URBAN DEVELOPMENT MODELS AS PLANNING TOOLS

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PREFACE

In the recent years various kinds of mathematical models have been emerging as new tools in the planning profession. The idea of the model as a practical application of the theory to actuality is not new in many fields of science and engineering. It is the high computational ability of modern computer that has made possible its application to the planning field of the present urban community, while at the same time it is the enormous complexity of our society that necessitates the thorough analysis through the computer.

The purpose of this paper is to review the principles and techniques of these new tools as applied to the current planning problems. In Chapter I the possible roles of the model technique will be discussed in relation to the planning process. In Chapter II the elements of actual model building will be presented. Some examples of models for regional growth forecast, land use-transportation forecast will be outlined in Chapter III.

The term "urban development models" in this paper indicates the simplified replication of urban phenomena in abstract forms, especially in the mathematical language. Its definition will be further clarified in the first two chapters.

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CHAPTER I

MODELS AND THE PLANNING PROCESS

Planning is defined as the process for determining appropriate future action. To the planner three basic problems have always existed. They are:-

1. What is the objective of the process?
2. What means is appropriate to achieve the stated objective?
3. How can the identified means be effectuated to achieve the objective?

While the complexity of our urban community has been enormously increasing, there have been a number of contributions from various academic and professional disciplines in an effort to supply the necessary information to answer the problems. Our concept of urban community and tools of analysis have been developing interdependently.

A model technique is one of these tools which seem to have a promising potential for the rationalization of the planning process. In this chapter the possible role of various models in the planning process will be discussed in order to get the broad prospect of this new technique.

A. NEW IMAGES OF URBAN SYSTEMS

Reflecting the early literature of urban studies, planners traditionally perceived the City as a discrete physical entity whose signal traits are size, shape and density. However, as the complexity of our urban life has increased, planners now understand the city as a composition of systems and subsystems interdependent but functionally specialized. The city, for example, has systems such as social systems, economic systems, physical systems and decision-making systems.[1] The boundaries of once separable and discrete parts of the city have been blurred and systematized in different terms. As Lowdon Wingo once put it, planners are now prisoners of the discovery that in the city everything affects everything.[2]

The main concern of urban studies has been shifted from stocks of the early stage, to flows, and then to systems. The growing enthusiasm for the use of computer models as aids to urban planning derives from their potential as a tool to analyze the relations and interactions of these systems as contrasted to the inadequacy of traditional tech-

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[1] This point raises a question about the status of urban design in the planning process. The urban physical structure capable of being perceived by our sensuous organs should be regarded as an urban system distinguished from others. Urban design should not be the mere physical interpretation of a previously determined planning decision at the final stage of the planning process, but rather be an integrated part of the decision from the start of the process. See: Kevin Lynch, The Image of the City, Cambridge, Mass.: M.I.T. and Harvard Press, 1960.

[2] Lowdon Wingo, Jr. Ed., Cities and Space, Baltimore: The Johns Hopkins Press, 1963.

niques. The accumulating refinement of theories of the relationships among urban systems and sub-systems will bring the more rational foundation for planning decision making than traditional techniques can offer.

For example in the early days of urban renewal, the slum was torn down in a straightforward way. Now we know the slum to be a complex social mechanism interwoven with the process of the metropolitan community as a whole. To distinguish favourable policy outcomes from unfavourable ones is no longer a simple problem. Decisions by governments, firms, and individuals in metropolitan areas turn on the state of such interdependent systems as use of recreation facilities, transportation networks, the markets for land, housing, labour and so on. It should be noted that the urban community as we see it now has been created by the innumerable decisions collectively made by atomistic citizens.

Today our planning actions are strategic, taking into consideration all the impacts and repercussions of each action taken. The organized understanding of how the relevant systems work precedes our proper judgment of strategic planning actions as such. The planning actions are on the other hand restrained among others by the possible means which planners can manipulate. The potential of models as tools for analysis of systems can be extended to the rational selection of strategic actions to achieve the objective.

B. CONTINUING PLANNING PROCESS

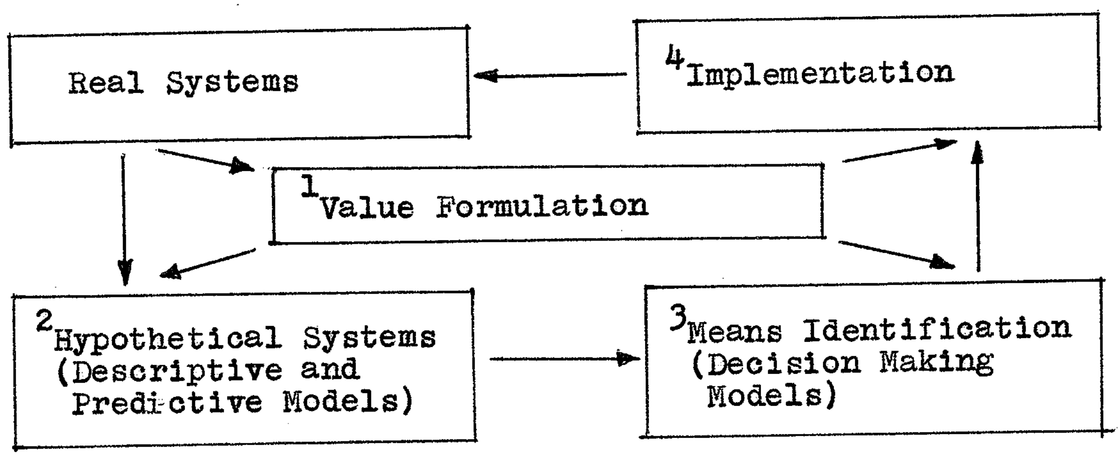

Figure 1

Continuing Planning Process

Figure I depicts the logical planning process to be operated on a continuing basis. There are four basic steps into which a planning process can be divided:

1. Formulation of goal values,[3]
2. Inventory and analysis of the existing and historical conditions, and prediction of the future based on the set assumptions,
3. Means identification of which the first step is to find out the possible alternatives and the

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[3] The widely recognized survey-analysis formula of planning process can be misleading because it implicitly alleviates the emphasis on value decisions the planner has to make all through the process. In fact, in this formula the key

second step is to evaluate them and select the most appropriate one in reference to the set goal values, and,

4. Implementation of the selected actions.

These steps are not necessarily placed serially in time, one starting after the preceding one has been completed, but are rather continuously traversed in a gradual convergence to the final step. Since values are inescapable elements of any rational decision making process, each phase of the planning process will be discussed with emphasis on the relevant value decision in the following part of the chapter.

(1) GOAL FORMULATION

Value decisions are underlying over all the planning actions either explicitly or implicitly. It is important that no institution holds values by itself. Value decisions are made personally by the individuals at different times and places.

A preliminary step the planner must take is to identify his clients who will be involved and affected by the possible action. He should be aware not only of his immediate clients but also of his ultimate clients. He is

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3 continued/
decisions are presumably imbedded in the ideological or disciplinary heritage of the individual professional groups. See: Paul Davidoff and Thomas A. Reiner, "A Choice Theory of Planning", Journal of the American Institute of Planners, Vol.XXVII, No.2, May 1962, pp.103-115.

considered a responsible agent of all his clients, immediate and ultimate. It is among his responsibilities to try to find out values of all his clients. Neither the planner's technical competence nor his wisdom entitles him to ascribe or dictate values to his immediate or ultimate clients.[4]

Since values are personal, it is unlikely that the planner could formulate the average uniform values attributable to all of his clients. Though for the purposes of providing criteria for a specific planning action, weighing of various values is required, he should recognize the immense diversity of values of his clients.

Goals formulated at the early stage of a planning process shall be refined and articulated as the process proceeds.

It is important that no computer can make value decision unless the relevant criteria are given. No sophistication of design methods can replace the human role as the setter of values. The decision-making models we will discuss later are designed to make routine judgment based on the given criteria.

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[4] This point implies the need of the "attitude survey" of the planner's clients. See: A.M. Voorhees, Attitude and Planning Goals, Proceedings of the 1963 Annual Conference of the American Institute of Planners, 1963. Because value is operative in any planning action, the planner is inevitably involved in value decision.

(2) SURVEY, ANALYSIS AND PROJECTION

Once the preliminary goals are formulated next step is to investigate how urban systems work with regard to the set goals. If everything affects everything in urban communities, this step is taken in an effort to understand how everything affects everything.

In the real world, it is rarely possible to undertake experiments as the chemist does in his laboratory. The inevitable assumption here is that what has happened in the past is likely to happen in the future, _ceteris paribus_. In other words, we have to assume a certain consistency between the past and the future, whether we like it or not.

The high computational ability of modern computers has made revolutional progress in handling the massive information of urban communities. Today the planner is more equipped in his ability of data collection than his predecessors.

The availability of information within his available time and/or money budgets may determine his scope of investigation. The first hand field survey, however attractive, may have to be discarded because of the cost.

While the availability of information may restrain the scope of the future analysis, the conceptual framework of the future analysis should be established to select necessary information efficiently and intelligently.

Once all the significant information is collected, the planner then identifies the inter-relationships among the observed phenomena.

The planner may have to be satisfied with the mere statistical relationships of unidentified reason, because of the apparent complexity of the phenomena. Or he may succeed to find the true cause-effect relationships.

Today there are various systematic methods to find out the structural inter-relations among many variables, such as "regression analysis", "factor analysis, or the technique vaguely termed as "system analysis". It should be noted that these new techniques are heavily dependent upon the method of quantification.

Supposing the planner has established successfully the inter-relationships which have existed, he may proceed to project them to the future. This operation is to make an abstraction of the hypothetical future world where the planner can experiment to estimate the impact of his possible actions.

(3) MEANS IDENTIFICATION

The means identification is an attempt to find appropriate instruments to achieve a stated end. The first step is to investigate a universe of all the possible alternative means in reference to the selected goals. The restraints may come from legislation, level of technology, climate, geography, historical events, resources, and so forth.

This phase of planning process is often called the design phase. This term is correct in the sense that the phase requires the synthetic and creative efforts of the planner. But the term should not be understood in such a way that the phase is the last-minute physical interpretation of the prescribed non-physical objectives.[5]

Variables of a system can be divided into the "controllable" which the planner can manipulate and the "uncontrollable" which lie outside the planner's reach. They can be classified, in another way, into the "endogenous" which are determined within the system and the "exogenous" which are given from outside of the system. Our "target" variables are usually uncontrollable and endogenous. An investigation of the alternative means can be interpreted as an effort to find out the possible sets of the controllable variables that yield the appropriate magnitudes for the target variables.

Models which predict the future system offer a good help for the planner to estimate the impacts and repercussions of his possible manipulation of certain controll-

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[5] The counter movement against the "city beautiful" seems to have gone far enough to regard the physical environment as a mere interpretation of non-physical determinants. As Kevin Lynch pointed out, the qualities of physical environments should have legitimate position as a distinct determinant. Kevin Lynch, ibid.

able variables. The hypothetical experiment on the condition of "other things being equal" can be performed in the models on a shortend time scale. This operation is called an "impact analysis".

The resistance of the process of alternative making against the computer operation should be kept in mind. The alternative making will be the last to be computalized next to the goal formulation.

Once the alternative means are chosen, each will be weighed in the light of the set goals. Then the most appropriate means will be selected for implementation.

This selection process usually takes two steps. The first step is often called "testing", that is, the detailed investigation of the inputs and outputs of each alternative. A technique developed for this study is known as "cost-benefit analysis". Usually money is chosen as the single metric of measurement for the sake of convenience. But it should be remembered that all the true costs and benefits are not measurable in terms of dollars and cents.

The second step is to evaluate and select the results of testing in terms of certain operational criteria derived from the set values. Familiar criteria are concerned with the efficiency, that is, the rate of the total benefits to the total costs. Others are concerned with a certain element of the benefits, such as the average income in the case of economic planning. The planner also has to take into consideration such factors as consistency with external conditions, community attitude, and feasibility of implementation. The final decision is usually left in the hands of the elected officials.

The mathematical methods designed to arrive at the optimum solution under given criteria are vaguely called "programming" or just "programme". Among them, "linear programming" is most widely known. It is a process allowing the efficient exploration of a very wide spectrum of alternatives under special restrictions as to permissible cause-effect relationships, and assuming complete information about alternatives and their consequences at the time of choice. "Dynamic programming" which is to identify optimal sequences more efficiently than trial and error of the linear programming is being developed by mathematicians.

(4) IMPLEMENTATION

The planner guides previously selected means towards attainment of goals adopted previously. Implementation is concerned with administration and control. The phasing of implementation should be finalized considering the capital spending programme, available man-power and other resources.

Once the policy decisions are made, the planner's role as an overseer is analogous to a feedback mechanism. When an assumed condition changes or an unexpected event happens, the planner should review the selected means in reference to accepted policies.

The implementation of any planning action changes the conditions which existed at the start of the planning process. For the planner, the whole process is analogous to the experiment. The last phase of the planning process is to review and evaluate all the consequences of implemented actions as invaluable reference to the future. The corresponding models should be altered according to the change rendered by the planning action in the real world.

CHAPTER II

THE ELEMENTS OF MODEL BUILDING

In the previous chapter we have reviewed the planning process and how the models can be used. This chapter is concerned with principles of model building.

A model is a simplified abstraction from the real world. The importance of urban simulation models in planning derives its possible role as a substitute for the experiment in the real world. It would predict what would happen if one course of action were taken rather than the other.

The model building is the synthetic processing of the accumulated analytical knowledge. A model is in a sense a systematic storage of our analytical studies. Efforts have been made to draw upon whatever is usable in social and other science theories in attempting to design capable operational models. The idea of model does not imply the use of a computer. Sometimes a simulation composed of the experienced persons, as well as the computer's routines, or a "man-machine" simulation, may be the best solution, when a computer fails to replicate the intricate subjective human judgments. But urban phenomena of our times are so complex and so resistant to abstraction that computer solutions to them come to have a great appeal. The contribution of the computer is that it offers systematic data storage and manipulation on a continuing basis at a scale, speed, and cost vastly better than anything before.

It should be remembered that a model is a simplified replication and never be an all-inclusive substitute for the real world. When the planner selects certain variables as significant, he cannot escape from the value decision. A model is inevitably value-oriented reflecting the initial intention. Computers are not wiser than their masters, but they perform the most monotonous and repetitive tasks at high speed and with absolute mechanical accuracy.

