Reference

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MODELING TRANSPORTATION SYSTEMS: AN OVERVIEW

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16. Abstract

The purpose of this report is to outline the role of systems analysis and mathematical modeling in the planning of transportation systems. The planning process is divided into three sectors (demand, supply, and policy) reflecting the demand for transportation services by the public, the ability of the system to deliver these services, and the effects of management policies on the equilibriation between supply and demand. The composition of each sector is examined and illustrated by samples from recent major transportation studies and the modeling literature. Emphasis is placed on structure, dynamics, and feedback effects.

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ILLUSTRATIONS

1. INTRODUCTION

The purpose of this report is to outline the role of systems analysis and mathematical modeling in the planning of transportation networks. Prior to the 1960's that role was confined to the secondary levels of decision making. For example, the scheduling of an airline's operations might have been based on a system study, but the allocation of government funds between railroads, airlines, and highways would have been based on intuition. Indeed, the Federal Aid to Highways Act of 1956, which channeled more than forty billion dollars into highway construction in a fifteen year period, was enacted without benefit of any comprehensive study of the roles highways should play in the total transportation system of the nation. Although the interstate highway network is undoubtedly one of the nation's great assets, it has been argued that its undesirable effects on railroads, urban evolution, and the environment could have been anticipated and reduced through a judicious application of systems analysis.

During the last decade, and especially since around 1966, system analysis has been moving from a secondary to a dominant role in the planning process. The cities of Detroit and Chicago were among the leaders in initiating city-wide planning based on comprehensive statistics and systems analysis techniques.* Many of the large cities have followed suit. (A list of major studies is compiled in Figure 1, and a detailed Bibliography is given in the Appendix.) More recently, regional studies (The Penn-Jersey Transportation Study, [A.9]** 1964-65; the Northeast Corridor Project [1]***, 1969-70) have been undertaken, and planning on a national scale has been started by DOT's Office for Policy and International Affairs [2,3].

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*The Detroit Metropolitan Area Traffic Study, started in 1955. The Chicago Area Transportation Study, started in 1959. (Also, see entries [A.1] and [A.2] in the Appendix.)
**Appendix
***References

	STUDY	APPROXIMATE DATES
1.	Detroit Metropolitan Area Traffic Study	1955
2.	Chicago Area Transportation Study	1959-62
3.	National Capital Region Transportation Plan	1959
4.	Houston - Harris County Transportation Study	
5.	Pittsburgh Area Transportation Study	1962-63
6.	The Boston Regional Survey	1963-69
7.	Baltimore Metropolitan Area Transportation Study	1964-65
8.	Niagara Frontier Transportation Study	1964-66
9.	Penn-Jersey Transportation Study	1964-65
10.	Tri-State Transportation Commission (New York Region)	1966
11.	Southeastern Wisconsin Regional Transportation Study (Milwaukee Region)	1965-66
12.	Puget Sound Regional Transportation Study (Seattle Region)	1965-67
13.	Dallas-Fort Worth Regional Transportation Study	1965-67
14.	Oahu Transportation Study (Honolulu Region)	1966-67
15.	Rapid Transit for Metropolitan Atlanta	1967
16.	Los Angeles Regional Transportation Study	1963-68
17.	Joint Program for Land-Use Transportation Planning (Minneapolis - St. Paul Region)	1967-68
18.	Miami Urban Area Transportation Study	1968
19.	Metropolitan Transportation (New York Region)	1968
20.	Northeast Corridor Transportation Project	1965-70

Figure 1.- Major Transportation Studies

There are several reasons for the increased reliance on systems analysis:

a. Transportation plans involve so many interdependent variables that they defy intuition. An investment in highways, for example, has major effects on railroad demand, airline demand, land utilization, population movement, etc., each of which depends on the others and in turn affects highway demand. Indeed, the behavior of large transportation systems is frequently counter intuitive as a consequence of negative feedback effects. For example, the widening of a highway can lead to increased demand and, contrary to what might be expected, increased congestion.

b. The advent of large digital computers has made complex systems with many interdependent variables tractable for the first time. The major transportation studies cited above, and in Figure 1, involve models comprising hundreds or thousands of interdependent equations, and could not have been undertaken without modern computers.

c. Various transportation acts passed by Congress require comprehensive planning. For example, the Federal Aid Highway Act of 1962 states, "... the Secretary shall not approve... any program for projects in any urban area of more than fifty thousand population unless he finds that such projects are based on a continuing comprehensive transportation process carried on cooperatively by states and local communities...." Similar provisions in various transportation acts have served as a powerful stimulus to the development of planning methodology and to the increasing use of mathematical or computer models.

At the present time DOT, HUD, and many state highway departments have incorporated fairly sophisticated systems approaches into their planning processes, at least at the staff level. Questions of allocation of funds between highway, rail, and air systems, or between new technologies such as tracked-air-cushion and steel-wheel-on-rail, are being subjected to intensive studies employing the whole spectrum of system techniques, from network analysis, dynamic modeling and nonlinear programming, to utility theory and the Delphi method [4]. Investment decisions are bound to be influenced by the outcome of these studies.

2. STRUCTURE OF A TRANSPORTATION PLANNING PROCESS

A transportation planning process consists of many interconnected components generally including the following: forecasts of population, land use, economic activity, and technology; cost and performance equations for alternative technologies (TACV's, steel-wheel-on-rail vehicles, STOL, etc.); routines for route assignment and scheduling; analysis of pricing, demand, network loading, environmental impact; etc. Together these components form a complex dynamical system with many internal feedback paths. We shall outline a structure, general enough to be valid for most planning processes, which shows how the various components interact.

The structure, which is an elaboration of one used in the Northeast Corridor Project [5], will emphasize the economic considerations of supply and demand. Similar supply-demand structures are becoming prevalent in modern mathematically oriented planning operations*.

*The more classical division [6] is into four categories: Inventory, Analysis, Forecasting, and System Evaluation.

2.1 A Supply-Demand Equilibrium Structure

A schematic of our structure is shown in Figure 2. The various blocks in the figure correspond roughly to the functions carried out by branches of a planning group or, in the case of a computerized planning operation, to the actual computer subroutines. The structure divides a transportation planning model into three main sectors: Demand, Supply, and Policy.

The Demand Sector Model.- The demand sector model produces a forecast of demand for passenger trips and freight shipments, which is used as a basis for calculating revenues and social benefits (time savings, jobs created, increased mobility). The demand model employs data on population, economic activity, land use, car ownership, and various other socio-economic factors. Demand also depends on characteristics of the proposed transportation system (trip times, schedules, level-of-service factors) which are inputs from the supply sector, as well as on price which is an input from the policy sector.

The Supply Sector Model.- The supply sector model in effect produces alternative transportation system designs and estimates their costs. It employs data on design and cost trends for vehicles, propulsion systems, guideways, communication and control systems, land, and terminal construction. It employs inputs on demand, supplied by the demand model, to arrive at a design. It may also be provided with inputs from the policy sector on level-of-service policies.

The Policy Sector Model.- The policy sector model sets pricing and level of service policies and calculates the necessary subsidies or taxes. It thereby determines the point of equilibrium between supply and demand. It accepts inputs on costs and revenues (or benefits) from the supply and demand sectors. The calculation of social benefits and environmental costs has been placed in the policy sector because the present

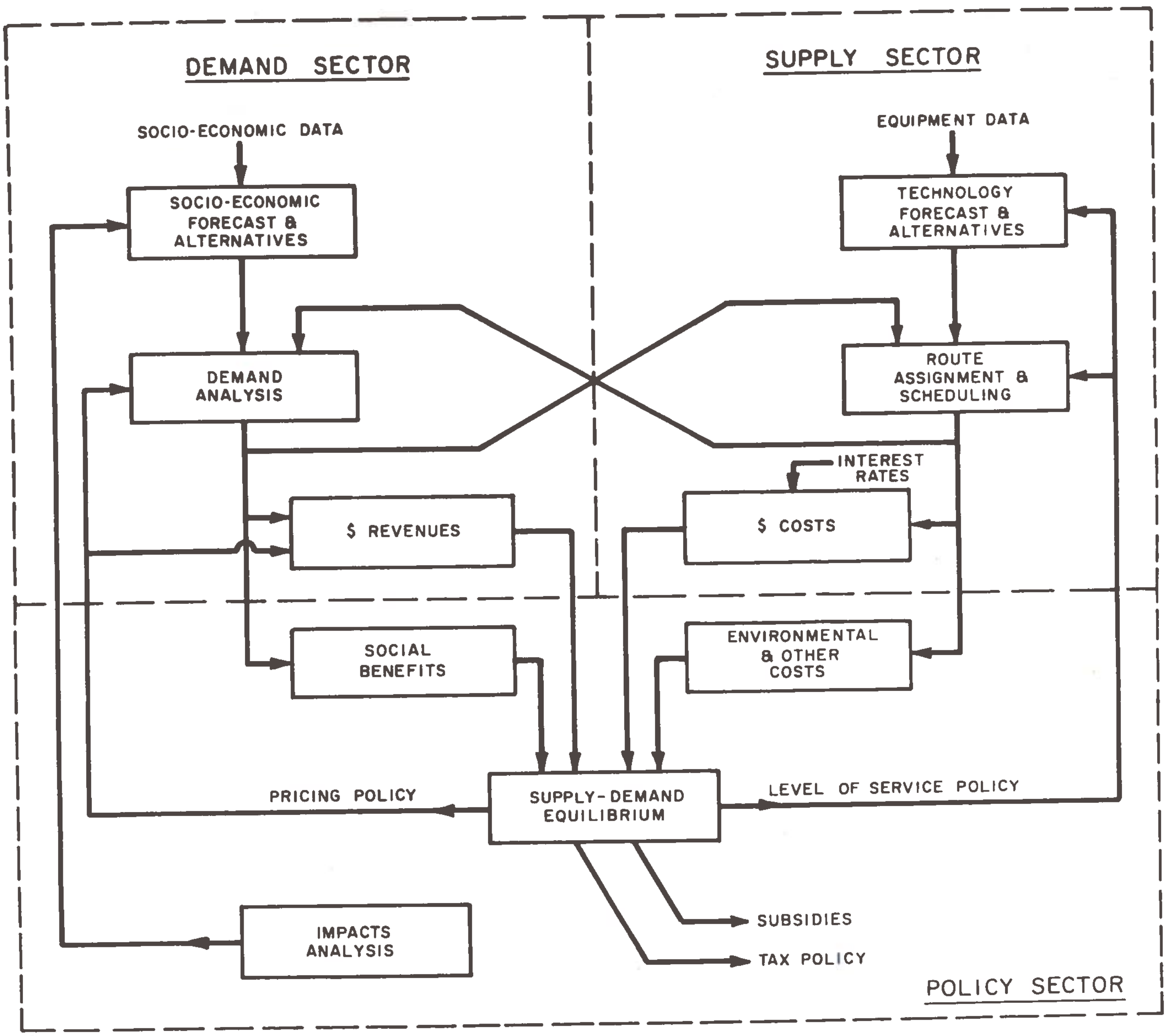

Figure 2.- Structure of the Transportation Planning Model

manner of calculating these costs and benefits is so arbitrary as to be a matter of policy itself. Similarly impact analysis has been placed in the policy sector.

