe urban development as a simple process in which land is developed outward from the central business district according to a certain probability, which in most models is constant for each parcel in the metropolitan area. Neither of these theories describes a real-life situation. In many urban areas land is developed outward from numerous hubs, such as shopping centers and employment centers rather than from the central business district (54). Also, in an urban area the probability of development for each parcel of land is not constant. Different developmental assets and liabilities of parcels of land give each parcel a different probability of development.

The use of series of individual equations derived through multiple regression to forecast land use requires the forecaster to choose which equations should be first and which should be next. This is tantamount to assuming that one type of urban activity begets another which in turn begets another (55). Thus, the accuracy of these type of simulation models depends on the closeness of the actual urban development process to the structured steps of the model describing it. For instance, the Pittsburg Model depends on how closely development of shopping centers follows residential development and how closely residential development depends on the location of employment centers.

Simulation models open the door to the future. As this chapter has shown the trend in land use model development has been toward models based on a thorough understanding of the intermingled factors comprising the urban land development process. The first attempts at model building related future land development to accessibility only. Then multiple regression models relating future land development to existing locator variables were developed, followed by linear programming models which were based on economic theories supposedly underlying the urban development process. Most recently, simulation models have been developed in an attempt to actually simulate the entire urban land development process in step-by-step procedures.

CHAPTER IV

CONCLUSIONS

The land use forecast is an important part of urban transportation studies because projections of future land use are inputs to the gravity model which distributes future trips in an urban area. The methods of intuitive judgment and land use accounting and accessibility, multiple regression, linear programming, and simulation models have all been used to forecast future land use in urban transportation studies.

Comparison of Techniques

In urban transportation studies of large urban areas the use of land use forecasting models has advantages over non-modeling forecasting methods. The factors contributing to land development are so numerous and so complexly interrelated in a large urban area that analyses by humans of the land development process are impossible. However, models, which are adaptable to computers, can analyze the large volumes of data about land development in an urban area and make predictions of future land use in a matter of hours. Also, models allow forecasts to keep pace with the changing structure of large urban areas because updated data can be used as new inputs to models, and updated forecasts can be made.

Land use accounting is also a forecasting method which can be applied to large urban areas. However, it involves many manual calculations and projections and much use of judgment. Also, it can only be applied in certain types of cities and produces very general types of land use data as output.

No modeling technique can be rated as more accurate than another, although all techniques have their strengths and weaknesses. Few models have been tested historically, and in most urban transportation studies the test is the future (56). Only one significant test of the application of different modeling techniques to the same urban area has been made. This test was made by Swerdloff and Stowers in Greensboro, North Carolina (57).

In the Greensboro test an accessibility model, a multiple regression model, two opportunity models, and the land use accounting technique were used to forecast land use. Swerdloff and Stowers found that all of the methods were sufficiently accurate to be recommended for use in metropolitan areas of the size of Greensboro (100,000 population), that all the methods produced accurate results for levels of geographic aggregation where the average areal unit contained a population of about 2,000 persons, and that differences in accuracy among the five forecasting methods were not large enough to warrant a strong recommendation for any single one in preference to others (58).

The Use of Judgment

It is important to note that all land use forecasting techniques, even mathematical models, require the use of much judgment on the part of the planning team.

The use of the land use accounting technique requires the most judgment, as was explained in Chapter II. Judgment is used in the process of projecting the shape of the future saturation curve from the shape of the existing saturation curve.

The use of multiple regression requires judgment from the planning team in the selection of locator variables. A computer which has been programmed to perform multiple regression techniques can only work with the data with which it is provided. The choice of what data to use is based on a thorough analysis of the trends in the urban area and a subsequent identification of factors (locator variables) related to urban development. This identification of locator variables is the responsibility of the planning team.

Simulation models also require much judgment on the part of the planning team. Before a simulation process can be structured and equations devised, a thorough analysis of the urban development process must be made and the steps in the process identified. Again, this process of analysis and identification is the responsibility of the planning team.

The Importance of Data

Land use forecasting techniques are only as accurate as the data on which they are based. A technique may be completely descriptive of the urban development process, but it may be useless because its input data are of poor quality.

Many techniques operate with some exogenous factors such as forecasts of total metropolitan area population and employment as inputs. Population and employment are then distributed among zones (such as in the land use accounting technique, the intuitive judgment technique, and certain multiple regression models). The output from these type models is only as accurate as the input forecasts on which they are based.

The land use accounting technique is only as good as the data about vacant land in zones and zonal densities and capacities on which the calculation and projection of saturation curves are based. Also, simulation models are only as good as the data (such as employment intensities and locations in Pittsburg) on which the assumptions about the land development process are based.

Models derived from multiple regression are very sensitive to the quality of data since they are based on calculations of past interrelations between locator and located variables in urban areas. If these data are not completely descriptive of past trends, the output of the multiple regression models will be misleading.