The model literally consists of named variables embedded in mathematical formulae (structural relations), numerical constants (parameters), and a computational method programmed for the computer (algorithm). The pattern generated is typically a set of values for variables of interest to the planner, each value tagged by geographic location and/or calendar date of occurrence.[1]

A. THE TYPES OF MODELS

The model in use for planning may fall into any of three types, depending on the interests of the planner.

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[1] For more discussion of this section, see: Ira S. Lowry, "A Short Course in Model Design", Journal of the American Institute of Planners, Vol. XXXI, No.2, May 1965. Henceforward the term "value" indicates the magnitude in mathematical sense.

These are descriptive models, predictive models and decision-making models.[2]

(1) DESCRIPTIVE MODELS

Descriptive models are made in the limited objective to have the computer replicate the relevant features of an existing urban environment or an already observed process of urban change. Good descriptive models are of scientific value because they reveal much about the structure of the urban environment, reducing the apparent complexity of the observed world to the rigorous mathematical language. They provide concrete evidence of how everything in the city affects everything else. They may also offer a short-cut to field-work, by generating reliable values for hard-to-measure variables from input data consisting of easy-to-measure variables. For example, it is suggested that the origin-destination survey may be substituted by the model which estimates the interzonal traffic from the land use data.

Descriptive models do not directly satisfy the planner's demand for information about the future, or help him to choose among alternative programmes. For these purposes, he must look to the predictive and decision-making models.

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[2] The terms "normative models" and "planning models" are sometimes used as equivalent as decision-making models in this paper. See: Ira S. Lowry, ibid.

(2) PREDICTIVE MODELS

Predictive models have the objective of providing the planner with information about the future. The first task is to establish a logical framework with which the variables of interest stand at the end rather than at the beginning of a causal sequence. In a descriptive model it may suffice to note that certain variables are interrelated. But when the aim is to predict the value of the future, the model must specify the structural sequence which will be consistant in the future. The second task is to make sure that the exogenous variables which are given at the beginning can be plausibly estimated as far into the future as may be necessary.

The planner is interested in the state of the world following some contemplated act on his part, or following some possible but uncertain event outside his control. Predictive models may satisfy the planner's demand for the conditional information of the future on his assumptions of some exogenous variables. In other words, predictive models may tell the planner the impacts and consequences of his alternative solutions. For the systematic evaluation of the impacts and consequences, he must look to the decision-making models.

(3) DECISION-MAKING MODELS

A decision-making model incorporates the method of conditional prediction and the evaluation of their outcomes in terms of the predetermined goals. The essential steps are as follows:

1. Specification of alternative means of action chosen or designed by the planner,
2. Prediction of the consequences of each alternative,
3. Scoring these consequences according to the goal-achievement, and,
4. Selecting the alternative which yields the most appropriate score.

If steps two, three, four are programmed in computer, it is feasible for the planner to trace a fairly large number of alternatives through to their final outcomes in the model. The mathematical methods of linear programmes and dynamic programmes may be used for computational routines.

B. THEORETICAL FRAMEWORK

The work of model building begins with the identification of persistent relationships among relevant variables, of causal structure and of a logical computational sequence for the model. In other words, the model-builder must develop theoretical framework of urban form and process. If the aims of theories are logical coherence and generality, the aims of models are the application of theories to a concrete case with empirically-based data. The model making does not dissipate the importance of theoretical consideration but rather makes it crucial. The theoretical framework may be developed by the planner or model-builder, or borrowed from the fields of sciences. The whole process of model building is guided by this theoretical framework.

(1) THE LEVEL OF AGGREGATION

Since the model is made up of variables, the model-builder is concerned with the level of aggregation of variables at which his search for causal structure receives the maximum profit. While there is an accepted distinction between "macro-analysis" and "micro-analysis", the differences between these modes of perception can be elusive.

The geographer, demographer, and ecologist prefer to deal with statistics of mass behaviour and the properties of collectivities. Faced with the same problem, the economist is likely to think in terms of competitive interaction of individuals whose behaviour is predicted on a theory of rational choice.

The principal criticism of the macro-analytic approach is that its theory consists of descriptive generalization which lacks explicit causal structure. For example, a macro-analysis of residential mobility may consist of a set of mobility rates for population subgroups classified by age, sex and family status. This set of mobility rates is obtained from historical evidence of the statistical frequency of movement of such groups. For purposes of prediction, one may assume that these rates will apply to future as well as past populations. But since the reasons for which people move is not explicit in such a macro-analytic model it is not easy to incorporate the future changes in the environment with the prediction based on the assumption of consistency.

Another objection to macro-analytic approaches is that they do not lend themselves easily to financial accounting. On the contrary, in an economic micro-analytical approach such as a "market model", every alternative behaviour is tagged with price as a material for rational choice.

The micro-analytic approach also has its problems. Chief among these is that a model based on the theory of rational choice can work only if the choosers' system of relative value or "preference system" is specified in considerable detail. For example in a micro-analytic approach for residential mobility rates, the reasons of moving of each household should be questioned and meaningfully postulated in connection with each environmental condition. The specification or even approximation of the preference system is not an easy task. Faced with the same conditions, one household may choose to move to a better house while another may stay and buy a second car.

Another problem of the micro-analytic approach is the imperfectness of the market because of the limited supply of information, inequity of bargaining position, and capricious irregularity. The stochastic expression of preference system, that is, the expression which does not specify the system directly but rather gives the range and frequency distribution of preference somewhat loosely, is theoretically attractive since it looks closer to the reality.

The model-builder is also concerned with the availability of existing and particularly historical data which withstand his analysis when he chooses the optimum level of aggregate.

(2) THE TREATMENT OF TIME

Any model dealing with changes over time in an urban system, the treatment of time is of considerable significance. Beginning with the state of the world at time $\underline{t}$, the model is carried forward to the state of that world at time $\underline{t} + \underline{n}$. The planning process by definition is concerned with changes over time, most models used in planning purport to represent the outcome with time dimension. Thus a population model may start with a 1961 census data in order to predict the 1971 population.

Three ways to incorporate the time dimension with models are described; one, "comparative statics"; two, "recursive progression"; and three, "analytical dynamics".

The method of comparative statics assumes that the system is self-equilibrating, and, that the endogenous variables respond quickly and fully to exogenous variables. The structure of the model represents the relationships which are at the stage of equilibrium between exogenous and endogenous variables. The model's parameters are typically fit from the "stock" data obtained by cross-sectional survey, as contrast to the "flow" data obtained by historical survey. A prediction requires specification of the values of the exogenous variables at the specified date.

The method of comparative statics does not specify the process by which the system moves from its initial to its terminal state. Models using the comparative statics are sometimes called "equilibrium models".

The method of recursive progression assumes that the changes of systems over time occur step-by-step with certain changes following a specified state of the world. Thus the state of the world at time $\underline{t} + \underline{n}$ is alleged to be dependent upon the state of that world at time $\underline{t} + \underline{n} - 1$. This method requires a limited amount of the "flow" data and can be easily incorporated with the periodic changes of exogenous variables by means of "drifting" parameters.

The complete information of the cause-effect relationships over time is purported by the method of analytical dynamics. Theoretically, the model is required to specify only the structural parameters and the initial conditions of variables. The structural relationships are specified by means of differential equations. But it is rarely easy to establish a completely closed structural relationship over time for an urban system. In urban system there is usually a time-lag between the happening of the cause and the one of its effect, because of the incomplete information and various historical carry-over. The specification of the kaleidoscope of preference systems with the time dimension could not be made realistic without an exhaustive effort for accumulation of the data.

(3) SOLUTION METHODS

The method of solution, or "algorithm", describes the concrete steps to be taken from the time that input data are fed to the computer until final results are read out. Four methods are prominent; the choice among them largely governed by the degree of logical coherence of the structure of the model.

The most straightforward method is the "analytic solution". Ordinarily, this method is applicable only to models which exhibit tight logical structures and whose internal relationships are not complicated by non-linearities and discontinuities. Technically, the set of equations constituting the model is resolved by analysis into a direct relationship between the set of input variables and the relevant output variables. If there is to be an anlytic solution, the set of equations constituting the model must hold "simultaneously" and be "consistent" and "independent" in the mathematical sense. If there are too many unknown variables as compared to the restraint rendered by the set of equations to give a unique solution, the case is called "lack of determination". If the restraints by the equations are greater than necessary to give a unique solution, we shall obtain a number of different solutions, depending on which variables we eliminate first. Then the model is said to be "over-determined". If there is a unique solution, the model is said to be "determinate".

For models lacking complete logical closure (lack of determination), or whose structures are overburdened with mathematical relationship inconvenient to solve, an alternative to the analytic solution is the "iterative method". This method comprises a search for a set of output values which satisfy all the equations of the model.

Initially it proceeds by approximate values for some of the variables and solving analytically for the remainder. The solutions of the first round are then used as the basis for the second round approximation. This process is repeated until it fails to result in significant changes in the solution, or in other words until the solution-values "converge". The repetitive process of the iterative method does not imply either a causal or a time sequence as is the case for the recursive progression method. A drawback of the method is that the convergence of the solution-values fails to signal the existence of alternative solution sets. The complexity of the inter-relationships among obivously relevant phenomena of urban system is highly resistant to the logical closure of causal structure. When models may not meet the requirements for either analytic or iterative solutions, "stochastic" or "Monte Carlo" method is an alternative. The model specifies an inventory of possible "events" representing variables and indicates the immediate consequences of each event by means of probabilistic statement without rigorous analytical equations of the causal structure. The mathematical tools for models of this class are characteristically probabilistic or statistical. There may be two cases for application of this method. The first case is that the causal structure is too resistant to analysis though there is all the evidence of the closed logics in the observed phenomena. The second case is that the real inter-relationships are probabilistic and do not render themselves to rigorous mathematical statement by nature.

Finally, there is the method of "man-machine simulation" in which computer processing of input data is periodically interrupted, and the intermediate state of the system is read out for examination by the human participant. He may then make a subjective judgment based on these intermediate results and feed back it into the computer process. The human participant may be included for educational reasons to give him practice in responding to the hypothetical condition, or he may be there because of the failure of the computer to replicate the real world plausibly enough.

C. FITTING AND TESTING

Once a theoretical framework firm enough to encompass the objectives of the model has been established, the next is to fit and adjust or "calibrate" the model. The theoretical framework is usually composed of the specification of the relevant variables and the structural relationships among them, and the solution method to arrive at the meaningful results. The tasks required for fitting and adjusting involves two types of transformation: the specified variables mentioned in the framework must be given precise empirical definition, and numerical values must be provided for the paremeters to specify precisely the structural relationships of the model. The preliminary data collection which provides for the formulation of theoretical framework may have to be replaced by the more thorough collection of data to give the precise empirical definition and value to the model.

(1) VARIABLES

The variables broadly specified in the theoretical framework must be defined in terms of the available data. For example, a variable considered in general terms such as the household income must be related to an available statistic such as the median income of families and unrelated individuals by the census of such and such year. The restrictions and qualifications surrounding the data must be carefully explored to ensure that they do not undermine the proposed role of the variable. Response errors and sampling variabilities may bring serious biases to the model.

A variable included in the model because of its theoretical significance may not be directly observable in the real world, so that some more accessible proxy must be chosen. Thus the theoretical "location rent" of a parcel of land is often replaced by the "market rent" or "contact rent" because it is impossible to measure the location rate with no influence of the existing structure and improvement on the parcel of land.

Sometimes it may be mandatory to launch a first-hand field survey to give a variable a meaningful definition to achieve its role in the model. In some cases, the model-builder might as well change the logical structure of the model to lessen its sensitivity to unreliable data or to make better use of the data actually available.

(2) PARAMETERS

The numerical constants of relationships must then be specified. It should be noted that these numerical constants vary according to the definition of variables. For example, the ratio of the labour force to the total population varies when it is defined as age groups of 15-60 years or as age groups of 14-65 years.

There are highly-developed statistical methods[3] for fitting the parameters. The best fit values for the parameters can be chosen statistically if the model is composed of a set of linear equations. The relationships between variables in these linear model are essentially based on proportionality, or on proportionality plus a fixed

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[3] For a good introductory exposition of the field, See: E.F. Beach, Economic Models, New York: John Wiley & Sons, Inc., 1957.

constant. Though such relations are clearly inadequate for the description of urban phenomena in the long run, they are plausible enough when used in the short run. They are widely used in the field because of the existence of large body of statistical knowledge of linear relations.

The most common tool for linear relations is regression analysis, the simplest case being the estimation of parameters for a linear function of two variables. The coefficient of correlation, $\underline{r}$, and the coefficient of determination, $\underline{r}^2$, indicate the extent to which the variation in one variable may be regarded as a function of the variation in the other variable. Since in urban analysis we are usually dealing with hypothesis of multiple causation, the variation in a dependent variable is usually regarded as a function of the variation in a number of independent variables. The model is typically composed of a set of simultaneous linear equations of various variables. The case is for multiple or multivariate regression analysis. The overall coefficient of correlation is $\underline{R}$ and the overall coefficient of determination is $\underline{R}^2$. Models fitted in this way are often called "econometric", although the method is equally applicable to non-economic models. A significant drawback of multiple regression analysis is that the criterion of selection for the values assigned to each parameter is the best overall fit of the model and does not reveal the actual causal explanation between the variables.

In regression analysis we assume that there is only one relationship among these variables, but there may be more than one relationship at any time among the variables. There are two different groups of multiple relations. First, there may be additional relations which exist among the independent variables. This is the case of "multi-collinearity". When there is a close relationship among the independent variables, the standard errors of the estimated parameters are very high. Second, there may be more than one relationship among the dependent variables. For example, supply and demand in a competitive market are considered dependent upon a number of explaining variables, but in the long run there is also a relation between supply and demand.

One approach to reducing the number of inter-related variables into mutually independent or nearly mutually independent variables while retaining the influence of a large number of variables is based on the use of "factor analysis", or "component analysis". Factor analysis is designed to develop a simple framework of factors whose interplay can adequately represent the interaction of the complex set of forces in actuality.

The data with which we are primarily concerned in model building are tagged with time. The correlation of a lagged series with a non-lagged series is known as the problem of "sereal correlation" or "autocorrelation".

When there is autocorrelation in a series, it generally implies that the data are cyclical or periodic. One method to examine the autocorrelation is to test the absence of randomness.

Alternatives to a comprehensive econometric fit can be described generally as "heuristic" methods. The model is compartmentalized into smaller systems of equations so that the parameters of each sub-system can be fit independently. This is in fact the typical approach, since few large models of urban phenomena can be formulated as a single system of linear equations. When the context rules out direct methods for deriving "best fits" simultaneously even for the parameters of a limited sub-system, trial and error search of iteration method can be used to find a set of values for the parameters. Or parametric values may be specified probabilistically in terms of the range and frequency distribution. If the model-builder fails to find a mathematical expression of relationships among certain variables, he may resort instead to "human" parameters. At the appropriate point in the operation, the intermediate result is read out and the human participant gives the parameter based on his experience in the field. The altered data are then fed back to the computer for further processing.