The structure describes a process which may be either static or dynamic. For the static case the process is modeled at one point in time. For the dynamic case a time history of the process is produced. In the remainder of this report we shall have mainly dynamical processes in mind.

The supply/demand/policy divisions are to a certain extent arbitrary; depending on how certain functions are performed, they can be viewed as belonging to either the supply or the policy sectors. There can be additional feedback paths besides the ones shown; some functions which are shown as being performed sequentially might in fact be performed simultaneously (e.g., impact analysis and socio-economic forecasting).

The structure we have outlined is an implicit one, i.e., each of the three sectors is a function of the remaining two. Implicit systems of equations are generally solved by a process of iteration, in which the demand and policy are assumed fixed and the supply is calculated, then the supply and policy held fixed and demand calculated, and so on. The iteration may be realized at high speed on a computer, or more slowly through a sequence of trial designs by a planning group. If the iteration is properly designed it converges to a solution in which supply and demand are in equilibrium. Equilibria arrived at in this manner represent potentially realizable transportation systems.

There are two purely mathematical problems here which have not been squarely faced in past studies: 1) the iteration may fail to converge (and the convergence properties of such iterations are not well understood); 2) in general there can be many equilibrium points (the iteration may yield one equilibrium while the actual transportation system may seek another). These two problems are proper subjects for research.

In the following sections the three sectors will be discussed in greater detail.

3. THE DEMAND SECTOR

We shall limit the present discussion to passenger demand.

The demand for passenger transportation, measured in daily or yearly passenger trips or trip miles, is a function of such socio-economic variables as population size, automobile ownership, income, etc. In order to predict demand it is therefore necessary to have a socio-economic forecast. The output of the socio-economic forecast is fed (see Figure 2) together with a description of the transportation system into a demand analysis model. Once demand has been forecast and ticket price decided upon, expected revenues can be calculated and some estimates of social benefits obtained.

3.1 Geographic Partitioning

A transportation-socio-economic system is distributed over some geographical continuum. Usually, in regional planning, the distributed system is approximated by a discrete one. To this end, the first step in any regional plan is a partitioning of the region into a finite number of districts. For example, the region modeled in the NECTP (Northeast Corridor Transportation Project), which consists of parts of ten states (New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Virginia) and the District of Columbia (Figure 3)), was partitioned into 131 county sized districts. Socio-economic data on population, income, employment, etc., was then aggregated for each district. In effect, therefore, a geographic continuum was approximated by a discrete set of 131 points.

The choice of county-sized districts was determined by the fact that counties were the smallest areal units for which

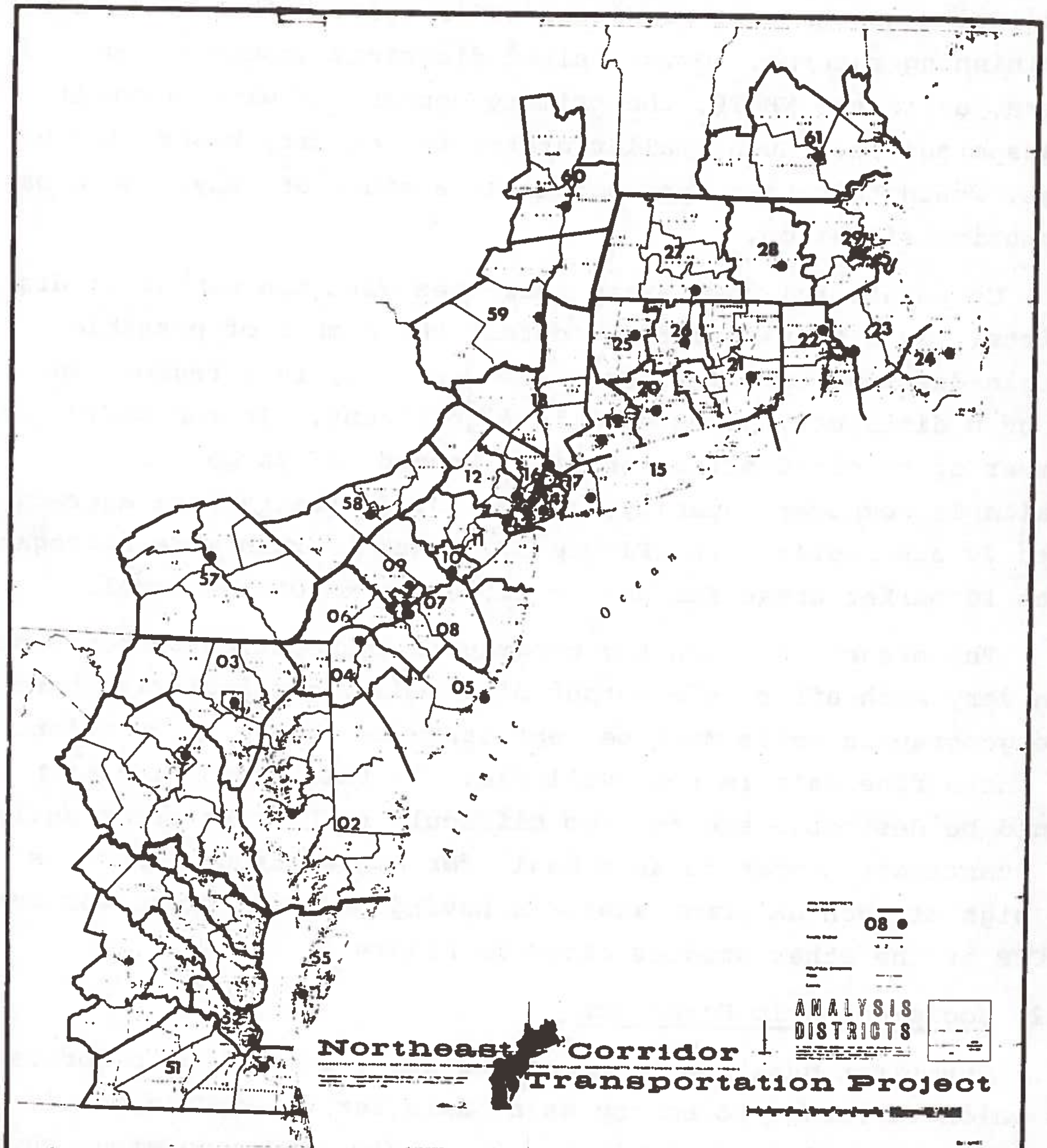

Figure 3.- Geographic Partitioning of the Northeast Corridor

population data was consistently available. In general the accuracy of a model is limited by the geographic resolution, increasing as the area of districts is reduced, but with rapidly diminishing returns. County sized districts appear reasonable where, as in the NECTP, the primary concern is with intercity transportation. Much smaller districts, of city block size or less, would have been appropriate in a study of, say, the urban commuting situation.

Computational complexity increases with the number of districts. In a transportation context the number of possible origin-destination pairs, which is $\frac{1}{2}n(n-1)$ in a region made up of n districts, is especially significant. In the NECTP the number of origin-destination pairs proved too large for the available computer capacity, so the 131 districts were aggregated into 29 super-districts (Figure 3), which in turn were aggregated into 10 market areas for use in cruder parts of the model.

The manner in which the geographic aggregation is performed can very much affect the output of a model, particularly where the geographic units must be kept large to reduce computation, or where fine data is not available. In this connection it would be desirable and not too difficult to have an error analysis of quantization effects as a basis for aggregation. There is no sign of such an error analysis having been performed for the NECTP or the other studies cited in Figure 1.

3.2 Socio-Economic Forecasts

The first question in preparing the socio-economic forecast is which variables to employ as a basis for the demand model. Income, automobile ownership per household, and population show a high degree of correlation with demand (measured in passenger trips per capita per day), and are therefore used frequently [7,8].

Almost every socio-economic forecast starts off with a population forecast. The population growth equation is

$$\frac{dP_i}{dt} = (b_i - d_i + m_i)P_i \qquad (1)$$

where

P_i = population of i-th region

b_i = fractional birth rate of i-th region

d_i = fractional death rate of i-th region

m_i = fractional migration rate of i-th region

In the simplest forecasts the birth, death, and migration rates are taken to be constant. For example, the first generation NECTP (Northeast Corridor Transportation Project) predicted 1975 population figures for each super-district by calculating growth rates for each district from 1960 and 1966 figures, assuming rates to be constant, and aggregating district figures to obtain super-district figures.