As mentioned in Chapter III, many of the problems which have hindered the utilization of linear programming models are due to the difficulties of data collection. Data about costs of land development are difficult to obtain, and, for this reason, a linear programming model for forecasting land use in the Penn-Jersey Transportation Study was abandoned.

The Type of City

The choice of which method to use in forecasting land use in urban transportation studies depends on the characteristics of the city in which the study is being made. Each forecasting method is most easily and accurately applied to certain types of cities. The utilization of a forecasting method in a study of an urban area requires a thorough study and understanding of the land development process in that urban use.

For instance, the land use accounting technique can only be applied in cities which exhibit decreasing densities in development outward from the central business district and decreasing proportions of land in use as distance from the central business district increases. Thus, the technique was used in Chicago and Pittsburg and in the Greensboro test, where these characteristics existed.

Multiple regression techniques are most easily applied in cities where certain trends are easily identifiable and where factors relating to these trends can be easily quantified. For instance, retail development trends in a certain city might seem obviously related to accessibility, income, and population of zones, thus, a multiple regression modeling technique could be easily developed; or, as in the Baltimore example, the factors relating to industrial development might be easily identifiable and a model subsequently devised.

Simulation models must be based on a close investigation of the city in which the study is being made. For instance, the basis for deriving a series of equations describing the developmental process in a particular city is a close study of the city. Thus, the Pittsburg Model was developed only after a study of the Pittsburg area revealed that the key to developmental growth was the location of employment centers. Also, opportunity models should only be used in areas where development of land seems like a random process which occurs outward from the central business district.

Linear programming models should only be used in cities where it seems obvious that the economic optimizing theories on which they are based exist. For this reason, linear programming models are still in the developmental stage. Much more research needs to be done to prove whether the economic theories behind the adaptation of linear programming techniques to land use development really describe the real-life developmental processes.

Thus, it seems that mathematical models should be used only in cities where the characteristics of urban development have been thoroughly studied and analyzed. The more one knows about the urban environment, the more one can turn to mathematical models for forecasting land use (59).

APPENDICES

APPENDIX A

CALCULATION OF TRIP INDICES

Various types of land use information have been used in transportation studies to determine the trip generating powers of zones. Some types of land use information used to determine generation of various trip types are listed below.

<u>Work Trip Indices</u>

Total employment
White collar employment
Blue collar employment
Retail employment
Acres of commercial land
Acres of industrial land
Acres of public and semi-public land
Residential population density
Number of dwelling units
Dwelling unit density
Income per household
Retail sales volume

<u>Shopping Trip Indices</u>

Population
Population density
Number of dwelling units
Dwelling unit density
Commercial employment
Retail employment
Retail sales volume
Convenience goods sales volume
Personal service goods sales volume
Acres of commercial land

<u>Social-Recreational Trip Indices</u>

Population
Population greater than 5 years old
Income per household

Social-Recreational Trip Indices (Cont.)

Number of dwelling units
Non-retail, non-manufacturing employment
Retail sales volume

Truck Trip Indices

Total employment
Commercial employment
Retail employment
Manufacturing employment
Non-retail, non-manufacturing employment
Specialized employment
Commercial acreage
Industrial acreage
Population
School enrollment
Income per household
Number of dwelling units

Source: Shuldiner, Paul W. "Land Use Activity and Non-Residential Trip Generation," *Origin and Destination*. Highway Research Record 141. Washington: Highway Research Board, 1966, p. 77.

APPENDIX B

NASHVILLE TRANSPORTATION STUDY
CALCULATIONS OF TRIP INDICES

$$T_w^{1960} = T_w^{1959} \times E^{1960}/E^{1959}$$

$$T_s^{1960} = T_s^{1959} \times A_c^{1960}/A_c^{1969}$$

T_w^{1960} = a trip attraction index for home-based work trips in 1960 for a given zone

T_w^{1959} = the number of home-based work trips attracted to the zone in 1959 (data)

E^{1960} = the number of employees in the zone in 1960 (projection)

E^{1959} = the number of employees in the zone in 1959 (data)

T_s^{1960} = a trip attraction index for home-based shopping trips in 1960 for a given zone

T_s^{1959} = the number of home-based shopping trips attracted to the zone in 1959 (data)

A_c^{1960} = total commercial acreage in the zone in 1960 (projection)

A_c^{1959} = total commercial acreage in the zone in 1959 (data)

Source: Shuldiner, Paul W. "Land Use, Activity, and Non-Residential Trip Generation," Origin and Destination. Highway Research 141. Washington: Highway Research Board, 1966, p. 80.

APPENDIX C

CALCULATION OF TRIP INDICES

The following formula was used in the Fort Worth Transportation Study to calculate trip attraction indices for zones.

$$Y_i = 0.115P_i + 0.048C_i + 0.025I_i + 0.150E_i$$

Y_i = the "basic attractiveness" of zone "i" for home-based trips in the urban area

P_i = population of zone "i"

C_i = commercial employment in zone "i"

I_i = industrial employment in zone "i"

E_i = other employment in zone "i"

Source: Shuldiner, Paul W. "Land Use Activity and Non-Residential Trip Generation," Origin and Destination. Highway Research Record 141. Washington: Highway Research Board, 1966, p. 82.