(3) TESTING

Finally, the question "Will the model really work?"

arises before the model is put into routine running. The appropriate test for the model depends on its initial objectives.

The easiest model to test is the descriptive group. Thus, the appropriate test would be its ability to replicate the details of an existing pattern on the basis of limited information concerning the area in question. Since most such models are built with a particular urban area in mind, the outcome of the model may be checked against the detailed observation of the area. This check against the particular area does not imply the model's generality. Applied to another circumstance, the model may fail miserably.

The appropriate test for a predictive model is to run a prediction and verify the details of its outcome. Usually a certain period preceding the date of the most recent data collection is taken as the period for prediction test. Comparable data must be available at the beginning of the period to give the initial condition for prediction. It should be remembered that the model is designed to make "conditional" predictions. More likely than not, the conditions in the testing period are inconsistent with the ones in the future.

The predictive part of a decision-making model may be tested as mentioned above. Then, the ability of selecting the optimal result from the universe of alternative outcomes is to be tested. This process may fail because, one, the search of the universe of alternatives may be incomplete; two, the criteria of selection may be poorly stated; or three, the evaluation of outcomes may be inappropriate.

"Sensitivity testing" is sometimes urged in addition to the performance testing discussed above. By varying a single parameter of an input variable in successive runs of the model, one can measure the difference in outcome associated with a given parametric change. If the response of the model to the wide difference in the input values is insignificant, this may be the indication that the parameter or variable is superfluous. On the other hand, extreme sensitivity of outcomes indicates either that the parameter or variable in question had better be fit with great care or that some further elaboration of this component of the model is desirable.

CHAPTER III

URBAN DEVELOPMENT MODELS

A city contains a multitude of urban systems each of which has its distinct functional mechanisms of operation but interdependent upon each other. Among these systems, planners are essentially interested in the activity or land use system and in the movement or transportation system. In fact the prime responsibility of the planning professionals is to determine the appropriate policy for the future activity and movement systems of cities. The "urban development models" in this paper are referred to the models which are designed to serve as tools for this comprehensive process of urban land use-transportation planning.

Such urban development models can be divided into three steps: first, the projection of economic activity and population for the entire study area; second, the distribution of activities into sub-areas in terms of land use plan; and third, the prediction of movement or transportation.

The first step is a part of regional planning process. Typical outputs of this step of models are the numbers of employment by industrial categories, the numbers of population by age and sex, and the income distribution. The second and third steps are mutually dependent since the land use generates the transportation demand and the transportation system in turn affects the location of the land use. The feed back relation between the second and third steps is essential.

The systematic collection of the data necessary to operate these models meaningfully has recently progressed remarkably.[1] As mentioned before, the effectiveness of models is heavily dependent upon the availability of the reliable data.

Figure II represents the diagram of the planning sequence of the comprehensive urban development models. This chapter is to discuss the principles and techniques of the models designed to meet each step of the sequence.

A. POPULATION AND ECONOMIC PROJECTION FOR A REGION

A region itself is a subject of the planning process identified as regional planning or regionalism and has been studied by economists and geographers extensively under the term of regional science.[2] This paper does not claim to discuss all the models designed as tools for regional planning but rather outlines major model techniques designed

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1 Some notes on data processing and recording are presented in Appendix B.

2 For example, see Walter Isard, Methods of Regional Analysis, Cambridge, Massachusettes: The M.I.T. Press, 1960.

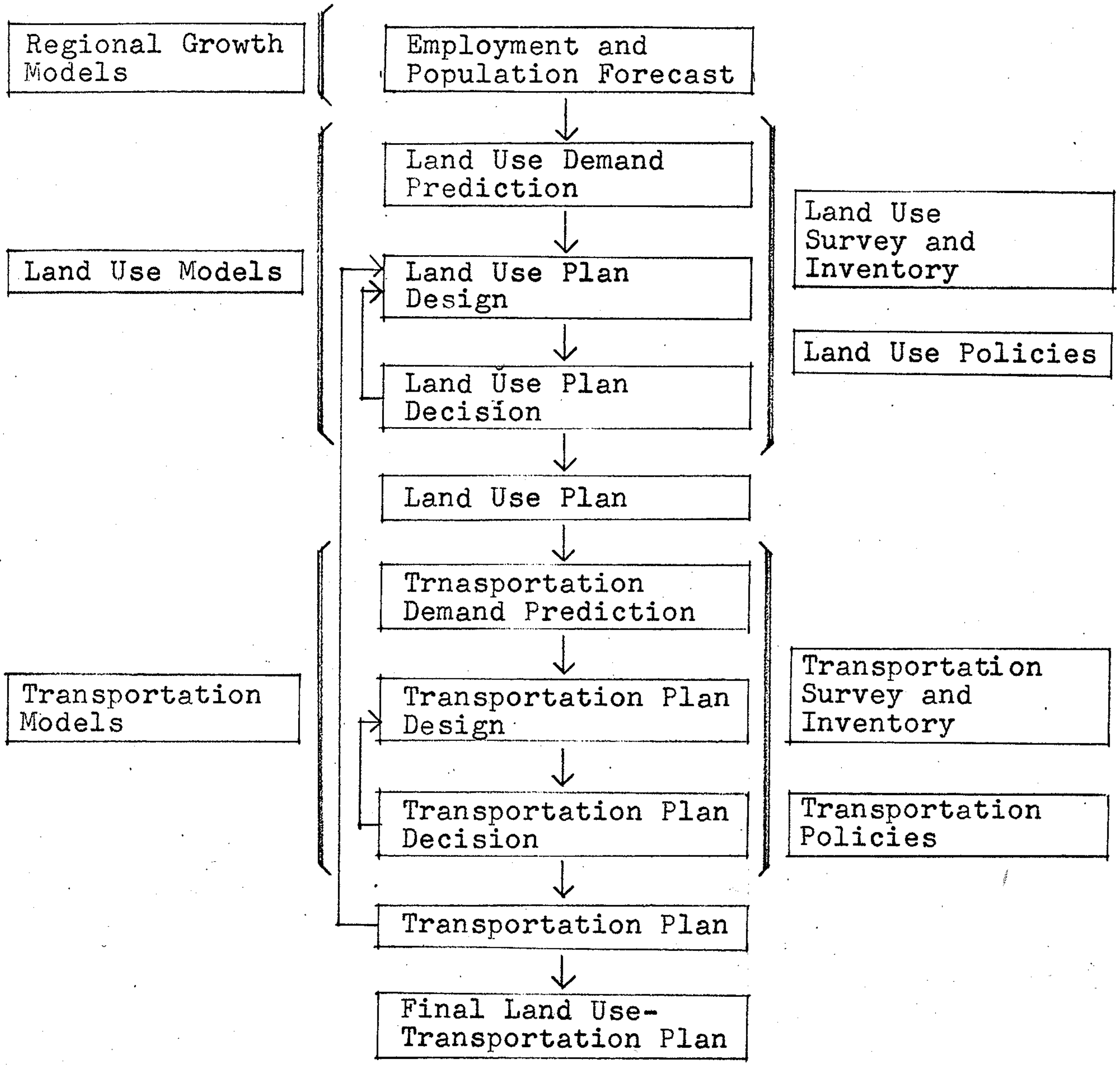

Figure II. Sequence Diagram of Urban Development Models to arrive at the forecasts of urban economic activity and population which in turn will become the part of the input data to the land use and transportation models. In the region where regional planning is in practice, those forecasts are usually included in the regional plan as its essential ingredients. The significance of this step of study is that the whole urban area, may it be a metropolitan area or a single city, is treated as a unit.

Two major groups of the forecasts are population forecast and economic activity forecast. As these two forecasts are interrelated, a check between their results may be made during the process. Figure III shows diagrammatically the steps to be taken in the regional growth forecast.

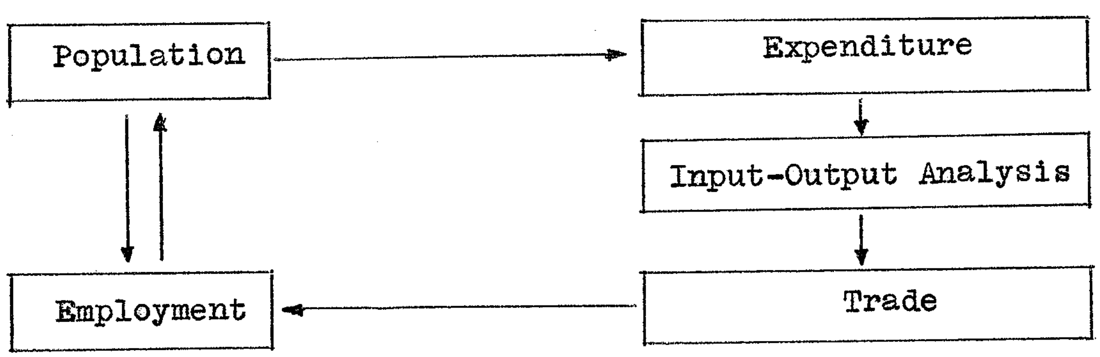

Figure III. Sequence Diagram of Regional Growth Forecast

(1) POPULATION PROJECTION

Population analysis is one of the most important sets of data for regional analysis. Past and current materials on population are generally available for political unit and regions even where relatively little attention is given to the collection and process of other statistics.

Techniques of population projection can be roughly classified as either direct or indirect. The direct techniques are usually based on current and past data. The indirect techniques usually relate numbers to other economic, social and political indices.

The change in population occurs from two reasons: natural or biological change such as aging, birth and death and migratory movements between the study area and the rest of the world. An "open" area is defined as one in which migratory movements are not controlled. A "closed" area is one in which control is exercised or migration estimated; for example, a nation. As a region is considered an open area in democratic countries, we are concerned with both types of population change.

Migration projection techniques can also be classified into two, one which is concerned with only the net change due to migratory movements and one which is concerned with both the in-migration and out-migration.

The following methods are widely used for regional population projection.

1. Projection of a gross population without distinguishing two types of changes. This is done mainly as a check device for the results of the more refined technique.

2. Projection by the composite cohort-survival technique. Birth, death, in-migration, and out-migration rates are projected by age and sex specific groups, taking into consideration socio-economic factors.

(a) Projection of Overall Population Without Regard to Age Composition.

Comparative Forecasting

The comparative method of forecasting the population of open area is simple in practice but has complex implications. The future growth of the study area is assumed to follow the pattern of another older area whose earlier growth has exhibited characteristics similar to those anticipated for the study area. Once such a pattern area has been selected, the desired forecast is obtained by extending into the future the growth curve of the study area according to the past growth curve of the pattern area.

There arise two serious problems for application of this method. The first problem is selection of a pattern area. How can we identify the pattern area whose initial growth characteristics are comparable with the present stage of development of the study area? The second one is how we can be sure that the future growth of the study area will parallel to the past growth of the pattern area, supposing we have selected the pattern area which meet the first problem.

The comparative forecasting method is, in essence, to choose the past experience of the pattern area as a model for the future growth of the population in the study area.

Projection by Extrapolation (Trend Analysis)

Forecasting population by means of graphic or mathematical extrapolation consists of:

1. Plotting the population of past census years against time.
2. Approximating the plotted past relationships by a mathematical function, linear or non-linear, and,
3. Extrapolating the mathematical function into the future to obtain population in future years.

The use of a mathematical function for forecasting assumes that past population growth has followed some law of growth in which population is explicitly a function of time, and that future growth will follow a pattern predictable from this past relationship. Thus, we have the general equation:

$$P_{t+\theta} = P_t + f(\theta)$$

where,

$P_{t+\theta}$ = population of the study area at any year $t + \theta$;

P_t = population of the study are at base year t;

θ = number of years from base year t to the forecast year $t + \theta$

and where the nature of the function f reflect the biological, social, economic, and political determinants of population growth. The following specific forms of the general mathematical equation have been used for extrapolation of population.

a. Polynomial curves

$$P_{t+\theta} = a_1 + a_2\theta + a_3\theta^2 + \quad \ldots\ldots \; a_n\theta^{n-1}$$

where a_1 a_2 .... a_n are constant. The simplest form of the polynomial curves is the straight-line, or first degree polynomial, that is a_3 and the following constants are zero. Any degree of polynomials may be applied to past population data by the method of least squares.

b. Exponential curves

$$P_{t+\theta} = ae^{r\theta}$$

where a and r are constants and e is the base of the natural logarithm system.

The characteristics of these curves vary according to the behaviour of the parameters a and r and may be fitted to the recorded data of past growth by the method of least squares. It is a straight-line curve on semi-logarithmic co-ordinate paper.

c. Logistic curves

$$P_{t+\theta} = \frac{k}{1 + e^{a+b\theta}}$$

where k, a, and b are constants. In contrast to the curves previously described, logistic curve is an S shape on plain co-ordinate paper. In the initial period of growth, the absolute increments are increasing in size, and in subsequent period of growth, the absolute increments are decreasing. The general shape of this curve is believed by many to describe realistically the actual growth of population in a "physically delimited" area. The logistic curve is usually fitted through three points, selected subjectively from past data.[3]

Ratio Methods

Population growth in any area may exhibit a relationship to population or other growth in another area if there are interconnections among the social, economical, political and biological factors governing growth in the two areas. Such interconnections have provided the foundation for ratio methods. These methods are used exclusively with respect to open areas.

In the crudest form the method employs a constant ratio, where the ratio is calculated from the most recently available data. In more refined forms, these methods allow for changing ratios, where the changing ratios may be derived through extrapolation of past trends by any of the

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[3] Walter Isard, ibid., pp.12-15.

graphical and mathematical methods previously discussed, or may be determined from a subjective analysis of the trend.

The general mathematical form for projecting a ratio as a function of current and past ratios is:

$$\frac{P_{t+\theta}}{Q_{t+\theta}} = f\left(\frac{P_t}{Q_t}, \frac{P_{t-1}}{Q_{t-1}}, \frac{P_{t-2}}{Q_{t-2}}, --- \frac{P_{t-n}}{Q_{t-n}}\right)$$

Where P is the population of the study area, Q the population or other base magnitude of the pattern area, and n the number of years before base year t. There are two basic ways in which the ratio technique may be applied:

1. through the use of total population numbers of another area or areas as the denominator of the ratio, and
2. through the use of some component of the population of the study area or a pattern areas as the denominator.