The assumption of constant population growth rates is unsatisfactory because:

a. Rates in fact are highly variable. The U.S. birth-rate has declined so sharply since 1960 that estimates of population increase for the period 1960-2000 have been revised downwards from 150 million to about half that figure.

b. Demand changes are sensitive to changes in population size and in fact proportional to them when other factors are held constant.

c. A constant population growth rate model is inherently incapable of predicting those impacts of new transportation systems which result from population shifts.

(A subsequent "Impact Analysis" [9] model for the NECTP made birth, death, and migration rates linear combinations of income per capita, land per capita, and constant terms. In addition the migration rate included a linear term representing "accessibility to employment opportunities.")

The main portion of the NECTP eventually employed a single socio-economic variable namely, the number of families in each district with incomes of more than $10,000 yearly. This relatively crude assumption was made to simplify the model and because of the difficulty of getting data on other economic variables uniformly throughout the Northeast Corridor.

A good example of a more ambitious socio-economic model is the one employed in the Susquehanna River Basin Survey (SURBS) [10]. Although SURBS is primarily a water resources survey, its socio-economic model could easily be adapted to a transportation study.

SURBS is a true dynamic model, i.e., it employs differential equations similar to Equation (1) to calculate <u>time histories</u> of pertinent socio-economic variables. For simulation on a digital computer, differential equations are approximated by difference equations. A fifty year time interval (1960-2010) is divided into 1-year increments. Programming is done on a 7090 computer in Dynamo, a computer language designed for the simulation of coupled difference equations for socio-economic modeling. The SURBS simulation employs over a thousand equations, and requires about 5 minutes for a single 50 year run.

The SURBS socio-economic model (see Figure 4) is divided into a population sector that forecasts population and labor force participation (by district), and an employment sector that forecasts employment (by industry type and district) and the unemployment rate (by district). The two sectors are coupled in that population growth is made a function of the unemployment rate, and employment by industries is a function of population and labor-force participation.

The SURBS population sector divides the population into six age groups (0-13, 14-19, 20-24, 25-44, 45-64, 65+). The population in each district is also characterized by a skills level (average number of years of education completed) and unemployment rate (supplied by the employment sector model). The various population growth rates are then functionally related to age, unemployment rate, and skills level (Figure 5). The rate of migration is particularly sensitive to unemployment rate and skills level. The death and birth rates also respond to national trends.

The SURBS employment model is in effect a model of industrial activity in the region, in which the activity in each industrial sector is measured by the number of people employed in it. The basic division is into Export and Local Service Industries, which are further subdivided as follows:

Export Industries:

A. Agriculture
B. Export Mining
C1. Manufacturing - Fabricating
C2. Manufacturing - Processing
D. Export parts of Education and Government

Local Service Industries:

A. Household Serving
B. Business Serving

More than 240 industries listed in the Standard Industrial Classification Manual are partitioned into the six categories listed above on an all or nothing basis.

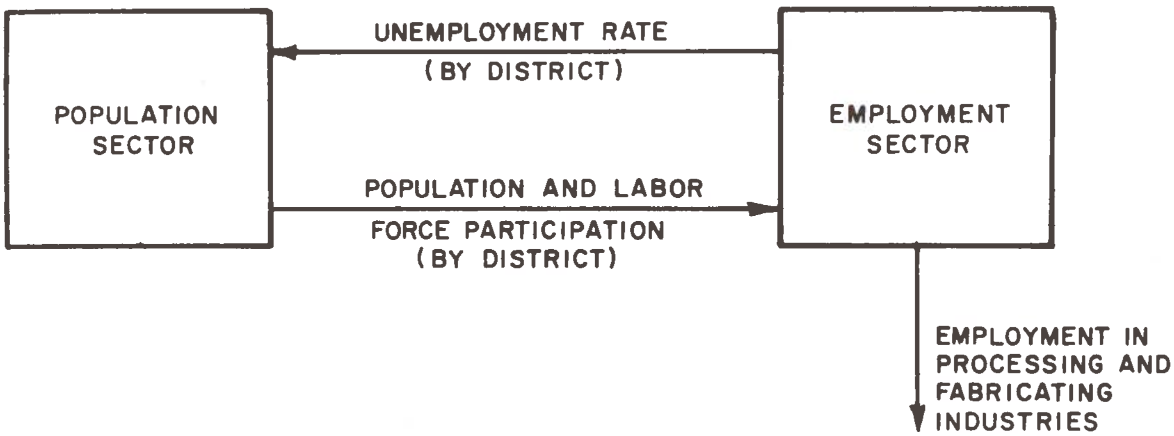

Figure 4.- Socio-Economic Model of the Susquehanna River Basin Study (SURBS) (Based on Text by H. R. Hamilton et. al., Systems Simulation for Regional Analysis - An Application to River Basin Planning, Copyright, MIT Press 1969.)

	AGE GROUP	UNEMPLOYMENT RATE	SKILLS LEVEL	NATIONAL TREND
DEATH RATE DEPENDS ON:	×			×
BIRTH RATE DEPENDS ON:	×	×		×
MIGRATION RATE DEPENDS ON:	×	×		
LABOR FORCE PARTICIPATION RATE DEPENDS ON:	×	×	×	

Figure 5.- Population Growth Rate Dependencies (Based on Text by H. R. Hamilton, et. al., Ibid.)

The SURBS employment model is an example of an "export based" model, i.e., it is assumed that overall industrial growth in the region is determined by growth of the export industries. In particular, employment in local service industries is a function of employment in export industries (for business serving industries) or of population (for household serving industries), as shown schematically in Figure 6. The foundation of any such model is the part that forecasts employment in the export industries. SURBS uses an elaborate model of export industry growth, particularly in the manufacturing sector, which takes into consideration wages in the region relative to the rest of the country, accessibly to markets and raw materials, and growth in the national market for the product. We shall not describe the export model in detail, but Figures 7 and 8 should give some idea of the considerations involved.

What is significant about the SURBS model is that population is not viewed as growing at a fixed rate, but as responding to the industrial and social environment. Since industrial growth is affected by accessibility, it would be affected by changes in the transportation system which would alter the accessibility factor. If such a model were to be adapted for use in a passenger transportation study, it would also have to include factors reflecting residential accessibility and desirability. These could be incorporated in the migration rate equation. The construction of a new rapid transit line into a suburb for example, would increase the residential accessibility factor for the suburb, and thereby affect the migration rate into the suburb.

3.3 Dynamic Models

J. Tinbergen [11] constructed simultaneous differential equation models of the Dutch, British, and U.S. economies in the 1930's, and is widely regarded as the father of dynamic modeling of economic systems. Early difficulties with dynamic models, arising from sheer numerical complexity, have to a large extent

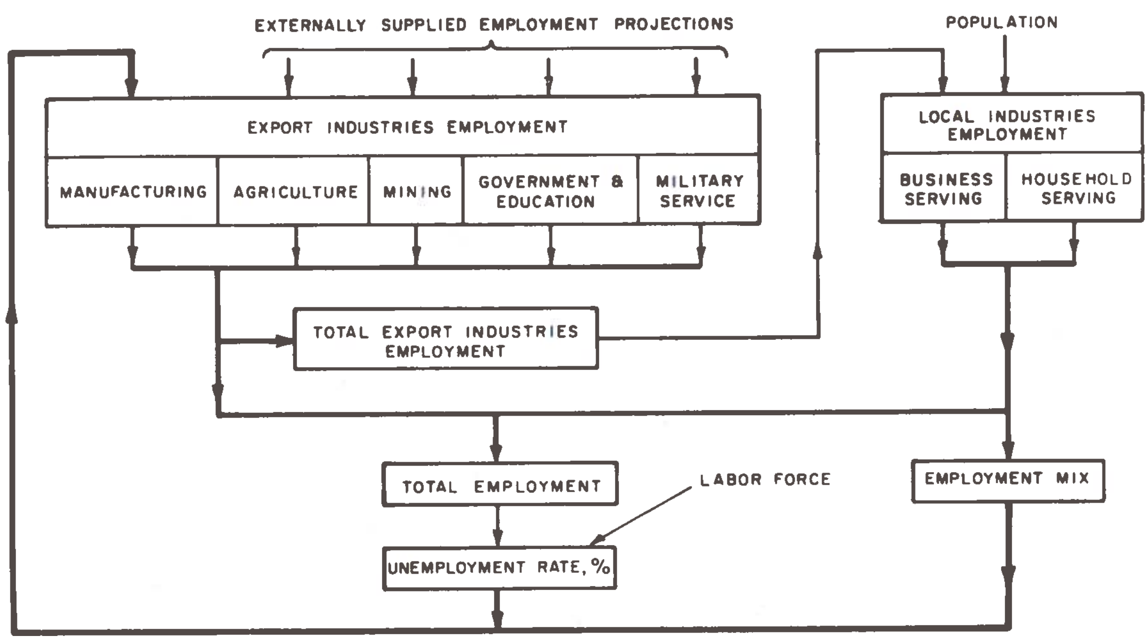

Figure 6.- SURBS Employment Sectors (Based on Text by H. R. Hamilton, et. al., op. cit.)