APPENDIX D

CALCULATION OF RESIDENTIAL ZONAL CAPACITIES*

$$C_r = P + D_r A_r$$

C_r = future residential capacity of a given zone (number of persons)

P = present population of a given zone

D_r = estimated future residential density of a given zone

A_r = estimated amount of presently vacant land to be devoted to residential use in the future in a given zone

*This formula was constructed by the author.

APPENDIX E

CALCULATION OF INDUSTRIAL ZONAL CAPACITIES*

$$C_i = D_1A_1 + D_2(A_2 - A_1)$$

C_i = future industrial capacity of a given zone (number of employees)

D_1 = present employee density of a given zone

A_1 = amount of present land devoted to industrial use in a given zone

D_2 = estimated future employee density of a given zone

A_2 = estimated amount of land to be devoted to industrial use in the future in a given zone

*This formula was constructed by the author.

APPENDIX F

HARTFORD METROPOLITAN AREA TRANSPORTATION STUDY

MODEL FOR MANUFACTURING GROWTH

$$E_i = 12x_1 + 37x_2 + 5x_3 + 34x_4 + 12x_5 + 2x_6 + 19x_7 + x_8 + 5x_9 + 120$$

E_i = the percentage of total metropolitan manufacturing growth which will take place in any zone "i"

x_1 = highway accessibility of the zone

x_2 = availability of vacant land in the zone

x_3 = tax rate in the zone

x_4 = availability of sewer facilities in the zone

x_5 = availability of rail service in the zone

x_6 = water supply in the zone

x_7 = airport accessibility of the zone

x_8 = a promotion index for the zone

x_9 = amount of industrial land bordering freeways in the zone

Source: Irwin, N. A. "Review of Existing Land Use Forecasting Techniques," Travel Patterns. Highway Research Record 88. Washington: Highway Research Board, 1965, p. 189.

APPENDIX G

PENN-JERSEY MODEL

$$\text{Maximize } \sum_i \sum_k x_i^k (b_i^k - c_i^k)$$

$$\text{Subject to Constraints:} \quad S_i^k x_i^k \leqq L^k$$
$$x_i^k = -N_i$$

x_i^k = the number of households of socio-economic group "i" located in zone "k"

b_i^k = the location that a household of group "i" will use if it locates in zone "k"

c_i^k = the annual cost of housing for group "i" if it locates in zone "k"

s_i^k = the number of units of land purchased by households of group "i" in zone "k"

L^k = total number of units of residential land available in zone "k"

N_i = the projected number of households of group "i" to be located in the region

Source: Irwin, N. A. "Review of Existing Land Use Forecasting Techniques," Travel Patterns. Highway Research Record 88. Washington: Highway Research Board, 1965, p. 186.

APPENDIX H

GARRISON MODEL

$$\text{Minimize} \sum_i \sum_j \sum_k f_{ijk} x_{ijk}$$

Subject to Constraints:

$$\sum_i \sum_j x_{ijk} \geqq b_k d_k$$

$$-\sum_j \sum_k x_{ijk} \geqq -e_i$$

$$-\sum_i x_{ijk} \geqq -k_{ij}$$

$$-\sum_k \sum_i a_k x_{ijk} \geqq -s_j$$

f_{ijk} = the total cost of production and transportation per worker for the worker living in zone "i", working in area "j", and employed in industry "k"

x_{ijk} = the number of workers from the residential zone "i" working in area "j", and employed in industry "k"

b_k = the number of employees required per unit of output in industry "k"

d_k = the demand for the output of industry "k"

e_i = the number of persons in the labor force from residential zone "i"

k_{ij} = the capacity of the route between residential zone "i" and working place "j"

a_k = the land used per employee in industry "k"

s_j = the total land available in working area "j"

Source: Irwin, N. A. "Review of Existing Land Use Forecasting Techniques," Travel Patterns. Highway Research Record 88. Washington: Highway Research Board, 1965, p. 206.

APPENDIX I

NIAGARA FRONTIER AREA TRANSPORTATION STUDY MODEL

$$A_j = A_j \left[e^{-10} - e^{-1(0 + 0_j)}\right]$$

A_j = amount of a given land use activity to be allocated to zone "j"

A = the total amount of a given land use activity to be allocated in the urban area

e = the natural logarithm base

1 = the probability of a unit of a given land use activity being located at a given opportunity

0 = the opportunities for locating a unit of a given land use activity, ordered by access from the central business district

0_j = the opportunities for locating a unit of a given land use activity in zone "j"

Source: Lathrop, George T. and Hamburg, John R. "An Opportunity Accessibility Model for Allocating Regional Growth," <u>AIP Journal</u>, May 1965, p. 96.

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