The national population is a frequently used example of the first case, because usually there exists a carefully prepared projection of the national population. In the second case, the school enrollment and the employment number are frequently used.

Correlation Methods

The relationship between the growth of population in a study area and social, economic and political factors can be attacked in statistical form by means of regression and correlation analysis. Usually, population growth in the study area is associated statistically with such factors as employment, investment, income, exports, school enrollment, population, density, persons per household, rents, telephone installations and automobile registrations. In such statistical analysis, population growth in the study area is usually designated as the dependent variable and the other factors as the independent variables.

In the mathematical notation, the general form of the equation is:

$$P_{t+\theta} = a + f_1(X_1) + f_2(X_2) + --- + f_n(X_n)$$

where a is constant and $X_1, X_2, ---, X_n$ represent the values taken by the several independent variables.

If there is only one independent variable and its function is linear, the statistical approach known as <u>simple regression analysis</u> is used. When there are more than two independent variables and their functions are all linear, the appropriate method is <u>multiple</u> or <u>multi-variable regression analysis</u>.[4]

[4]For example, Bogue and Harris have performed a multiple regression correlating 1940-1950 population growth rates of 125 standard metropolitan areas in the United States and arrived at the following model:

$$P_{1950} = P_{1940} + \frac{P_{1940}}{100}(1.543 - 0.007\,x_1 - 0.137\,x_2 - 0.081\,x_3 + 0.111X_4 + 5.676\,x_5 + 0.952X_6)$$

Growth Composition Analysis

A number of methods of forecasting population of open areas are based on the analysis of the following major elements of population growth: natural increase (or decrease), in-migration (or out-migration), and annexation (or abandonment). The last element is of significance only when dealing with a political entity, and may be considered to be a special case of the migration element.

The relationship is written in general form:

$$P_{t+\theta} = P_t + N_\theta + M_\theta$$

where N_θ = net natural increase during period θ and

M_θ = net migration during period θ.

The above equation may be written in the following form:

$$P_{t+\theta} = P_t\,(1 + a - b + c - d)$$

Where a = birth rate during period θ,

b = death rate during period θ,

c = in-migration rate during period θ, and

d = out-migration rate during period θ.

---

4 continued

Where

P_{1950} = estimated 1950 population,
P_{1940} = actual 1940 population,
X_1 = density of central city, 1950.
X_2 = age of standard metropolitan area,
X_3 = degree of industrialization, 1940,
X_4 = change in industrialization,1939-1947
X_5 = logarithm of distance to nearest standard metropolitan area, and
X_6 = growth rate of standard metropolitan area, 1930-1940.

These expected crude[5] birth and death rates may be determined by a subjective analysis of the past trend or by any of the methods of mathematical extrapolation. Likewise, future migration, either in terms of numbers or rates, may be projected, 1) subjectively, 2) from analysis of the regional economy and society, 3) by extrapolation from past data or by some combination of these procedures.

(b) Projection of Population by Age Groups

One of the refined techniques for projection by age group known as "cohort-survival" method has been widely used.[6] Birth, death, in-migration and out-migration rates are specified to various age and sex groups and, commonly, by ethnic groups. The initial population is disaggregated, say into five year age group, according to sex and ethnic origin. The number of survivors of each of these groups at the end of time interval, say one year, is calculated by multiplying the initial number

4 continued
The coefficients of multiple correlation and determination are 0.75 and 0.53 respectively. See D.J.Bogue and D.L. Harris, Comparative Population and Urban Research via Multiple-Regression and Convariance Analysis. University of Chicago, Studies on Population Distribution No.8, 1954, p.24 and also, W.Isard, Methods of Regional Analysis, Cambridge, The M.I.T. Press, 1960, p.22.

5 The crude birth or death rate is the observed rate for overall population without regard to its age and sex composition.

6 In mathematical notation, the cohort-survival technique is satisfactorily described by matrices. Andrei Rogers, "Matrix Methods of Population Analysis", Journal of the American Institute of Planners, Vol XXXII, No.1, January, 1966, pp.40-44.

by the specific "survival" rate. The specific survival rate is calculated from death, in-migration and out-migration rates for all the <u>cohorts</u> or age and sex specific groups other than the lowest age group.

For each time interval, the number of births is projected, as the sum of the products of age-specific birth rates for women of child-bearing age and the number of women in each of the age groups of child-bearing age.

This number of birth is to be qualified by the infant mortality rates and also by the in- and out-migration rates. The number is then added to the survivors in the lowest age group. This procedure is repeated for each time interval up to the forecast date.

Migration may be treated in a different way without regard to the existing number of each age group. The number of in-migrants and out-migrants of each age group is projected from other sources of study. The procedure previously discussed is then operated only for the natural increase with regard to death and birth rates. The age specific number of net-migration is added to the survivors of each age group at the end of time interval instead of being calculated by net-migration rates.

(2) ECONOMIC PROJECTION

The objective of this step of study is to project important economic magnitudes such as employment, production, population, income, consumption, etc. in the future. Demographic projection of population in contrast with economic projection has been discussed previously. The results of two projections of population must be checked against each other.

Techniques of economic projection can be classified into trend analysis, ratio and comparative methods, multiplier analysis, and input-output analysis. The input-output analysis has been widely used for the regional projections with necessary modification owing to the availability of the required data. This technique is of particular importance since it is the most powerful technique yet devised to express the interdependence among various sectors of industry.

(a) Trend Analysis

In this approach all available data on employment and other economic signals are extrapolated into future years on the assumption that the past trends have followed some law of change and that future change will follow a pattern predictable from this past relationship. The techniques discussed previously for population extrapolation can be applied also to the trend analysis of economic denominators.

This approach does not properly account for the changing demand for goods and services in the urban area. There is no way to incorporate the effect of interdependence of economic activities except by intuition and hunch. This drawback is particularly critical when applied to the growing region where the considerable change in the industrial composition is expected in future.

(b) Ratio and Comparative Methods

Economic magnitudes may exhibit a relationship to population or other growth factors if there are interconnections among the governing factors. In the crudest form, the method employs a constant ratio, where the ratio is calculated from the most recently available data. For example, the ratio between the future employment and population is kept the same as observed at present. In more refined forms, these methods allow for changing ratio, where the changing ratios may be derived through extrapolation of the past trends.

The relationship between the economic growth of the study area and the one in some other area where the reliable projection is already available can be utilized. For example, assuming that the location quotient of the study area is predictable, of specified industry one may project the future growth from the national projection. Theoretically any approach discussed previously for population projection by means of ratio and comparative methods can be applied to the economic projection. The same criticism against the lack of logical reasoning as applied to these methods for population projection is legitimate.

(c) Multiplier Analysis

The multiplier analysis stresses the inter-relations of industrial sectors within a regional economy and the spread of impulses originating in any one sector to all other sectors either directly or indirectly. Through the continuous back and forth play of forces, such spreading leads to a series of effects on each sector, including the original one, although these effects need not always be in the same direction and of significant magnitude.

The multiplier analysis distinguishes between "basic" industry and "service" or "non-basic" industry. This premise states that the reason for the existence and growth of a region --- whether it is a community or a small resource area at one extreme or a huge metropolitan region at the other extreme --- lies in the goods and services it produces locally but sells beyond its borders. These basic activities not only provide the means of payment for raw materials, food, and manufactured products which the region cannot produce itself but also support the "service" activities, which are principally local in productive scope and market areas.

Based on this premise, the idea of "basic-service" ratio is developed. This ratio purports to describe either (1) the proportion between total employment in a city's basic or export activities and total employment in its service or local activities; or (2) the proportion between the increase in employment in a city's basic or export activities and the increase in employment in its service or local activities. The term "multiplier" means the proportion between the total (or increase in) employment in both basic and service activities and the total (or increase in) employment in basic activities. Multiplier is thus equal to basic-service ratio plus unity. The projection of employment by means of the multiplier approach takes the following steps:

1. calculation of specific multipliers from survey,
2. projection of the future basic industry from some other sources, and
3. application of the multipliers to existing industrial composition.

One of the technical problems in constructing basic-service ratio concerns the selection of measurement. Although almost all studies of this economic base type have used employment as such a unit, employment as a unit of measure of a community's basic and service components has drawbacks. First, data on number of jobs do not catch the significance for total expansion of different wage levels in different activities. Second, employment data do not reflect the expansionary effects or scale economy which result over a period of years from changes in productivity.

Another technical problem is that of identifying basic and service components. In most of the actual studies, the practice with respect to commercial or industrial firms has been first to divide them into those that are wholly basic, those that are wholly service and those that are mixed. Serious problems arise with regard to the allocation of this mixed sector. In some instances for each industry the proportion between the per capita employment in the study area and the per capita employment in the nation is calculated as a criterion to distinguish the basic and service activities.

One of the conceptual problems of this approach concerns the assumption that there is a consistency between the past and present basic service ratio and the future one. The general increase in productivity makes possible the support of more and more service type activities. Along with the broad productivity increase, there will be changes in locational factors affecting any particular region. These changes may tend to make it either more self-sufficient or more specialized. For example, as the population of a community grows, it provides a constantly growing local market. This tends to encourage the local development of a succession of industries which are in turn significantly affected by economics of scale. Another reason why the basic-service ratio is quite likely to be inaccurate as a basis for projection is a result of the fact that the change in volume of service activity associated with a change in basic activity is typically a delayed reaction. There is always a time-lag.

In short, as an instrument for projection, it can be used only under certain ideal conditions. Nevertheless its value in a descriptive sense must not be denied.

(d) Input-Output Analysis

The input-output analysis is in a sense the more thorough application of the idea of the multiplier analysis. The interactions of industrial sectors within and outside a regional economy are expressed structurally by means of matrices. The input-output type model makes it possible to follow the impacts originated by one sector of activities to other sectors on the assumption of ceteris paribus. Another promising outlook of the input-output technique is that it is flexible enough to be incorporated into an inter- and intra-activity system, particularly with respect to scale, localization, and urbanization economies. It represents a fruitful approach for depciting and investigating the underlying processes which bind together the regions of a system and all the separate facets of their economies.

To consider the statistical framework we assume that the study region is stationary and has no trade relation with outside of the region. The economy of the region consists of a number of industries, or more broadly, sectors. Each sector makes purchases from all sectors including itself within the region, and in turn makes productions to sell to all sectors including itself within the region. Households and governments are usually treated as sectors respectively. Suppose we know from census for each industry either its purchases from each of all industries or its sales to each of all industries, we could construct an input-output flow table. In the table, industries are arrayed in the same order horizontally at the top and vertically at the left. Each row shows the sales of a certain sector to all sectors within the region including itself. Each column shows the purchases made by a certain sector from all sectors within the region including itself. The aggregate of all the columns or the total purchases must be equal to the aggregate of the total rows, or the total sales or productions.

After all the cells are completed, we have for the region a comprehensive and systematically organized set of data on the total outputs or productions of its industries and the distributions of these outputs to all industries. Also, such a table is of value from the standpoint of data collection. Apart from indicating data that are available, it suggests ways for obtaining or checking figures when there are gaps in statistical information.

We now consider a region that is not stationary but is growing. When we are studying the dynamic problems of growth, it is essential to have knowledge of the resources devoted to or required for building up the productive potential or capital stock of an economy, that is, its factories, equipment, social plant, know-how, and quality of labour and management. Therefore, it is desirable to keep separate the sales (or purchases) on "current" account and those on "capital" accounts. One convenient way to do this is to add another column and row to the table. Figures in this column would indicate the output from each industry devoted during a year to the building up of the capital stock of an economy. The corresponding row would indicate for each industry the value of inputs from the capital goods sector, or its consumption during the year of capital goods; it therefore would represent the depreciation reserves which each industry should set aside because of its depletion of capital stock. The sum of the items in this row represents capital good formation required for replacement purposes alone and when subtracted from the sum of the items of the corresponding column yields net capital formation.

Another way to present the data relative to growth and capital formation would be to construct a "capital flow table". This would in form resemble the input-output flow table. It would contain a row and column for each industry and would indicate for each industry its sales to and purchases from every industry in connection with replacing and increasing the capital stock of the region. Another approach to present the data might be to construct a table, any column of which indicates for the corresponding industry required inputs (on capital goods account) from every other industry per unit of new capacity of this industry. The elements of such a table are termed "capital coefficients" and the table is called a "capital coefficient table".

Next step is to assume the region A not only grows but also trades with a region B. For simplicity's sake, we consider that region B represents all the world except region A.

One way to represent the inter-regional transaction is to introduce another column and row in the input-output flow table. The column would show for each industry of region A its total exports to region B; the row would indicate for each industry of region A the total value of its imports from all industries of region B.

If there were available for region B an input-output table similar in character to that for region A and all exports and imports could be disaggregated by type of receiving and originating industries, we could construct an "interregional input-output flow" table. In this table, every interaction among industries in region A and region B is presented. In this way the input-output table can expand to incorporate any number of regions provided necessary data are available.

One of the chief problems in input-output work concerns the choice of the particular set of industries to be employed. This choice is dependent on costs of, and resources available for, data collection and processing, amount and kind of existing data, type of regional and inter-regional situation, objectives of a study and the inclination of the researcher.

Suppose we construct a complete input-output table, we could see for each industry how much input from every industry is required to produce one dollar of output. The elements are termed "production coefficients".

The elements which indicate for each industry in region A how much input from every industry in another region is required to produce one dollar of output are termed "interareal input coefficients".

The use of the input-output approach for projection involves a number of basic assumptions. Among them, the most basic assumption is that of "constant production coefficients" in the single regional model, of "constant interareal input coefficients" (involving constant supply channels) in the inter-regional model and of "constant capital coefficients" when a capital coefficient table is constructed. The validity of this assumption concerns among others economies of scale, localization, and urbanization. Price change and technological advance may also change the values of the coefficients. Nevertheless, we may estimate these factors which may change the coefficients accordingly.

Once all the coefficients are estimated and established, the typical first step for projection is to estimate the household consumer expenditure by sectors through judgement from other sources. Because the coefficient table is mathematically a set of linear equations, we can then follow all the impacts of the household consumer expenditure until we arrive at equilibrium where all the inputs and outputs of all the sectors are in such a state that the estimated household consumer expenditure is properly located in the economic interactions. The number of employment may be obtained by dividing the amount of production by specific number of employment per unit production.