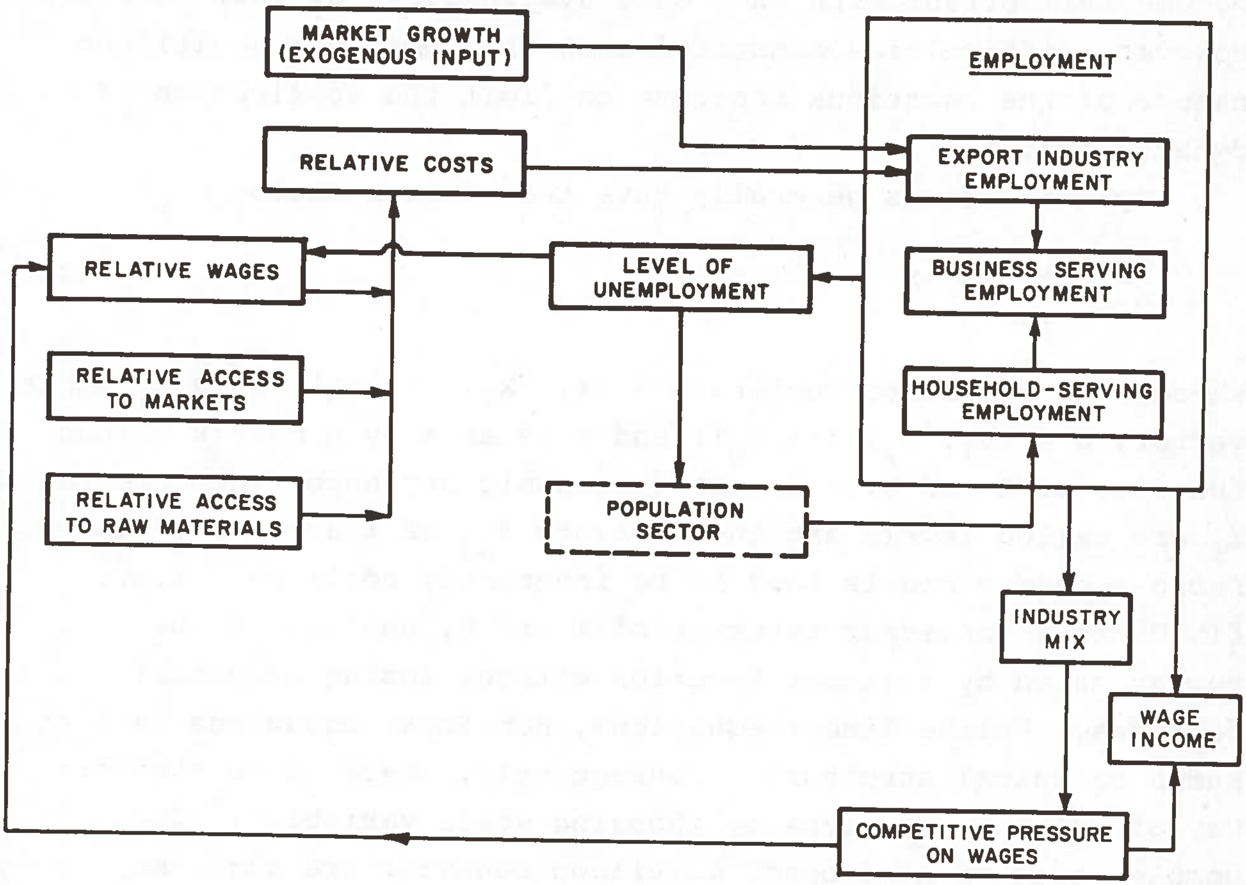

Figure 7.- The SURBS Employment Model (Source: H.R. Hamilton, et. al., Systems Simulation for Regional Analysis - An Application to River Basin Planning, pg. 160, Figure 9.1, copyright MIT Press, 1969.)

INDUSTRY / LOCATION INFLUENCES	LOCAL		EXPORT			
	HOUSEHOLD SERVING	BUSINESS SERVING	MANUFACTURING		MINING AND AGRICULTURE	GOVERNMENT EDUCATION, AND MILITARY SERVICES
			FABRICATING	PROCESSING		
ACCESS TO MARKETS	×	×	×	×		NONECONOMIC INFLUENCES
ACCESS TO LABOR			×	×		NONECONOMIC INFLUENCES
ACCESS TO NATURAL RESOURCES				×	×	NONECONOMIC INFLUENCES

Figure 8.- Locational Factors by Industry in the SURBS Model (Source: H.R. Hamilton, et. al., ibid. pg 161, Figure 9.2)

become unimportant with the ready availability of fast computers. However, difficulties connected with the nonlinear, multiloop nature of the equations continue to limit the application of dynamic models.

Dynamic models generally have the representation

$$\frac{dX}{dt} = f(X,U)\cdot X \qquad (2)$$

where X is the state vector, $X = (X_1, X_2, \cdots X_n)$; U is an input vector, $U = (u_1, u_2, \cdots u_m)$; and f is an n by n matrix valued function of X and U. (In socio-economic parlance, the components X_i are called levels and the elements f_{ij} of f are called rates.) Socio-economic models tend to be inherently nonlinear, i.e., f(X,U) is a nonlinear function of X and U, and can not be approximated by a linear function without losing essential features. Unlike linear equations, nonlinear equations have no known canonical structure. Consequently, there is no standard way of writing equations or choosing state variables. The complexities of nonlinear, multiloop behavior are such, moreover, that until recently efforts were concentrated on simulating the equations, without much attempt at analyzing their dynamics, stability, effects of feedback paths, etc.

Recently, Forrester [12] and others have taken a mathematically simplistic approach to modeling nonlinear multiequation systems. Forrester, in constructing models of city growth [12], represents nonlinear functions of several variables by products of functions of one variable, i.e., $f(X_1, X_2, \cdots X_n) = f_1(X_1)\cdot f_2(X_2)\cdot \ldots \cdot f_n(X_n)$. The fact that many functions can not be represented in this way is disregarded.

Forrester emphasizes the dynamics of city growth, showing that it tends to have characteristic time constants and periodicities determined by internal feedback effects. For example, a city with a reservoir of skilled labor and unused land attracts new industries, which in turn attract new employees; as the city grows, land costs go up and, in conjunction with other factors, produce a negative feedback effect which reduces the city's attractiveness and acts to limit growth; there is, however, a delay of 10-30 years in the perception of a city's attractiveness, which has a destabilizing effect and introduces an oscillatory component (Figure 9).

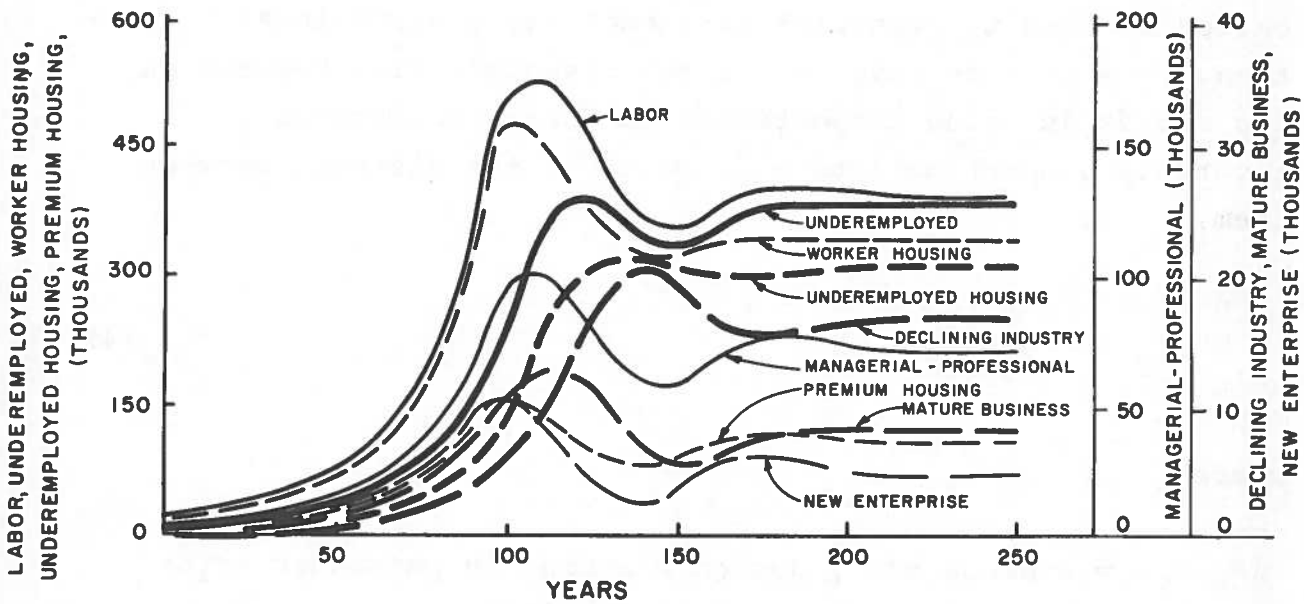

Figure 9.- Life Cycle of an Urban Area - 250 Years of Internal Development, Maturity, and Stagnation (Source: Jay W. Forrester, Urban Dynamics, Figure 1-1, pg. 4, copyright, MIT Press, 1969)

Forrester also attributes many older failures in planning to negative feedback effects which lead to "counter intuitive" results. For example, he claims that certain worker housing projects can have the effect of attracting underemployed labor but driving away industry, resulting in an eventual deterioration of worker housing.

3.4 Demand Analysis Models

The purpose of Demand Analysis is to predict the total numbers of passengers traveling between pairs of points in a transportation system, and the manner in which the total will divide between various modes (modal split) or, in the case of networks of highways, between alternative branches of the network.