One improvement for this projection is to exclude from the structural matrix certain sectors of the economy which produce only non-economic goods and services, such as military operations. These sectors are termed the "final demand" or "bill of goods" or "exogenous" sectors. Foreign exports have also been typically treated as a final demand sector. The set of sectors which should be treated as final demand sectors will vary with the problem on hand, the region under study, the availability of data etc.

Various modifications of output-input technique have been proposed and practiced according to objectives of study and availability of required data.[7]

B. LAND USE MODELS

Land use models are in essence concerned with changes in the locational pattern of activities in cities.[8] Planners believe that a certain activity system should bring more welfare and more efficiency to the population than other systems. This conviction lies at the heart of the

[7] As an example of the modified input-output model, the model used for the economic projection for the New York Region by B.R. Berman is outlined in Appendix A.

[8] Some problems of processing and recording of the planning data are discussed in Appendix B.

professional role of city planners.

There may be three types of land use models according to the classification we discussed in Chapter II, that is, descriptive models, predictive models and decision-making models. Land use models of descriptive category ask how and why the activity system had or has changed over time. Their role is mainly educational. Their objective is to reveal the underlying "law" of change in land use, if such a law ever exists. The question of land use models of predictive category is how the activity system will change under given and projected conditions such as existing land use, projected activity and population growth, land use policy, and proposed transportation network. The future land use would be replicated in a short time span experimentally in the models. Land use models of the last category are termed decision-making models. They would evaluate the activity systems proposed as alternatives and arrive at the optimal solution in reference to the given criteria.

Because it is usually assumed that the underlying "law" postulated by the descriptive models is consistent or nearly consistent with a slight qualification in the future, the first two types of land use models will be discussed together. Decision-making land use models are still at the embryonic stage of development, because of difficulties of qualifying the pros and cons of various alternative land use plans. Some theoretical proposals for such a type of land use models will be dealt with at the end of this section.

While activities generate traffic, locational decisions of activities are heavily dependent upon the available transportation. In fact, land use plan and transportation plan are mutually dependent and one cannot be discussed without the other. Transportation facilities are traditionally one of responsibilities of public authorities and can be considered to be controllable to a certain extent as a planning instrument. As a unit to measure the summary effect of transportation network at a given location, the concept of "accessibility index" has been developed.

(1) ACCESSIBILITY INDEX[9]

The widely accepted concept of "accessibility index" is based on the idea of gravity model. It has been observed empirically that the magnitude of the interaction between location i and location j is depicted by the following equation:

$$I_{ij} = G \frac{P_i P_j}{d_{ij}^b}$$

Where:

I_{ij} = the magnitude of the interaction between location i and location j,

[9] For detailed discussion of the topic, see: Walter G. Hansen, "How Accessibility Shapes Land Use", Journal of the American Institute of Planners, Vol. XXV, no. 2, May 1959, pp. 73-76.

P_i = the attractive force of location i,

P_j = the attractive force of location j,

d = the distance between location i and location j which may be measured in terms of either real length, necessary travel time, or required expense, whichever may be appropriate,

b = exponent constant, and

G = constant

Therefore the interaction between a single location i and all the other locations is written as

$$\sum_{j=1}^{n} I_{ij} = G \sum_{j=1}^{h} \frac{P_i P_j}{d_{ij}^{b}} \quad (j = 1, 2, 3, ---, h)$$

The interaction on a "per unit attractive force" basis is obtained by dividing both sides by P_i,

$$\frac{\sum_{j=1}^{n} I_{ij}}{P_i} = G \sum_{j=1}^{n} \frac{P_j}{d_{ij}^{b}}$$

This is the general formula of accessibility index.

For land use models, such accessibility indices as social accessibility index, commercial accessibility index and employment accessibility index are used. Social accessibility index takes number of population in sub-areas as a notion of the attractive force. Either amount of sales, number of commercial employment or floor areas of commercial establishments is used as a notion of the attractive force for commercial accessibility index. For employment accessibility index, number of gainful employment is applied to a notion of the attractive force.

The most appropriate measure of distance might be termed psychological distance which we have no way to measure objectively at present. Consequently we have to select other practical unit of measurement as suggested before. Travel time in minutes is usually employed to measure the distance for accessibility index in urban land use models.

The variation in the exponent constant accounts for different trip types such as reaction trips, homework trips and shopping trips in a specific urban area.

Travel time varies according to the mode of transportation. Such accessibility as automobile accessibility, transit accessibility or pedestrian accessibility may be considered, though in North America automobile accessibility indices are of the most significance.

(2) DESCRIPTIVE AND PREDICTIVE MODELS

In Chapter II it has been mentioned that there are two types of approaches in model building, namely, macro-analytic approach and micro-analytic approach. We have also discussed about solution methods. From the point of view of solution methods, land use models in use may be classified into deterministic models and probabilistic models. Deterministic models yield a unique solution as output to given conditions, while probabilistic models produce different solutions for different runs of models.

Deterministic models of macro-analytic approach typically employ the regression technique as structural expression. The simple gravity model where only the accessibility index is considered as an area's attribute may be classified in this category. When a model's structure involves random process, it falls into the category of probabilistic models.

Deterministic models of micro-analytic approach characteristically use the linear program. Each firm or household searches all the opportunity surface of the total urban area and locates itself at the optimal location. This search has two aspects; demand side and supply side. On the demand side, each firm or household is deemed to have its preference rank of location. On the supply side, each location has its characteristic attributes.

In the actual urban life, it is reasonable to assume that such a chooser has neither perfect knowledge of all the opportunity surface nor concrete preference system which stands objective analysis. Moreover, there is a time-lag between the happenings of a cause and its effect.

When the stochastic process is introduced to simulate these phenomena in models, they are probabilistic models of micro-analytic approach.

Theoretically it is possible to classify further, according to the treatment of time, into equilibrium, recursive and dynamic models.

Five examples of land use models of descriptive and predictive category will be discussed in the following part of this section.

The Baltimore and Boston models are typical examples of multiple regression models. While the Boston model is mathematically sophisticated, the Baltimore model has less data requirement than the Boston model.

The Pittsburgh model adopts the multiple regression technique like the Baltimore and Boston models but is noted as it shows a direction to decision-making models.

The Niagara Frontier model employs the opportunity model, and thus may be classified into the probabilistic category.

The San Francisco model is notable for the detailed attention to the atomistic decisions made by individual households. The approach may be called micro-analytic.

(a) Growth Allocation Models for the Baltimore Metropolitan Area

The models were developed by Alan M. Voorhees and Associates, Inc. under the contract with the Baltimore

Regional Planning Council.[10] The models may be labelled as the deterministic models of macro-analytical approach with the iterative solution method.

The objective of the models is to allocate the previously projected total population and employment growth to 579 transportation zones of the Baltimore Metropolitan Area for the year 1980 as a basis for the land use and transportation planning.

It has been recognized that the urban community has resulted from locational decisions made by a large number of individual households and business establishments. These units aggregate into groups with similar behaviour patterns. This has resulted one population and seven employment categories to be analyzed as dependent variables through suitable models. It is assumed that each of these eight categories has its own homogenous preference system of location; hence, this approach is macro-analtyical.

Each of 579 transportation zones or their combinations has various independent variables relevant to the eight categories of growth and change. The historical data of these variables are collected and each of the variables is predicted into the future independently.

The multi-regression technique is employed as a structure to express the relation between each of eight dependent

[10] A Projection of Planning Factors for Land Use and Transportation (Technical Report No.9. Baltimore: Baltimore Regional Planning Council, 1963).

variables and its relevant independent variables. After the initial multiple-regression analysis, the selection of independent variables are checked by the study of the unexplained residuals and further refined until the acceptable level of statistical explanation is obtained.

Public-policy variables such as zoning, density, and land use controls are also considered as inputs and entered into the models as constraints. Urban renewal is considered as discrete change in the independent variables and as constraints where it takes place. The indices of accessibility are calculated based on the Regional Highway Network Plan. These indices are considered as the summary effect of the transportation system at the relevant point in time.

The sequence of steps followed is shown in Figure IV. Initially a previously estimated total of manufacturing employment is distributed through a multiple-regression model into sub-areas. The next step is to distribute predetermined population projection considering such factors as employment distribution, public utilities, and preference of people. Non-manufacturing consumer-oriented employment such as service activities and retails are allocated after residential population are distributed.

In the Baltimore models, the Central Business District is treated separately outside the framework of these

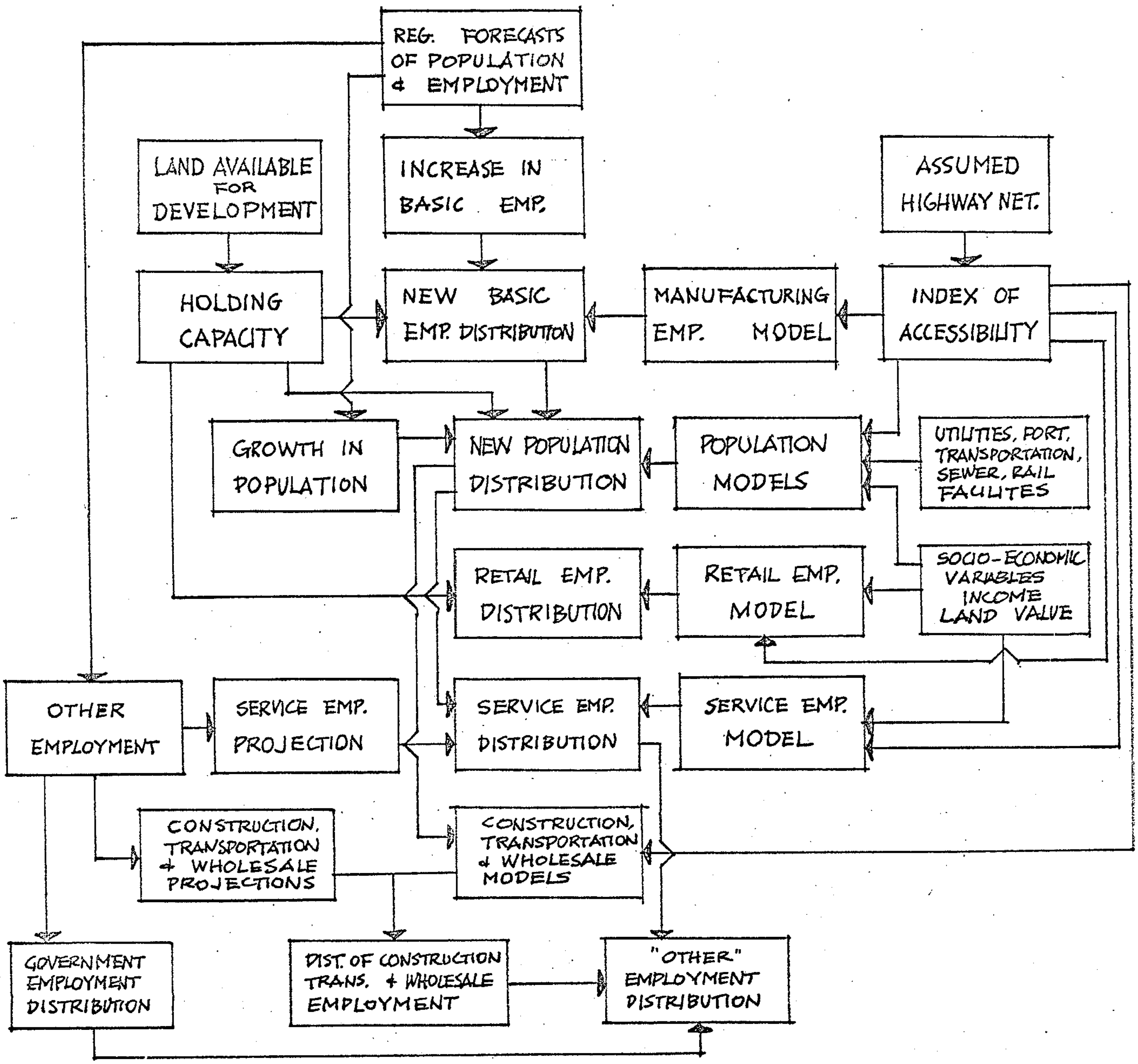

FIGURE IV. MODELS FOR FORECASTING EMPLOYMENT models.

The detailed description of the eight models is presented in Appendix C as an illustrative example.

(b) A Growth Allocation Model for the Boston Region

Traffic Research Corporation developed the land use model for the Boston Regional Planning Project as a basis for a comprehensive development plan for the Greater Boston Region, an area of approximately 2,300 square miles with population about 3,400,000.[11] Like the Baltimore model, the Boston model incorporates a linear form through regression analysis. The significance of the Boston model as contrast to the Baltimore model is that it employs the same areal units for all the equations and adopts the growth rate rather than actual number for all the output variables. As a consequence each linear equation set for every sector of activities holds simultaneously and therefore is soluble simultaneously at a specific time. This allows for taking account of the interactions among the output variables recursively for the next round of projection. The reported coefficients of determination (R^2) are noticeably high.

The objective of the model is to allocate the externally supplied regional projection of population and employ-

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[11]Donald M. Hill, "A Growth Allocation Model for the Boston Region", Journal of the American Institute of Planners, Vol.XXXI, No.2, May 1965.

ment growth into the subregions at the end of a given forecast period.[12]

The activities to be allocated are called "located" or output variables, signifying that the task of the model is to allocate given regional totals of these variables at the end of the forecast period to the subregions comprising the region. The activities which influence the locations and intensities of the located variables are called "locator" or input variables.

Then the concept of the model may be stated as follows:

The change in the subregional share of a located variable in each subregion is proportionate to: <u>one</u>, the change in the subregional share of all other located variables in the subregion; <u>two</u>, the change in the subregional share of a number of locator variables in the subregion; and <u>three</u>, the value of the subregional shares of other locator variables. This concept is expressed by the following equation system:

$$\Delta R_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} a_{ij} \Delta R_j + \sum_{k=1}^{M} D_{ik} \left(Z_k \text{ or } \Delta Z_k \right)$$

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[12] An interesting discussion of the influence of the number of subregions is reported in the same article. D.M. Hill, <u>ibid</u>.

Where:

i or j : 1,2,3,---,i,j,---,N. Number of the located variables (a total of N equations),

k : 1,2,---,k,---,M. Number of the locator variables,

$\Delta R_{i \text{ or } j}$: change in the level of the ith or jth located variable over the forecast time period,

Z_k = level of locator variable k at the beginning of the forecast time period,

ΔZ_k = change in the level of the kth locator variable over the forecast time period, and

a_{ij}, b_{ij} = coefficients expressing the inter-relationships among variables.