One of the simplest demand models is the gravity model, so called because it resembles the model for gravitational attraction. The gravity model gives the passenger flow between any two cities as being proportional to their populations and inversely proportional to a function of the distance between them, i.e.,

$$D_{ij} = \alpha \frac{P_i P_j}{F(d_{ij})} \qquad (4)$$

where

D_{ij} = average daily demand measured in passenger trips between the i-th and j-th cities

P_i = population of the i-th city

d_{ij} = distance between the i-th and j-th cities

$F(\cdot)$ = a suitable function

α = a calibration factor

Elaborations of the simple gravity model, generally called potential models, are used in a large proportion of current demand analyses. Although there is a great deal of variety in the detailed structure of demand models, they tend to have certain features in common. The travel demand is generally expressed as the ratio of two functions: the numerator or potential function accounts for the dependence of passenger volume on social characteristics such as population, income, car ownership, etc.; the denominator function, known as a travel impedance function, incorporates all dependences of passenger volume on characteristics of the transportation system such as trip distance or time, cost, frequency of service, number of interchanges, comfort level, etc. In the case of the simple gravity model the two functions are:

potential function for i-j-th link: $\alpha P_i P_j$

impedance function for i-j-th link: $F(d_{ij})$

Although the gravity model is capable of giving crude estimates of aggregate travel demand, contemporary demand studies usually employ models which are more elaborate in at least three respects:

a. The population is disaggregated into socio-economic groupings and a separate demand forecast is made for each grouping. Total demand is obtained by summing demands within groupings. Income is favored as an economic variable for groupings.

b. Within each class the population figures are raised to a power μ, where μ is determined from a regression analysis of historical data.

c. The impedance function is made to depend on travel time, cost, number of interchanges and frequency of service.

A generalized potential model gives the demand for each city pair ij, population group g, and mode m, in the form:

$$D_{ijgm} = \frac{\alpha \, (P_{ig} \, P_{jg})^{\mu}}{F(t_{ijm}, c_{ijm}, f_{ijm})} \qquad (5)$$

where

D = demand in daily number of passenger trips;

P = population;

t = travel time;

c = out of pocket trip cost;

f = frequency of service;

α, μ = constants determined by regression;

i, j = subscripts denoting i-th and j-th cities;

m = subscript denoting m-th mode;

g = subscript denoting g-th group.

The NECTP employs a potential model [5, 13] in which the population product $P_i P_j$ is replaced by the product $F_i F_j$ of the number of families in each city earning more than $10,000 yearly. This is an approximation which combines the population and income dependence of travel into a single index while avoiding the complexity of a full income distribution. The NECTP demand equations have the form:

$$D_{ij} = \frac{\alpha (F_i F_j)^{\beta}}{(W_{ij})^{\partial}} \tag{6}$$

$$W_{ij} = \left[\sum_m (w_{ijm})^{-1} \right]^{-1} \tag{7}$$

$$w_{ijm} = \frac{\rho \, t_{ijm}^{\mu} \, c_{ijm}^{\eta}}{[1 - \exp(-\kappa f_{ijm})]^{\varepsilon}} \tag{8}$$

where

Greek letters denote constants determined by regression analysis

D_{ij} = demand in daily passenger trips between i-th and j-th cities;

F_i = number of families with income over $10,000 yearly in the i-th city;

W_{ij} = travel impedance between i-th and j-th cities;

w_{ijm} = impedance of mode m;

t_{ijm} = travel time by mode m;

c_{ijm} = cost by mode m;

f_{ijm} = service frequency by mode m.

Improvements in a transportation system are reflected in a reduction of travel impedance. Travel impedance, as defined by Eq. (8), can be reduced by reducing travel times, increasing frequency of service (whose effects are characterized by the saturating characteristic [1-exp(-•)], suggesting a law of diminishing returns), or by the creation of new links. However, Eq. (8) does not reflect comfort or aesthetic factors, and, indeed, few demand studies attempt to consider these factors explicitly as they are difficult to quantify.

The NECTP impedance function is a product of trip time, out-of-pocket cost, and waiting time. The product function is nonlinear and unlike a linear function, has the feature that it tends to exaggerate or be swamped by any one or more components that depart far from a set of nominal values. This is a desirable feature in modeling human behavior, as demand is likely to disappear very rapidly once any one of the important characteristics of the travel system drops outside an acceptable range. Nonlinear functions, however, are more difficult to analyze and compute than are linear ones.

Many current demand studies [2, 14] employ a "time-value" method, in which travel impedance is taken to be a function of the cost of travel, and cost is the sum of ticket cost and the value assigned to the passenger's traveling and waiting times. The cost of travel in such an analysis is thus forced to be a linear combination of certain characteristics of the transportation system. Travel time, measured in dollars per hour, has a distribution in the population according to such factors as income, trip purpose, and trip length. For a fixed trip type the distribution usually has the Lorenz-like shape shown in Figure 10. The shape of this distribution is usually either calculated, from available modal split data, or assumed to be identical to the income distribution. Average time-values usually fall into the range of $1.00-$3.00 per hour.

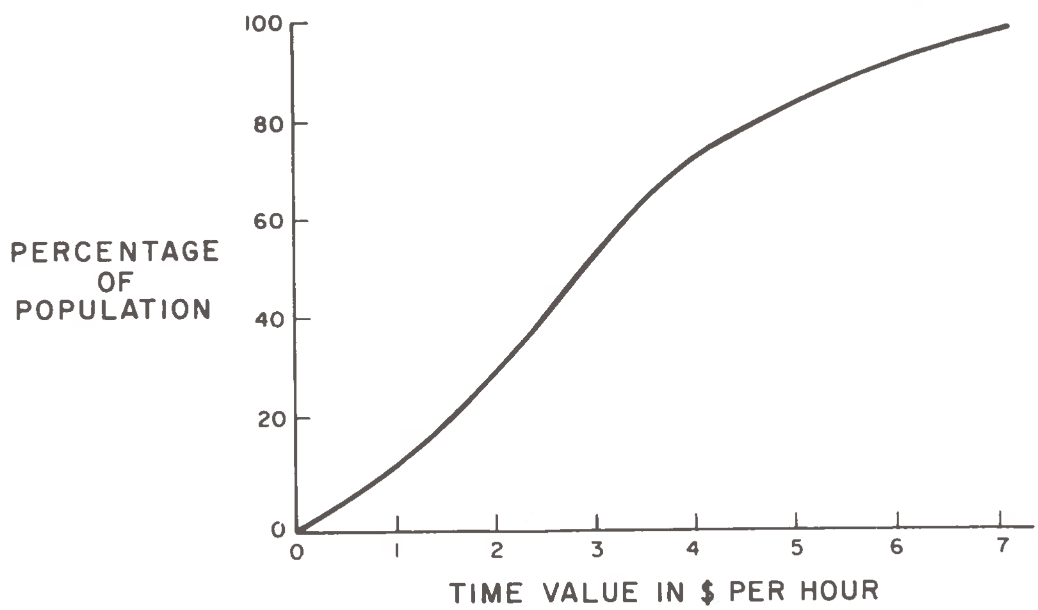

Figure 10.- Time-Value Cumulative Distribution

Time-value analyses are particularly favored in modal split studies, in which total travel demand is known or assumed fixed, and the problem is to determine how the demand will split between various available modes or routes. It is frequently assumed that the individual traveler chooses that mode which minimizes his trip cost. In that case the time-value distribution determines the fraction of the population using any particular mode, with travelers whose time is expensive trading out-of-pocket cost for reduced travel time. Further increases in demand resulting from increased income are then obtained by a suitable translation of the time-value distribution curve to the right. Such a time-value modal split analysis is the basis of DOT's Office of Policy and International Affairs 1975-2000 Technological Forecast [3].

Where the number of competing modes or available paths is large, the calculation of a minimum cost path can be quite complicated. A good example is the calculation of a minimum cost (or time) path in the highway network between two distant cities. Even more complicated is the calculation of the total loading (i.e., number of travelers using) any given link in the network. A whole branch of network and graph theory, employing mainly programming methods, has grown up around the subject of minimum path and loading calculations (building on the pioneering work of Dantzig)* and is employed widely in highway design for the purpose of calculating desirable link capacities.

The demand functions described here entail certain assumptions which make for simplicity but which restrict generality namely:

a. That it is possible to express demand in terms of two functions, one of which is independent of the characteristics of the transportation system, while the other is independent of the characteristics of the traveler.
b. That the potential for travel between two cities is proportional to a product of certain characteristics of the two cities taken separately.
c. That travel impedances can be expressed as linear combinations or simple products of the characteristics of the transportation system.

*G.B. Dantzig, Linear Programming and Extensions, Princeton University Press, Princeton, N.J., 1963.

Wohl [15] and others have pointed out these limitations and proposed employing more general functional forms in demand models. However, they have not supplied any practical ways of implementing the more general models, i.e., of simulating them on computers or calibrating them against measurements. Moreover, the models are so complicated as to afford little analytical insight.

Some idea of the accuracy of current demand models can be obtained from the NECTP results shown in Figure 11, in which observed bus passenger volumes in the Northeast Corridor are compared with predicted figures. The cumulative error frequency analysis depicted in Figure 12 shows that, for 24 bus links studied, in no case was the error less than 9% or greater than 400% and 14 links had errors of less than 100%. In short, potential models give the order of magnitude of travel demand, but accuracies are lower than would be desirable even for crude design estimates.

A perusal of the literature on demand analysis leads to the following conclusions: There is a great need for better demand models. As the amount of work that has already been expended on demand methodology is large, it is unlikely that there will be cheap and easy breakthroughs in methodology. On the other hand, there has been relatively little verification of models against real data, and available data has generally been crude and lacking in uniformity. Data analysis and substantiation is, of course, not cheap either, but must be undertaken if demand analysis is to be put on a solid footing.

3.5 Revenue Calculation

Once the demand is known and ticket price policy has been set, calculation of yearly revenues is straightforward, involving simply the product of ticket price and passenger trips undertaken. Subsidiary calculations may have to be made where concessions for food services, retail stores, air rights, and the like bring in sizable income.

O-D PAIR	TOTAL TIME (MIN)	TOTAL COST (CENTS)	FREQ. (TRIPS PER DAY)	NO. OF FAM. OVER 510K(I)	NO. OF FAM. OVER 510K(J)	OVSERVED VOLUME	PREDICTED VOLUME	RATIO OF OBSERVED TO PREDICTED VOLUME OR RECIPROCAL
BOS-PROV	130	50	8	122585	22680	219000	159800	1.38
BOS-NH	270	75	7.5	167984	34730	106000	58100	0.59
BOS-NY	372	79	18	188335	931936	352000	566300	0.53
BOS-PHIL	512	73	8	188335	226294	50600	79200	0.64
BOS-WILM	522	69	3	188335	27785	3600	10200	0.35
BOS-BALT	601	62	5	188335	77330	9500	18800	0.51
BOS-WASH	643	64	8	188335	175207	91300	34600	0.26
BOS-HART	176	65	7.5	167984	60010	344000	204300	1.63
PROV-NH	181	56	1.5	22680	34730	30800	16300	1.38
PROV-NY	313	70	9.5	26598	931936	166000	147300	1.12
PROV-PHIL	452	62	5	26598	226294	7700	18400	0.42
PROV-BALT	548	55	3.5	37654	77330	1430	6000	0.24
PROV-WASH	584	58	3	37564	175207	7700	9400	0.32
PHIL-WASH	261	65	14	226294	175207	255000	391400	0.65
PHIL-BALT	195	62	12	226294	77330	186000	383900	0.49
PHIL-NY	191	107	56.5	226294	882713	1150000	2750900	0.42
BALT-WILM	169	46	14	77330	20688	48400	62600	0.78
BALT-NY	286	70	24	77330	931936	316000	480100	0.67
WASH-WILM	242	60	8.5	175207	27785	75900	69000	1.10
WASH-NY	326	75	42	175207	1021852	732000	736100	0.92
NY-WILM	210	83	10	931936	20688	83300	279500	2.99
WASH-NH	446	66	2	175207	34730	6600	14800	0.45
PHIL-NH	313	75	2	226294	34730	18600	43200	0.43
BALT-NH	411	63	2	77330	34730	1820	9400	0.19

Figure 11.- Bus Passenger Volumes for the Northeast Corridor

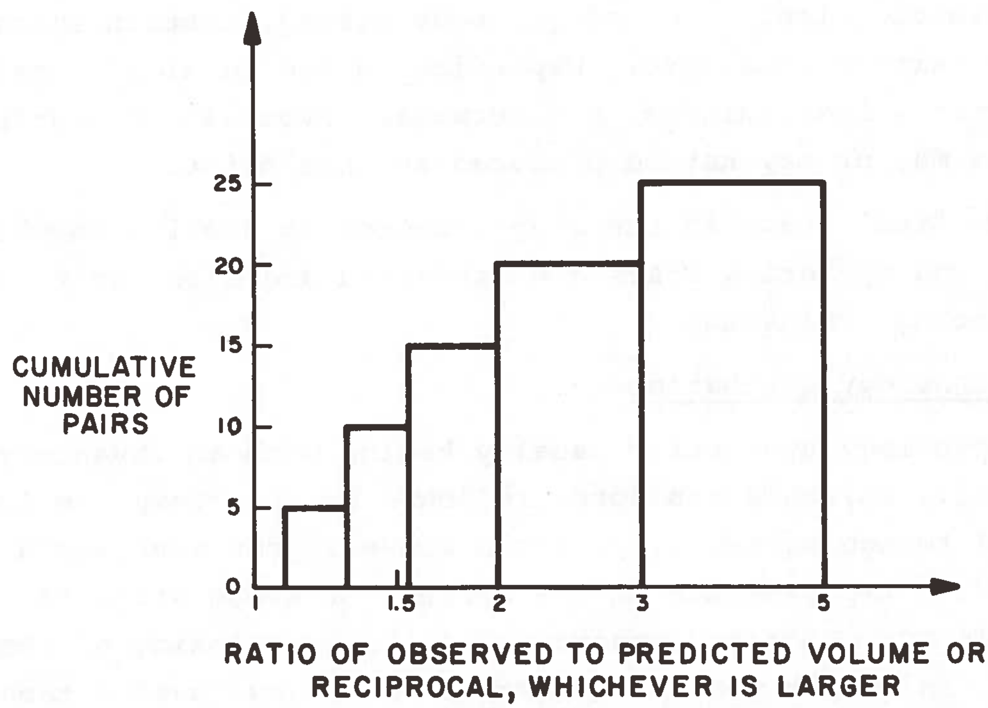

Figure 12.- Error Frequency Analysis: NECTP Bus Passenger Demand Study

4. THE SUPPLY SECTOR

Supply Sector Modeling begins with a Technology Evaluation in which an inventory of available transportation components and concepts is made. Candidates which are not obviously unsuitable are selected, areas requiring research or development identified, and research costs estimated. In comprehensive national planning the trend is to project the evaluation as far into the future as possible via a Technology Forecast.

The Technology Evaluation together with data on demand (from the demand sector) and desired level of service (partly based on profit considerations and partly on policy) act as inputs to a Route Assignment and Scheduling operation. This operation synthesizes the components into a system and produces what in effect is a preliminary system design with gross specifications on fleet size, vehicle size, miles of guideway needed, station spacing, average waiting time, etc. Depending on the level of detail required, an actual guideway and terminal layout and operating schedule may or may not be produced at this point.

The final stage in the supply sector is costing in which capital and operating costs are estimated and alternative methods of financing evaluated.

4.1 Technology Evaluation

Technology Evaluation usually begins with an inventory of potentially suitable concepts, followed by an attempt to locate critical technologies, i.e., those whose improvement would lead to dramatic improvements in the system, or whose state is uncertain but which are essential to the functioning of the system. In recent years a number of formal evaluation techniques of the "decision tree" and "critical path" type have been proposed, and some have been employed with much acclaim in NASA's Apollo Program [16]. The purpose of these techniques is to: 1) systematize the location of critical points and paths in a program with many components (where the successful completion of one component depends on many others) and 2) maximize the probability of success or profit in a program with components whose attainment is uncertain but to which a probability can be attached. For example, Figure 13 illustrates some contingencies that occur in planning small-vehicle small-headway automatic systems of the "personalized rapid transit" type. If air-cushion levitation is adopted, then the development of a linear induction motor (which requires no traction) is critical and there is little point in investing in development of the former without development of the latter. On the other hand, if a high speed, puncture-proof tire is developed, then development of the linear induction motor is not critical, since a rotary motor would be satisfactory. The development of a control system for small headway operation is critical in either case. The probabilities of achieving the various alternatives are, using the probabilities shown in Figure 13 (in brackets):

air-cushion pads and l.i.m. - 0.54

puncture-proof high-speed tire and l.i.m. - 0.34

puncture-proof high-speed tire and rotary motor - 0.36

Probabilistic methods are increasingly being advocated for long range technology forecasting, despite the difficulty of assigning realistic probability estimates to future events. A number of techniques have recently been introduced in an effort to make future probability assignments less arbitrary. For example, the "Delphi" method [4] has been used [2] to forecast future development costs and completion dates of transportation research projects. The method involves polling a number of experts to obtain their estimates of costs and completion dates. The results of the poll together with average estimates are supplied to all the participants, who then send in a second set of estimates. If there is enough money and time, this procedure

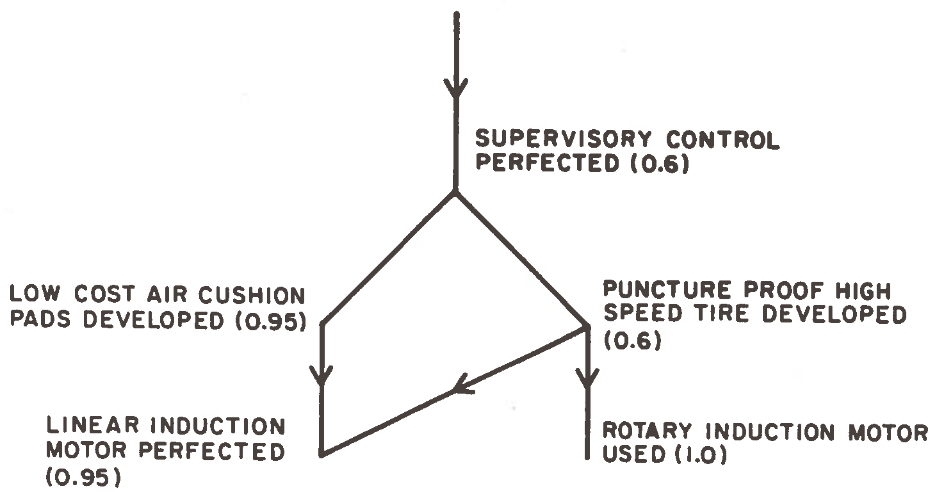

Figure 13.- A Decision Graph

is repeated with the expectation that it will converge to a concensus. The final estimates obtained this way are adopted for the forecast. For example, Figure 14 shows the results of a recent Delphi survey conducted by McDonnell-Douglas [17] of some 300 experts in the air transportation industry, in which each participant was asked to predict the dates by which specified developments would occur. (The "cross-impact matrix" method [18] is an elaboration of the Delphi method, in which joint and conditional probabilities of events are estimated.)