There is one such equation for each located variable. The a and b coefficients are determined by simulataneous regression analysis of the data from two past points in time (1950-1960). After the coefficients are determined, the equations are used to estimate future subregional values of each located variable by substituting in each equation the pertinent values of the locator variables for that subregion and solving the equations simultaneously for the subregional located variables. To obtain the forecast in absolute values rather than relative values, the subregional shares at the end of the forecast interval are multiplied by the externally supplied control figure for the total of each located variable in the study region.

The following set of activities is selected as the located variables:

1. White-collar population, that is, the resident population which participates in the white-collar labour force (workers and dependents),
2. Blue-collar population, that is, the resident population which participates in the blue-collar labour force (workers and dependents),
3. Retail plus wholesale employment,
4. Manufacturing employment, and
5. All other employment.

This breakdown of population and employment was based on special investigations by means of component analysis technique. The findings demonstrated distinct locational preferences of each of the five categories.

The following three sets of located variables are employed for the model:

Set I. Intensities of land use (density), zoning practice,[13] and automobile accessibility to population.

Set II. Set I plus transit accessibility,

Set III. Set II plus quality of water supply, and quality of sewage service.

The results of calibration with these three sets of locator

[13]Zoning practice was measured in terms of the actual density of new development in the calibration time period (1950-1960).

variables illustrate the effect upon the forecast accuracy of the model by decreasing or increasing the number and types of input variables.

(d) The Pittsburgh Urban Renewal Model

The model outlined here has its origin in the work of Ira S. Lowry for the Pittsburgh Region Economic Study.[14] The model composed of more than thirty computer routines not only aims at the distribution of population and employment growth into the subareas of the city but also proceeds to keep track of environmental conditions implied by the projected distribution. The multiple regression technique is used as expression of structural relationship among various variables. The flow chart of its operation is shown in Figure V.

The first assumption is that employment opportunities are directly or indirectly responsible for most development decisions. The other major determinants are independent population growth and large-scale development projects (such as the construction of new university). The initial step is to project basic employment for the region, county and city. These projections are then examined for probable labour force participation and patterns of work trips. Then they are exploded into an estimate of total population and employment of the city by

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[14] Ira S. Lowry, A Model of Metropolis, The Rand Corporation, Rand Research Memorandum RM-4035-RC, August, 1964. William A. Steger, "The Pittsburgh Urban Renewal Simulation Model", Journal of the American Institute of Planners, Vol. XXXI, No. 2, May 1965.

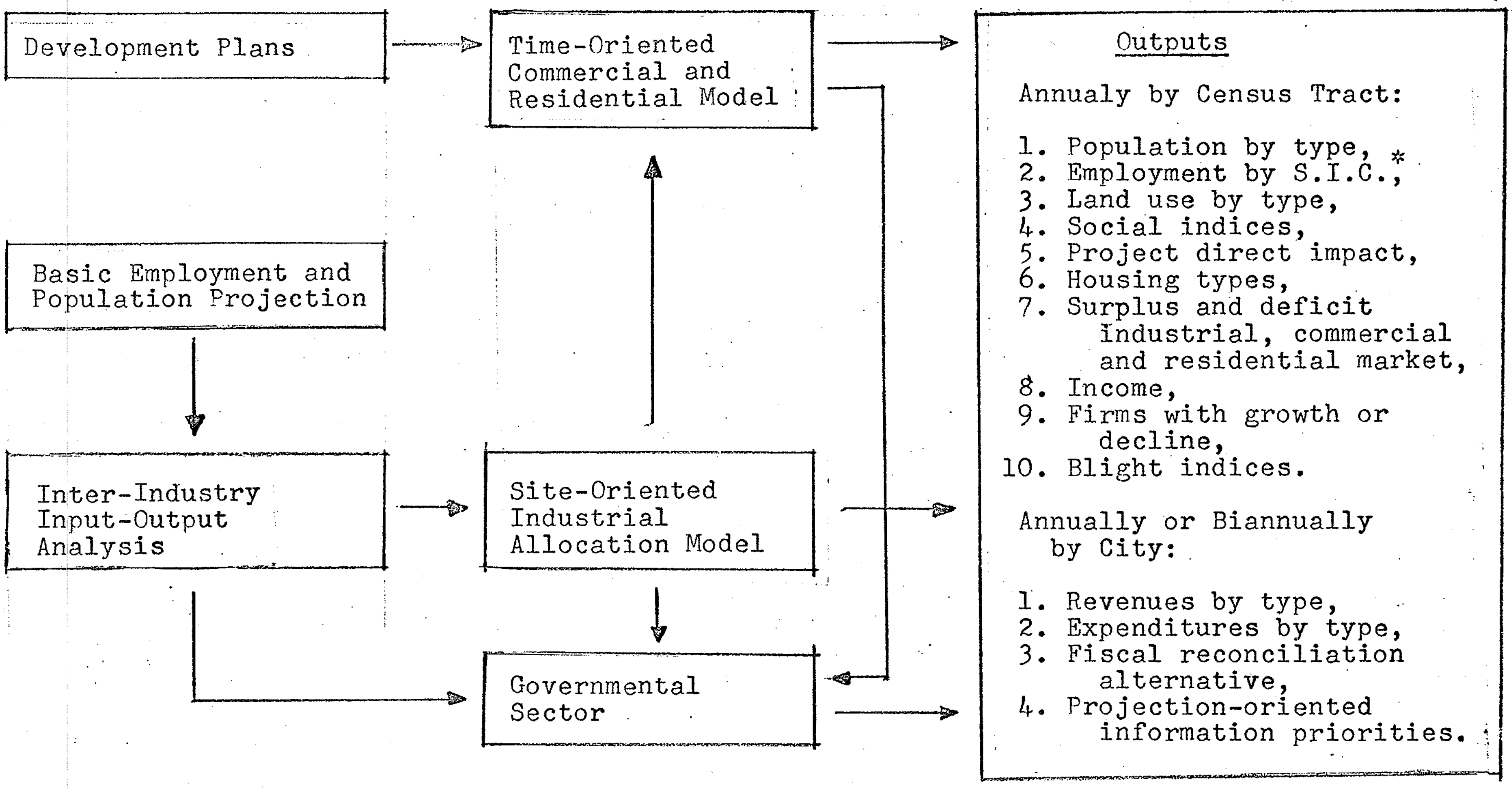

FIGURE V. URBAN SYSTEMS MODEL FLOW CHART

* Standard Industrial Classification.

means of the input-output technique.

The second assumption distributes the "site-oriented" employment throughout the surface of the city. It is assumed that various types of "site-oriented" employment will gravitate to specified areas of the city according to locational criteria, such as present employment clusters, land use policies, access by various transportation modes, and so forth.

The third assumption allocates the remaining employment which is not site-oriented but rather residential or time-oriented. Given the attributes of employment located previously, households of a certain size are located within a specified distance from locations of the employment, creating service employment in turn at specified distances from the households. This new employment generates new households which produce additional service employment.

For the selection of the input variables, the component analysis was extensively used as one of the basic data reduction methods. Separate component analyses were run for household housing, commercial activity, industrial activity, and municipal expenditure and revenue data.

Once the variables and their parameters are established satisfactorily to express the locational behaviour of various population groups and firms, the projection is made for each two-year step. The changes in the environment then affect the later decisions in the next step of the projection in recursive manner.

The expected consequences of the projection are also generated by means of mathematical models. The right side column of Figure V portrays these ultimate outputs for appropriate areal units. These outputs may be interpreted as a direct guide of the planning decision-making. For example, if we could identify the causal relationship between a certain alternative plan and the consequent acreage of urban blight, we could establish the operational criteria such as "to minimize blight" to evaluate various alternatives.

(d) A Growth Allocation Model for the Niagara Frontier Area, New York

The objective of the model is to allocate externally supplied future estimates of activities to small geographic areas in the Niagara Frontier Area centered on Buffalo, New York. The model has been developed by the Transportation Planning and Programming Subdivision of the New York State Department of Public Works.[15]

The framework of the model is a modification of the intervening opportunity model developed by Morton Schneider for the Chicago Area Transportation Study.[16] As the model involves the concept of probability in its structure, it may be classified as a probabilistic model of macro-analytic

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[15] G.T.Lathrop and J.R. Hamburg, "An Opportunity-Accessibility Model for Allocating Regional Growth", Journal of the American Institute of Planners, Vol.XXXI, No.2, May,1965

[16] The Chicago Area Transportation Study, Vol.II.

approach according to the criteria previously discussed.

In this model the spatial distribution of an activity is viewed as the successive evaluation of alternative opportunities for sites which are rank-ordered in time from an urban center. Opportunities are defined as the product of available land and density of activity (units of activity per unit area of land).

This concept is expressed in the following formula:

$$A_j = A\,[\,e^{-L\theta} - e^{-L(\theta + \theta_j)}\,]$$

where

A_j : the amount of activity to be allocated to zone j,

A : the aggregate amount of activity to be allocated,

L : probability of a unit of activity being sited at a given opportunity,

θ : the opportunities for siting a unit of activity in the rank-ordered zones preceding zone j, and

θ_j : the opportunities in zone j. The e is the base of natural logarithm.

The use of the negative exponential formulation following an access search across an opportunity surface presumes that the settlement rate per unit of opportunity is highest at the point of access, or, most usually, the center of a region.

The concept of an opportunity for siting a unit of activity involves the amount of available land and the intensity of use of that land. The intensity of land use may be influenced by such factors as transportation cost, land value, building cost, changing requirement for location among competitive activities, and zoning practice. Largely because of difficulties in simulating the intensity of future land use, the present density has been selected and introduced into the model.

The parameter L is the probability that a unit of activity will settle or be sited at a unit opportunity. For a given surface of opportunities, the larger this value, the more tightly packed the region will be. The smaller the value of L, the more scattered the settlement pattern will be. Thus it is a measure which describes, within the constraint of the density-land opportunity surface, the relative importance of central positioning within the region.

An opportunity surface is rank-ordered by time path value to the center. In this model it is assumed that growth begins at the center and proceeds outward. The surface of opportunities for growth will be examined according to the required travel time from the center. This assumption should not be confused with the index of accessibility which assumes that a given location is related to all other locatioms by the sum of the quotients formed by each location's activity, divided by its time or distance to the given zone raised to some power.

Once the probability L and the rank-ordered opportunity surface are established, the model distributes growth increment of an activity across the surface starting from the center. After each increment of growth is allocated at the end of the forecast time period, the available land is reduced by the amount of land required to site the allocated increment, the opportunity surface is updated.

The most debatable point of the hypothesis of this model may be the composition of opportunity surface. Two problems are involved: <u>one</u>, criteria for the ranking of zones, and <u>two</u>, a chooser's order of the search for the surface. Though this model employs the simplified assumption ~~assumption~~ for these problems, the framework of the opportunity model is flexible enough to incorporate more sophisticated assumption.

(e) A Residential Market Model for the City and County of San Francisco

The model described here is notable for the detailed attention it gives to the atomistic decision-making process which leads to changes of occupancy and the state of the housing stock in cities. It has been developed as a new analytical tool for a community renewal program by Arthur D. Little, Inc., under contract with the San Francisco City Planning Commission. The model was at the stage of calibration when it was reported in the article.[17]

The model deals primarily with the residential sector for which data are most available in the necessary detail. If the model proves as useful as anticipated, the intent is to incorporate the industrial and commercial sectors at the later date.

The model is not so much oriented to the transportation planning but rather to the identification and assessment of the impact of alternative planning actions for development of the City of San Francisco.

Six-time intervals of two years each, providing a twelve year forecast, are taken as forecast periods of the model. At each interval, the model is updated in recursive manner.

In essence, the model is a replication of the land and building market in San Francisco. The model attempts to simulate the demand schedule or the locational decisions of different users of space, and the supply schedule or the investment behaviour of the investors. The effects of public actions and controls on the market can then be evaluated by introducing alternative "hypothetical" planning actions into the model. Analysis of these effects provides a basis for developing a long-range strategy and

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[17] Ira M. Robinson, Harry B. Wolfe, and Robert L. Barringer, "A Simulation Model for Renewal Programming", Journal of the American Institute of Planners, Vol.XXXI, No.2., May 1965.

program for community renewal.

Demand Side

The demand of the housing market is generated by the population of which the household is the basic unit. Households are categorized by:

Number of members in household,

Race of head of household,

Household income,

Occupation of head, and

Rent-paying ability.

The user types are so clasified that all households that belong to the same group can be expected to behave in a like fashion, given any particular state of housing stock. There will be between 150 and 200 user groups.

The model will start with the current inventory of San Francisco population in each category, and will be provided exogenously with projections of the number of users in each category for each two-year period. The projections will take the form of a set of alternatives based on varying assumptions about the factors affecting population and household characteristics, such as birth rate, death rate, net migration rate, persons per household and so on.

Each household type is assumed to have a "preference list" of desired housing with respect to types, conditions, and location characteristics of housing stock. The preference list is in order of priority so that the first type of accommodation represents the first choice of living space for the household.

Each household is also associated with a statistical distribution of "rent-paying ability". This represents the normal range of payments that household in the particular user category can afford for rent, or for monthly payments in the case of single-family home-owners.

Supply Side

The entire city is divided into approximately 100 different neighborhoods. For convenience in gathering data, neighborhood boundaries will follow the boundaries of census enumeration districts. Each neighborhood is identified by a "location category" reflecting its special social composition, land use pattern, physical amenities, and accessibility to freeways and public transportation. A neighborhood may change in location category from one time-period to the next, depending on the conditions created as a result of private and public actions.

Each neighborhood unit is further divided into imaginary "fracts" which are the basic land units of the model. A "fract" has about three to four acres of area. Each "fract" is assumed to be homogenous with respect to its space use and condition, that is, a "fract" cannot have mixed land use on different structural conditions within it. Moreover, a "fract" is not necessarily a contiguous group of parcels but rather a grouping of many parcels in different parts of a neighborhood having a common space-use and structural conditions. The concept of a "fract" was devised in order to keep the inventory within the memory capacity of a computer.

Each "fract" of the residential land is described according to the following attributes:

Type of housing,
Number of rooms per dwelling unit,
Condition,
Tenure, and
Rent or value.

In each forecast period, the first step is concerned with changes of these attributes associated with the passage of time. The natural aging of structure and the normal maintenance repair are considered first.

Changes in the use and/or condition of a "fract" may occur by "artificial" project or development. It is assumed that two different projects will not occur in a fract within the same two year period.

Market Operation

The basic assumption is that the market operates in response to maximal investment yields. In other words despite different motives and preferences of individual developers, more "projects" will be executed in those areas where the yield is larger in the long run.