		One fourth of the respondents thought by this date	One half thought by this date	Three fourths thought by this date
1.	A commercial aircraft powered by a nuclear propulsion system will be operational.	(1990)	(1995)	(2000)
2.	Revenue from commercial air cargo on certified airlines will equal passenger revenue.	(1985)	(1990)	(2000)
3.	A large, separate cargo airport for a major population center will be operational.	(1980)	(1982)	(1990)
4a.	Free world certified and chartered revenue passenger miles will reach one trillion.	(1990)	(1990)	(2000)
4b.	Free world certified and chartered revenue passenger miles will reach two trillion.	(2000)	(2000+)	(2000+)
5.	A 1000 passenger aircraft will be introduced into commercial service.	(1985)	(1990)	(1995)
6a.	A cargo aircraft having a 500 ton cargo payload capability will be introduced into service.	(1985)	(1990)	(1995)
6b.	A cargo aircraft having a 1500 ton cargo payload capability will be introduced into service.	(2000)	(2000+)	(2000+)
7.	Twenty-five percent of the commuters who travel one-way distances greater than 15 miles will use air transportation.	(2000)	(2000+)	
8.	Twenty-five percent or more of the passengers departing from a major air terminal will arrive at the terminal by a feeder airline.	(1980)	(1985)	(1990)
9.	You and your associates will normally use air transportation to travel to conferences with your business associates located in different parts of the same megalopolis.	(1990)	(2000+)	
10.	New exotic materials such as boron filament and beryllium will be commercially competitive and in general usage to partially replace the conventional aluminum, titanium, and steel aircraft structure.	(1980)	(1985)	(1990)

Figure 14.- Results of a Survey on Air Transportation Developments (by the Delphi Method)

One shortcoming of such probabilistic methods is that there is no way of determining whether probability assignments are reasonable or not. It can be argued that the methods serve to systematize intuitive planning. However, it can also be argued that, by removing problems from the reach of immediate intuitions and "common sense", such methods can contribute to the perpetration of colossal blunders. It has also been argued that, in any case, the results produced are not worth the large cost and effort entailed in some of the more complex approaches.

Another shortcoming of the Delphi procedure is that it can fail to converge. Even if it converges, it has been noticed that it converges most easily when the participants are laymen, less so when they are well informed. Moreover, it has been argued that, where there is a divergence of opinion, it is preferable to list the full range of estimates than to force a concensus.

For highly structured industries, such as automobile manufacturing, aircraft manufacturing, electric power generation, etc., there have been attempts to forecast the time dependence of expected developments using what in effect are impulse-driven dynamical models. An example of such a forecast are Bouladon's [19] envelope curves, predicting aircraft speeds until the year 2000, shown in Figure 15. There appears to be two assumptions implicit in such a forecast:

a. That new developments are triggered by impulse-like "significant changes". In the aircraft industry these would be the breaking of the sound, heat, and gravity barriers; in transportation they might result from the introduction of air cushion suspension, or from nontechnical changes such as public acceptance of short headway operation.

b. That between significant events development occurs at a rate determined by the structure of the industry.

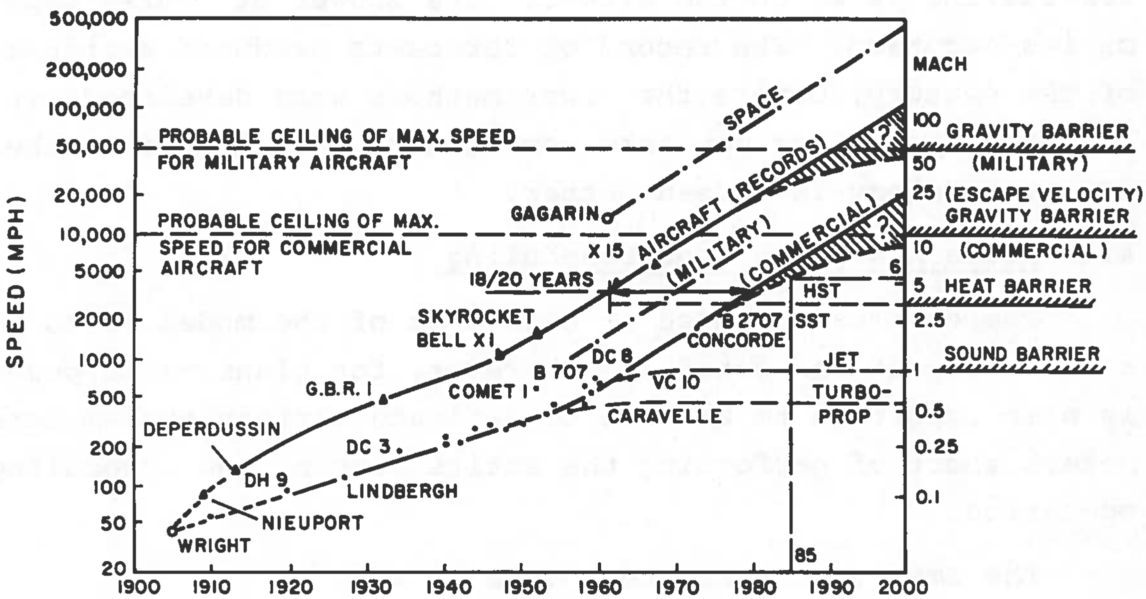

Figure 15.- Trends in Aircraft Speed (Source: G. Bouladon "Aviation's Role in Future Transportation", Technological Forecasting, Vol. 1, (1969), Figure 1, pg. 7, copyright 1969, American Elsevier Publishing Company, Inc.)

> The response is usually S-shaped, i.e., a slow beginning followed by a rapid expansion, followed by a leveling-off as a result of encountering a barrier. The duration of one cycle is characteristic of the industry, and has been about 50 years for power generation, 20 years for automobiles, 10 years for aviation, and 5 years for computers. The newer industries have shorter cycles.

There are legitimate questions as to whether technology forecasting is worth the effort. The answer of course depends on its accuracy. The record of forecasts produced at the turn of the century, before the newer methods were developed, is laughably poor. It may take some generations to see whether the new methodology is indeed better.

4.2 Route Assignment and Scheduling

The eventual purpose of this part of the model is to produce a route layout and schedule. However, for planning purposes it is also important to be able to estimate certain system parameters short of performing the entire routing and scheduling operation.

The important parameters usually are:

1. Fleet size and vehicle passenger capacity.
2. Frequency of service.
3. Station spacing.
4. Total guideway length (where guideways are employed).

It would be desirable, furthermore, to relate these parameters to some relatively simple characteristics of the environment such as land area, average population density, and average per capita demand.

Ad hoc estimating procedures are employed by Ford, Roesler, and Waddel [20], and in the Columbia Transit Study [21].

For estimating purposes it is usually assumed that the area in question is covered by a uniform grid of specified density per unit area, that population density and per capita daily demand are uniformly distributed over the area, and that a specified portion of daily trips (usually around 10%) occur during the peak hour. Estimates are then obtained in terms of averages.

The Columbia Study [21] for example, characterizes its operations primarily by four parameters:

D = total number of passenger trips per hour;

d = average trip length, miles;

P = average number of passengers per vehicle;

V = average velocity of vehicles, m.p.h.

The number N of vehicles required in the fleet is then given by:

$$N = \frac{KDd}{PV} \qquad (9)$$

K being an adjustment factor for vehicles not in use ($K > 1$).

Similar, average estimates are widely employed, although their usefulness is limited because they neglect fluctuations from uniform behavior. Although finer estimates could probably be obtained using full distributions of population density, such data is not usually available, nor has the methodology been assembled.

Indeed, the graph-theoretic problems associated with guideway and station layout are not well understood. For example, given a specified population density distribution by area in a fixed area, how many miles of guideway and stations are needed to reach within a 1/4 mile of 2/3 of the population? Is distribution of density the relevant characteristic for guideway estimates? Could better estimates be obtained from, say, the distribution of first or higher moments of density? Such questions lie at the very foundations of transportation system design, but good answers are not yet available.

There has been a considerable amount of work on the use of convex programming for the optimization of system parameters to minimize system costs. However, problems solved have generally been limited to small subsystems, under idealized assumptions of time-invariant or piecewise-constant demand and neglecting network interation. Some recent texts [22] and studies [23, 24] do attempt to analyze system wide operations, but for very simple configurations. For example, NECTP's TRANSOP model [23] considers a linear network with one branch line. Snell [24] attempts to optimize operations on a single point-to-point link. Studies such as [20] and [21] which take a more comprehensive approach in attempting to characterize cumulatively the operations of an entire urban network, do so using oversimplified demand and layout assumptions and methodology.

In general, the area of Routing and Scheduling is a fertile one for further research especially in the Urban Framework. Experience in the airline industry has been that advances in operations planning effectively translate into improved profits, often making for the difference between profit and loss (e.g., some of the smaller overseas carriers). It is an easier area to make advances in than, say, demand analysis, because it is tied to more unambiguous data and progress in it depends more on mathematics and methodology than on subjective data.

4.3 Costing

Cost estimation for a future system involves breaking up a system into its components, and estimating component costs by comparing with existing similar components, extrapolating price trends, and sheer intuition. Estimation of system costs is further complicated by difficulties in characterizing system operations. For example, the costing procedures outlined by Meyer, Kain, and Wohl [22], or employed by NECTP [2], or the Columbia Study [21], all suffer from the oversimplified characterizations and assumptions mentioned in 4.2.

One of the problems in costing is what to assume about future interest rates, to which cost estimates are usually sensitive. (On a government level there are more complex questions of the value of future vs. current expenditures). The studies cited generally employ an arbitrary interest figure of 6-10%.

In the transportation field, the estimation of land acquisition costs has been a major source of difficulty. Land costs represent more than half the cost of most urban systems, and are subject to wide fluctuations.

5. THE POLICY SECTOR

For a private transportation company operating in a free enterprise economy the goals of the policy sector are relatively easily defined; they are to find those pricing and level-of-service policies which maximize profits, i.e., difference between revenues and expenses. The main problems then are to determine the price and service "elasticities" of the system, i.e.,

a. What percentage change in demand will result from a 1% change in ticket price?

b. What percentage change in demand will result from a 1% change in frequency of service?

However, most transportation systems nowadays are at least partly government-controlled and subsidized, and thus their policy sectors are much more complicated. One government point of view on the operating goal of a transportation system is that it should maximize total social profit, or total social benefit-to-cost ratio, where now total costs include pollution and environmental costs, and benefits include creation of new jobs and improvements in industrial efficiency. However, even the purely economic components of social cost are hard to measure; e.g., what is the present dollar cost of future medical expenses attributable to increased pollution? Should non-economic factors such as improved quality of life, aesthetics, etc., be weighted in the cost equation? These and similar questions are the subject of much current research in the fields of Transportation Economics, Optimization Criteria, Utility and Value Theory, and Decision Theory.