The yield of a given project depends on the ratio of net rent obtained for the resulting space to the cost of executing the project. The rent obtainable for the resulting space is the current rate for the space. This is sensitive to the "space pressure" or the ratio of "relevant users" to the total number of housing units available. The "relevant users" include those who desire the kind of space in question and can pay for it and also the users who are forced to accept this as a second or lower choice because they could not obtain the space they primarily desired. In other words, the pressure is the ratio of demand to supply.

Public Actions

The public actions must be expressed in model terms in order to be fed into the computer for testing alternative policies and programs.

For model operation, public actions are divided into three basic types. One type involves actions which change the value of any of the fixed parameters in the model's structure, such as the zoning by-law or the rent-paying ability of households. The second type involves direct changes in space-use and condition of a "tract", such as tax concession, subsidies, or mortgage insurance. The third type involves direct changes in space-use and condition, such as construction of public building, urban redevelopment and rehabilitation or condemnation.

Benefit-cost analysis with regard to the municipal finance accounts is included to examine the fiscal implication of the alternative public actions.

Once the model is established, it is expected to simulate the housing market of San Francisco in abstract manner. The purpose of the run of the model will determine the desired output options. Thus, for example, if we are testing public actions designed to alleviate overcrowding in the city, we would want to know which user groups are forced to live in overcrowded environment. During some runs, it might be useful to know the number of households who could not find any space within their financial ability.

The model is intended to serve as an ongoing tool of City government with continuous updating.

(3) DECISION-MAKING MODELS

There are two mathematical techniques which may be used as framework for a decision-making model. The first technique, linear programming, has been used successfully in many fields and has efficient, highly developed computational procedures. Dynamic programming, the second technique, while not as productive in previous applications or comutational procedures, is less restricted in its assumptions and, potentially at least, is a more flexible framework.

Both linear and dynamic programming have as their objective the solution of problems involving the optimization (maximization or minimization) of some objective within the restrictions of certain constraints. The techniques involved differ considerably, with linear programming imposing rather severe restrictions on the nature of both the objective and constraints while dynamic programming being almost unrestricted. However, since linear programming models can usually be solved by the use of standardized computational procedures as compared to the complexity of dynamic programming models, it is linear programming that have been exclusively used for land use models.

A linear programming model consists of an "objective function" which is to be maximized or minimized and a set of constraints. Two experimental proposals are presented in the following examples.

The objective function of the first example is concerned with the cost.[18]

Let us assume a simplified state for purposes of presenting principle. Our city consists of n subareas and there are only two land use categories a and b. Our objective of the model is to distribute the externally supplied total land requirement for the categories a and b.

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[18] Kenneth J. Schlager, "A Land Use Plan Design Model", Journal of the American Institute of Planners, Vol. XXXI, No.2, May 1965.

Our objective of the model is to distribute the externally supplied total land requirement for the categories a and b into the n subareas with minimal development cost.

Our objective function is written as follows:

Minimize:
$$\sum_{i=1}^{n} C_i^a\, x_i^a + \sum_{i=1}^{n} C_i^b\, x_i^b$$

where

x_i^a : land area to be developed for use category a in the ith subarea, and

C_i^a : constant representing the developing cost per unit land for use category a in the ith subarea.

First, the total land area devoted to use category a must be equal to the supplied control total;

$$E_a = \sum_{i=1}^{n} x_i^a$$

$$E_b = \sum_{i=1}^{n} x_i^b$$

where

E_a : total land requirement for use category a, and

E_b : total land requirement for use category b.

Second, a subarea may have minimal and/or maximal limit for a certain use category:

$$F_i^a \leq x_i^a \leq G_i^a$$

where F_i^a : minimal land requirement, and

G_i^a : maximal land requirement for use category a in the ith subarea.

The like constraint may exist in a combination of some subareas:

$$H_m^a \leq \sum^m x_i^a \leq J_m^a$$

where

H_m^a : minimal land requirement in zone m (composed of one or more subareas), and

J_m^a : maximal land requirement in zone m for use category a.

The letter m on top of the summation sign indicates the summation of all the area of the corresponding use category within zone m.

Third, there may be a constraint in relation between the two use categories within a zone:

$$\sum^m x_i^a \leq K \sum^m x_i^b$$

where the constant K represents a maximal rate. For example, this constraint may indicate that the industrial land should be K times as small as or smaller than the residential land in a certain zone.

The like constraint may exist between abutting zones m and n:

$$\sum^m x_i^a \leq L \sum^n x_i^b$$

where the L is constant.

This principle may be extended to allow for more land use categories and different constraints in its framework so long as it remains within the memory capacity of a computer.

The second example of linear programming models was developed in conjunction with the Pittsburgh model prevaiously discussed.[19]

Let us imagine that for the next t years the goal of city planning will be to maximize the number of sound housing units in Pittsburgh within limited public and private resources. The city is divided into n areas. For each area a specific urban renewal program is selected through the hypothetical experiment in predictive model. Such an urban renewal program includes redevelopment, rehabilitation, conservation, code enforcement and so on and is tagged with its cost. It is assumed that all such treatments will be completed in the t year period. The number of sound housing units that each treatment will provide over the t year period, if applied to the entire area for each of the n areas, is estimated through the running of the predictive model.

However, the extent to which this goal can be carried out is limited by the budget estimated for the renewal. It is usually not possible to treat the entire city and add as many sound units as would be desired, since the budget would not allow this. Therefore, it is necessary to deter-

[19] Wilbur A. Steger, ibid.

mine how much of each of the areas can be treated so that the added number of sound units will be as large as possible, taking into consideration the budget constraints.

Let x_i be the fraction of an area treated and q_i the remaining untreated fraction in the ith area ($x_i + q_i = 1$). These are unknowns that the linear programming is to determine. It is assumed that the number of sound units added by a treatment is proportionate to the cost of the treatment with a specific coefficient in each area; that is to say, a half of the cost of a treatment of the entire area for each of the n areas would yield a half number of sound units which the full-scale treatment is to yield, for instance.

The above statement may be written as follows:

Maximize: $$\sum_{i=1}^{n} h_{it}\, x_i$$

where

h_{it} : number of sound units in the ith area in the t year period,

provided

$$\sum_{i=1}^{n} C_{it}\, x_i = B_t$$

$$x_i + q_i = 1 \quad (i = 1,2,3,---,n).$$

The constant C_{it} represents the cost of a full-scale treatment in the ith area in the t year period. The constant B_t stands for the budget available for the t year period.

C. TRANSPORTATION MODELS

Activity system or land use pattern and movement system or transportation network are the two major fields of the planner's concern. It is the activity system that generates traffic requirement as its function, but without the movement system no activity system can operate. The two systems must be complimentary in function and compatible as human environment with each other.

Land use models are designed to distribute the various urban activities in systematic manners, provided the regional economic and demographic projection and level of available transportation service are given. The purpose of transportation models is first, to analyze the past and present transportation phenomena as a function of the land use system, second, to predict the future transportation phenomena according to the projected land use system, and third, to evaluate alternative transportation plans and select the most appropriate solution.

Many techniques of analysis and prediction of urban transportation have been developed by transportation engineers in the last two decades.[20] Recently such extensive studies as the Chicago Area Transportation Study have been

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[20] Brian V. Martin, Frederick W. Memmott, III, Alexander J. Bone, Principles and Techniques of Predicting Future Demand for Urban Area Transportation; Cambridge, Mass. The M.I.T. Press, 1961.

carried out in several metropolitan areas. In the past it was once thought that we could build as much transportation facilities as would be desired by the city's activities through the judgment of transportation engineers. But the more important and crucial role a transportation network has become to play in development of urban environment, the more we want to see the synthetic co-ordination between the transportation planning and other facets of city and regional planning.

This section of the paper is concerned with basic principles of such prediction techniques currently employed by transportation engineers as a basis for transportation planning.

A standardized sequence of transportation models is shown in Figure VI. A study area is divided into a number of transportation zones whose boundaries are usually taken to correspond to the zones for land use models. The inventory of existing transportation facilities and the survey of existing transportation phenomena with relation to corresponding land use activities are initially carried out.

The first step is to predict the amount of trips which will be "generated" by activities for each zone. Then the generated trip demand is classified according to the mode of transportation, such as vehicular, pedestrian and transit. This process is usually called "modal split".

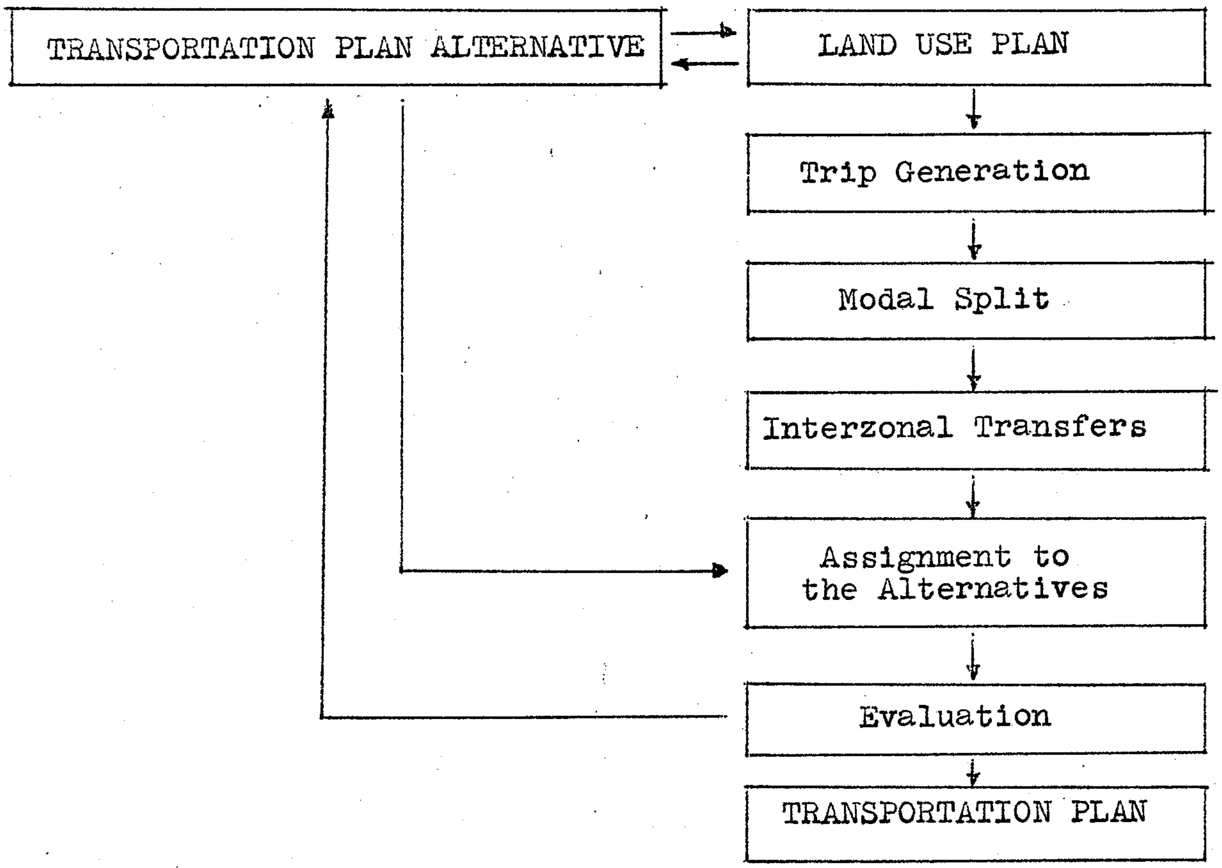

FIGURE VI. Transportation Model Flow Chart.

The next step is to tag the already split trip demand with its zones of "origin" and "destination". This process is usually referred to as "interzonal transfer". In some instances, particularly in small urban area, "modal split" is done after "interzonal transfer" as a part of "assignment" to the alternative transportation network. In the process of assignment every member of the transportation network is allotted its predicted volume.

After all the nodes and links of the alternative transportation network are assigned their future load, the first check is to examine the relation between the load and capacity. The unbalanced members of the network are then altered and a new alternative undergoes a new assignment. The consideration for compatibility of required traffic facilities with the environment of human activities must be taken here. Another determining factor is concerned with the benefit-cost analysis. The benefit of each alternative may be measured by the total travel time or index of accessibility for instance. If all the alternatives fail to meet the requirement of the given land use plan within the available resources, the land use plan has to be changed. New land use plan alternatives then repeat all the procedures. This operation will be repeated until it yields at least a satisfactory couple of land use and transportation plan. Usually a few satisfactory alternative sets are selected for final decision.

In transportation models it is necessary to recognize the dual and overlapping patterns of "personal" and "vehicular" travel. Neither category is entirely inclusive of the other, although approximately three quarters of person travel is also included under vehicular travel. For example walk and some mass transportation trips are not considered under vehicular trips, likewise truck trips are usually not taken to be person trips.

In the parole of transportation engineers, a "trip" refers to the act of travelling between an origin and a destination without respect to length or distance. Trips are expressed as events per person or per vehicle per unit time (e.g. day, week, etc). "Travel" combines a trip as an event with length or distance between an origin and an destination. "Travel" is expressed as persons or vehicles multiplied by the length or distance travelled, the units being person or vehicle-miles. A "mode" of travel refers to the type of means of travel (e.g. railroad, buses, automobile drivers, automobile passengers, trucks, taxis, walks, etc). A "travel" can be specified by purpose, origin and destination, route, mode, and time of occurrence for a person or vehicle.

The following part of this section will discuss the steps from trip generation to assignment.

(1) TRIP GENERATION

The following factors are considered to be influential to the amount of trips generated in an area.

These factors may be classified into traffic generation factors and traffic attraction factors. Generation factors are those which identify and measure the number and rate of trip origins. Traffic attraction factors are those which measure attraction of major trip movements, particularly those which begin at home. Some of these factors vary continuously, and some do discontinuously. Continuous variables include family income, trip length, density, geographic location, and time of day. Discontinuous or discrete variables include trip purpose, land use type, and mode of travel.

1. "Trip purpose" is a social characteristic of travel. It is a discontinuous variable in which trip purpose categories are essentially independent from one another. Such categories include home-work trips, shopping trips, social-recreational trips and other miscellaneous trips.

2. "Family income" is another social characteristic of travel, pertaining mainly to person travel. It is a continuous variable, although often only a few income classes are used. Family income correlates best with vehicle ownership. As family income increases, greater trip generation is observed.

3. "Vehicle ownership" or the number of automobiles

available per unit of population is a continuous variable. It correlates with trips per person, population density, family income and distance from the city center.