Almost any transportation policy adopted by the government implies in effect a subsidy of some modes and a tax on others. For example, the Interstate Highway Act has been interpreted by many as creating a subsidy of rural roads at the expense of urban roads and, especially, of railroads (which was one of the factors leading to the demise of passenger railroad service). One of the functions of the Policy Sector is to calculate hidden as well as apparent subsidies and taxes, and to project their effects.

5.1 Impact Analysis

A new transportation system changes the environment; it induces people and industry to move to new locations; it creates new demand; it changes economic efficiency. The modeling of these effects goes under the heading of impact analysis. Impacts appear as feedback paths in the model structure.

In a properly designed model the impact of new transportation systems really should be modeled internally in the equations of the socio-economic and demand models (for example, by making migration rates variable), rather than in a detached impact model. However, as quantitative impact data was very meager in the past, it was the practice in many studies (e.g., NECTP [9]) to assume a constant environment at first, and to add on a tentative impact model later.

Impact Analysis is an extremely important (though difficult) area of research at present, as impacts produce feedback paths that drastically alter the behavior of the system. Many of our current problems are the result of having neglected Impacts (e.g., movement of population to the suburbs in response to improved arterial highways; shifts of freight movements from railroads to trucks in response to the interstate system).

6. CONCLUSIONS

Almost everyone of the component areas shown in Figure 2 is at an elementary stage of development, and requires much more work to reach any sort of maturity. The following areas appear particularly fruitful.

a. Routing and Scheduling.- Primarily an area requiring mathematical research and improvements in methodology. Considerable advances would probably not be difficult to attain. Operations of Urban Systems are particularly timely and important.

b. Demand Analysis.- Data analysis and model verification is required. This is an important area but advances in it will be expensive in time and money.

c. Impact Analysis.- A critically important area on which theory and data are both meager. It will probably be easy to generate models, but very difficult to validate them, particularly for newer modes with short and time-varying histories.

APPENDIX: MAJOR URBAN AREA TRANSPORTATION REPORTS*

The following transportation studies have issued final or interim reports:

STUDY NAME		REPORT YEAR
A.1	DETROIT METROPOLITAN AREA TRAFFIC STUDY (DMATS).	
	Part I, Data Summary and Interpretation	1955
	Part II, Future Traffic and a Long Range Expressway Plan	
	Sponsors: Michigan State Highway Dept. Wayne County Road Commission City of Detroit U. S. Bureau of Public Roads	
	Director: J. D. Carroll, Jr.	
A.2	CHICAGO AREA TRANSPORTATION STUDY (CATS)	
	Volume I, Survey Findings	1959
	Volume II, Data Projections	1960
	Volume III, Transportation Plan	1962
	Sponsors: State of Illinois Cook County City of Chicago U. S. Bureau of Public Roads	
	Director: J. D. Carroll, Jr.	
A.3	NATIONAL CAPITAL REGION TRANSPORTATION PLAN	1959
	Only mass transit plan completed.	
	Sponsors: National Capital Planning Commission National Capital Regional Planning Council	
	Directors: K. M. Hoover, P. C. Watt, R. A. Keith	

*Following Deutschman, Solomon and Silien [25].

STUDY NAME		REPORT YEAR
A.4	HOUSTON - HARRIS COUNTY TRANSPORTATION STUDY	
	Houston - Harris Co. Transportation Plan, 1960-1980	
	Sponsors: Harris County	
	Cities of Houston and Pasadena	
	Texas Highway Dept.	
	U. S. Bureau of Public Roads	
A.5	PITTSBURGH AREA TRANSPORTATION STUDY (PATS)	
	Volume I, Study Findings	1962
	Volume II, Forecasts and Plans	1963
	Sponsors: Commonwealth of Pennsylvania	
	Allegheny County	
	City of Pittsburgh	
	U. S. Bureau of Public Roads	
	Director: L. Keefer	
A.6	THE BOSTON REGIONAL SURVEY	
	Mass Transportation in Massachusetts [PB 174 422]	1964
	The Boston Region, Supplement No. 1	1963
	Supplementary Statistics, Supplement No. 3	1964
	Sponsors: Massachusetts Mass Transportation Commission, and U. S. Housing and Home Finance Agency	
	Director: J. Maloney	
A.7	BALTIMORE METROPOLITAN AREA TRANSPORTATION STUDY (2 volumes issued) (BMATS)	1964
	Consultant: Wilbur Smith & Associates	
	BALTIMORE AREA MASS TRANSPORTATION PLAN	1965
	Consultant: Parsons, Brinckerhoff, Quade & Douglas	

STUDY NAME		REPORT YEAR
A.8	NIAGARA FRONTIER TRANSPORTATION STUDY (BUFFALO REGION)	
	Volume I, The Basis of Travel	1964
	Volume II, Travel	1966
	Sponsors: New York State Dept. of Public Works U. S. Bureau of Public Roads	
	Director: R. Creighton	
A.9	PENN-JERSEY TRANSPORTATION STUDY	
	Volume I, The State of the Region	1964
	Volume II, 1975 Projections, Foreground of the Future	1964
	Volume III, 1975 Transportation Plans	1965
	[PB 173 327, PB 173 326, PB 173 330]	
	Sponsors: Pennsylvania Dept. of Highways New Jersey State Highway Dept. City of Philadelphia U. S. Bureau of Public Roads	
	Director: D. Longmaid	
A.10	TRI-STATE TRANSPORTATION COMMISSION (NEW YORK REGION)	
	1985: An Interim Plan	1966
	Sponsors: States of New York, New Jersey and Connecticut U. S. Bureau of Public Roads U. S. Dept. of Housing and Urban Development	
	Director: J. D. Carroll, Jr.	

STUDY NAME		REPORT YEAR
A.11	SOUTHEASTERN WISCONSIN REGIONAL TRANSPORTATION STUDY (MILWAUKEE REGION)	
	Volume I, Inventory	1965
	Volume II, Forecasts and Alternative Plans, 1990	1966
	Volume III, Recommended Regional Land Use and Transportation Plans	1966
	Sponsors: Southeastern Wisconsin Regional Planning Commission U. S. Bureau of Public Roads U. S. Dept. of Housing and Urban Development Wisconsin State Highway Commission	
	Director: K. W. Bauer	
A.12	PUGET SOUND REGIONAL TRANSPORTATION STUDY (SEATTLE REGION)	
	Summary Report	1967
	Sponsors: Puget Sound Governmental Conference Washington State Highway Commission U. S. Bureau of Public Roads U. S. Dept. of Housing and Urban Development	
	Director: J. K. Mladinov	
	Also sponsored by the Puget Sound Governmental Conference and the City of Seattle:	
	Feasibility of Rapid Transit Operation	1965
	Report on a Comprehensive Public Transportation Plan for the Seattle Metro. Area	1967
A.13	DALLAS-FORT WORTH REGIONAL TRANSPORTATION STUDY	
	Population Forecast	1965
	Economic Base Analysis	1967

STUDY NAME	REPORT YEAR
<u>Land Use Population Distribution-Trip Forecasting</u>	1967
<u>Origin-Destination Study</u>	1967
Sponsors: Cities of Dallas and Fort Worth Dallas and Tarrant Counties Texas State Highway Department U. S. Bureau of Public Roads	
Director: J. R. Stone	
A.14 OAHU TRANSPORTATION STUDY (HONOLULU REGION)	
<u>Trip Production and Attraction</u>	1966
<u>A Study of the Economy of Oahu</u>	1967
<u>Oahu Transportation Study - Transit Planning and Modal Split Study</u>	1967
Sponsors: City and County of Honolulu State of Hawaii U. S. Bureau of Public Roads U. S. Dept. of Housing and Urban Development	
Director: Ah Leong Kam	
A.15 RAPID TRANSIT FOR METROPOLITAN ATLANTA	
<u>Preliminary Engineering Report</u>	1967
Sponsor: Atlanta Region Metropolitan Planning Commission Metropolitan Atlantic Rapid Transit Auth. U. S. Dept. of Housing and Urban Development	
Director: G. Bennett	

STUDY NAME		REPORT YEAR
A.16	LOS ANGELES REGIONAL TRANSPORTATION STUDY	
	Volume I, <u>Base Year Report</u>	1963
	Volume II, <u>1980 Progress Report</u>	1967
	Sponsors: Transportation Assoc. of Southern California	
	U. S. Bureau of Public Roads	
	Director: E. T. Telford	
	LOS ANGELES RAPID TRANSIT STUDY	
	<u>Final Report, May 1968</u>	1968
	Sponsors: Southern California Rapid Transit District	
	U. S. Dept. of Housing and Urban Development	
	Director: J. Curtis	
A.17	JOINT PROGRAM FOR LAND USE-TRANSPORTATION PLANNING (MINNEAPOLIS-ST. PAUL REGION)	
	<u>Metropolitan Development Guide</u>	1968
	<u>Preliminary Report on a Long-Range Transit Plan for the Minneapolis St. Paul Area</u>	1967
	Sponsors: Twin Cities Metropolitan Planning Comm.	
	U. S. Bureau of Public Roads	
	U. S. Dept. of Housing and Urban Development	
A.18	MIAMI URBAN AREA TRANSPORTATION STUDY	
	<u>Transit Coast Allocation and Model Development</u>	1968
	Sponsors: Dade County Planning Dept.	
	Florida State Road Department	
	U. S. Bureau of Public Roads	
	U. S. Dept. of Housing and Urban Development	
	Director: R. R. Walters	

STUDY NAME		REPORT YEAR
A.19	METROPOLITAN TRANSPORTATION (NEW YORK REGION) Metropolitan Transportation: A Program for Action Sponsors: Metropolitan Commuter Transportation Authority State of New York	1968

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