4. "Land use at origin" is a discontinuous variable by itself, although the densities associated with land use are continuous.

5. "Residential density" is continuous and usually correlates with the distance from the city center and also with vehicular ownership.

6. "Labour force density" or the number of workers residing in an area is an important continuous variable.

7. "Resident student density" is becoming increasingly important as traffic generators.

8. "Land use at destination" is essentially the same characteristic as that of land use at origin.

9. "Employment density" affects the trip generation considerably. Studies have shown that thirty to forty per cent of all trips in the urban area are generated by home-work movement.

10. "School and college attendance" is related to the resident students in the area.

11. Since transportation planning must take account for the future land use plan, "ultimate use of vacant land" is considered. When the reliable land use plan is not available, this variable becomes extremely important.

12. "Distance from the city center" is a continuous variable usually well correlated with density. Increasing distance from the center leads to increased trips per person or vehicle.

13. "Length of trips" is dependent upon the mode of travel utilized. Tendency is to minimize length, time, cost and nervous strains and maximize comfort.

14. "Mode of travel" is discontinuous variable equally important to both person and vehicular travel. Each mode has a particular place and function in the urban transportation scene.

15. "Automobile occupancy" is a function of trip purpose, family income, vehicle ownership, and distance from the center.

16. "Time of day, week and season" also affect the trip generation. A common procedure is to base traffic volumes on an average 24 hour week-day, and to apply a fixed percentage to this value to represent a peak hour volume.

Now that we have cited all the variables which are considered to be relevant to the magnitude of trip generation, our next step is to establish the structural relation among the variables. There have been used at least two types of technique to describe the interdependence of the variables; one is graphical method and the other is multiple regression analysis.

The graphical method is self-explanatory. A set of charts are drawn; each representing the correlation of the generated trips to a corresponding variable. Bar graphs may be made for the discontinuous variables.

The regression analysis is not capable of including discontinuous variables. One way to cope with this is to substitute them with other continuous variables if possible. For example, the land use of a trip origin may be represented by its intensity of use, such as employment or population density. Another way is to make a different set of regression analysis for each discontinuous variable separately. In this way, there may be made n sets of regression equations for n land use categories at origin and at destination, m sets for m trip purpose categories and p sets for p categories of mode of travel.

A simple example of a multiple regression equation for the trip generation is given as follows:

$$T = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$

where

T = residents' trips per person (or per vehicle) per day,

a = constant,

$b_1b_2b_3b_4$: multiple regression coefficients,

x_1 : family income,

x_2 : vehicle ownership,

x_3 : residential density, and

x_4 : distance from the city center.

William L. Mertz and Lamelle B. Hamner reported the following result from a study in Washington, D.C. on an average weekday in 1946 for the above formula.[21]

$$T = 4.33 - 0.012x_1 + 3.89x_2 - 0.005x_3 - 0.128x_4$$

Standard Error of Estimate : 0.87

Coefficient of determination (R^2) : 0.70

(2) MODAL SPLIT

Once the total number of trips per day generated from every transportation zone is estimated, next step is to classify the trips according to their modes of travel. The modes of travel include suburban commuter train, subway or elevated rapid transit, buses, automobile drivers, automobile passengers, walk, trucks, and taxis. From the point of view of the city-wide transportation planning, the first division should be made to classify the trips made by private automobiles versus those made by public transit. Intercity travel by bus, railroad or air is not normally included in study.

While public transit no longer serves the majority of trips in urban areas, it is particularly valuable in serving those movements which are concentrated in time and geographic location. Changes in public policy may exert substantial influence upon the proportions of persons

[21] William L. Mertz and Lamella B. Hamner, "A Study of Factors Related to Urban Travel", Public Road, Vol.29, No.7, April, 1957.

using public transit in the future.

Public transit serves three basic categories of trips;

1. Trips to and from the city center or central business district,
2. School trips, and
3. Other trips within the urban area.

The amount of travel by public transit in any area for each category is largely dependent upon the following variables:

1. Automobile ownership,
2. Intensity of land use including residential and employment density, and
3. Relative cost, time and comfort of travel by public transit versus the private automobile.

Finally people making trips other than by walking can be divided into three general categories:

1. Those who must use a private automobile,
2. Those who can use either public transit or a private automobile, or some combination of both, and
3. Those who must use public transit.

(a) <u>Trips to the City Center</u>

Public transit trips to the city center are of vital importance for the future form of urban area. All the three variables listed previously affect the future trips to the city center by public transit.

The methods used to estimate the future public transit trips to the city center may be classed in two groups:

1. Automobile ownership and residential density method, and
2. Travel-time ratio diversion curve method.

The first method calculates a "transit use factor" for each transportation zone, that is, the number of households per automobile multiplied by the zone's population density in thousands. The correlation chart of the transit use factor to the percentage of trips by public transit is made from the field survey. In this method, it is implicitly assumed that the level of service of transit is proportionate to the actual need. In other words, the higher the residential density and the lower the area's car ownership are, the better and more frequent transit service is assumed to be available.

The second method depends on the third variable, that is, relative cost, time and comfort of travel by public transit versus private automobile. Usually the ratio of travel time by public transit to that by private automobile is taken as an indicator. Like the first method, a chart is drawn from the trend analysis showing the correlation of the travel-time ratio to the percentage of trips by public transit. In this method, the assumption says the available level of transit service in relation to private automobile is determinant, as contrast to the assumption of the first method. The second method is superior to the first so long as it can take account of the influence of the receiving capacity of the city center. The first method presumes that the city center can absorb as many automobiles as would be desired by automobile users. A major drawback of the second method is that it lacks the direct consideration to automobile ownership.

(b) School Trips

School trips are made mostly by non-automobile drivers who are, therefore, people who must use transit. Some school transit service is provided by special buses operated for this purpose alone and therefore they are on the highway only twice a day. The best correlation has been obtained with residential density. A correlation chart of the number of school trips per unit population to the area's residential density is obtained from the trend analysis.

(c) Other Trips

"Other" trips by transit may include all trips other than those oriented toward the city center; or if school trips have been considered separately, then "other" trips include the remainder. These trips have origins and destinations widely dispersed throughout the urban area, and in many cases the desire line of travel is perpendicular to the radially arranged transit lines. Thus, anyone who has an automobile available will likely to use it, reducing the transit usage primarily to those without automobile.

Both methods discussed for the trips to and from the city center can be applied also to "other" trips though with the difference correlation chart. The level of transit usage for "other" trips is significantly lower than that for the trips oriented to the city center.

(3) INTERZONAL TRANSFER

Once the total amount of trips generated from a very transportation zone is estimated, and classified by the mode of travel, we now proceed to identify the zones of destination of the trips. Various mathematical procedures which have been developed for this purpose may be classified as follows:

1. Growth factor method,
2. Gravity model,
3. Interactance model,
4. Opportunity model, and
5. Multiple regression model.

(a) Growth Factor Method

The basic philosophy underlying growth factor method is that present travel patterns can be projected into the future on the basis of anticipated zonal growth rates. The ordinary origin-and-destination study includes the information of existing interzonal movement.

The simplest method is to multiply the existing interzonal volume of traffic by a uniform growth rate, assuming the constant growth rate to all the transportation zones. When the specific growth rate is available for every transportation zone, we can use the arithmatic mean of the growth rates of the zones of origin and destination. However, above two methods produce less trips for zones with higher-than-average growth rates than those predicted through trip generation estimates, and vice-versa.

The Detroit Area Transportation Study employs as the growth rate of the interzonal movement the product of the growth rates of activities of the zones of origin and destination divided by the area's mean average growth rate of activities. The method developed by W. M. Fratar uses the mean average weighted with the existing volume of interzonal movement instead of a simple arithmetic mean.

Because the first-round total of the interzonal movement estimated by any of the above methods does not usually agree with the previously predicted trip generation, the iterative process must be used to restore equilibrium.

Though the growth factor method is simple and can directly be applied to the origin-and-destination survey data, it cannot consider the effect of future changes in a transportation network in a systematic manner and requires the full information of the origins and destinations of the past and/or present urban trips.

(b) Gravity Model

The principle of gravity model has been explained previously in conjunction with the index of accessibility. It assumes that the magnitude of interaction between two zones is proportionate to the product of the attractive forces of the two zones divided by the travel time between origin and destination raised to some power. In mathematical form it may be written as follows:

$$T_{ij} = T_i \frac{\dfrac{S_j}{D_{ij}^x}}{\dfrac{S_1}{D_{i1}^x} + \dfrac{S_2}{D_{i2}^x} + \qquad + \dfrac{S_n}{D_{in}^x}}$$

$$i,j = 1,2,3,---n$$

where

T_{ij} : future vehicle trips from zone i to zone j,

T_i : future vehicle trips generated from zone i, thus $$\sum_{j=1}^{n} T_{ij} = T_i$$

S_j = future attractive force of zone j, e.g. population,

D_{ij} = future travel time between zone i and zone j, and

x = exponent constant.

The exponent constant varies according to the trip purpose, being the largest for non-home based trips and the smallest for work trips.

The primary advantage of the gravity model is that it is sensitive to changes both in travel time and intensity of activities and also to competition for trips among different transportation zones. The most debatable point of the gravity model is the attempted application of a simple physical law of gravitation to social behaviour. The gravity model does not depend directly on the origin-and-destination survey.

(c) Interactance Model

While the gravity model employs the simple mathematical formula to state the magnitude of interzonal movement, the interactance model depends directly on the empirical data derived from origin-and-destination survey.

In this method a set of relationships between the volume of interzonal trips and the travel time is drawn on chart for different trip purposes from the survey data. From the survey it was found that as the travel time from the city center increased, the amount of interaction also increased. To take account for this phenomenon, the urban area may be divided into a set of concentric rings according to the travel time from the city center, and different relationships may be established for each of the rings.

The procedure of the interactance model is the same as that of the gravity model except the former uses the empirical figure instead of rigorous mathematics. One problem of the interactance model is that it requires the complete home interview survey of origin and destination.

(d) Opportunity Model

The principle of the opportunity model has been presented previously in conjunction with the growth allocation model for the Niagara Frontier Area.

The opportunity model states that the probability that a trip will terminate at a certain area is equal to the probability that this area contains an acceptable destination, multiplied by the probability that an acceptable destination closer to the origin of the trip has not been found. Mathematically this can be expressed as;

$$T_{i \to j} = T_i \left[e^{-LT_o} - e^{-L(T_o + T_j)} \right]$$

where

$T_{i \to j}$: future trips from zone i to zone j.

T_i : future trips originating in zone i,

e : base of natural logarithm,

L : probability of the acceptability of the destination at the zone in question (a constant for each zone), and

T_o : future volume of destination closer in time to zone i than zone j to zone i.

To a great extent, the validity of the projection by the opportunity model depends upon the accuracy and time stability of the L value, which is usually obtained from origin-and-destination survey.

(e) Multiple Regression Model

The multiple regression model is, in a sense, a wider application of the principle of the growth factor method. Instead of the simple growth rate of the total activities in each of transportation zones, the multiple regression model adopts a few to several relevant factors such as population density, car ownership, and travel time among which the interdependence is established by the multiple regression analysis. The mathematical form is similar to that presented previously as the regression equation for the trip generation.

To date there has been no recognized evaluation of the comparative advantage and disadvantage of the various methods of interzonal transfer. The most appropriate method must be chosen according to the characteristics of the community, the available data, and the time and cost budget.

(4) ASSIGNMENT OF TRAFFIC TO FACILITIES

The assignment of interzonal transfers to alternative network plans is the first step of the testing phase. The purpose of the assignments is to determine the expected load to every link of the alternative network plans based on the results of the interzonal transfers.

After each link is assigned its future load of traffic, we proceed to the evaluation of the relative advantage and disadvantage of the alternative network plans. The final plan must be functional with respect to the future traffic, compatible to the future quality of the environment and feasible in economic sense. The consideration of environmental compatibility has been too often neglected by traffic engineers unfortunately.

The assignment procedure provides the data for the review of each alternative plan. The principal information, supplied by an assignment program, is as follows:

1. The volumes of vehicles or persons expected to use each link of the network under test.

2. The volumes of vehicles or persons using every intersection or interchange of the network.

The above two data are then interpreted to provide the following information:

3. Data for the evaluation of the quality of service provided by the network,
4. Data for the evaluation of the environmental fesibility,
5. Data for the evaluation of the economic feasibility.

The methods of assignement programmes can be classed into four general categories:

1. "All or nothing" assignment with no capacity restraints.
2. "All or nothing" assignment with capacity restraints.
3. Diversion assignment with no capacity restraints.
4. Diversion assignment with capacity restraints.

In "all or nothing" assignment, all vehicles are assigned to the path with the least travel resistance between origin and destination zones. Diversion assignments divide the total number of trips into two or more possible alternative routes in proportion to the relative values of travel resistance for the different routs, particularly for the freeway versus the city street routes.

The indication of capacity restraints is obvious. If the first-round assigned traffic volume exceeds the designed capacity, the overflow is redistributed to other routes in iterative manner, considering the slow-down of traffic on the overloaded route.

A diversion curve shows the effect of the difference of the travel resistances of the alternative routes upon the choice of the actual travel route to be taken. There have been developed numerous ways to measure the relative travel resistance. The principal factors which have been used are time, distance, cost, speed of travel, or some combination of these. The difference may be expressed either by the actual value of the difference or by the ratio of the value of each route to the route of the least travel resistance. All of these diversion curves are obtained from the field survey.

The assignment of traffic to facilities involves a tedious repetitive calculation which is most suitable to the computer. An example of the diversion curve assignment with no capacity restraints will be outlined as follows:

1. Build Network Description. This program edits the network description as input data in computer's language.
2. Build All Trees. This program identifies the minimum paths from selected nodes and write them out to external storage.

3. Load By Diversion. This program matches minimum paths via the existing street system with minimum paths via the proposed freeway system, determines the time ratio (or some other measure), computes the diversion percentage, and assigns volumes to the appropriate course.
4. Sum Volumes and Turns. This program takes the loaded networks from the program 3, computes all turning movements, performs an analysis of vehicle-hours and vehicle-miles on various elements of the highway system, and prepares the results suitable for printing.

Additional programs are used for bookkeeping and printing out results. The output of these programs includes the following data:

1. The link volumes.
2. The turning volumes at nodes (intersections and interchanges).
3. The vehicle-miles and vehicle-hours for the complete network. The last item is calculated for the evaluation of the performance of the network as a whole.

SUMMARY

CHAPTER I

In this chapter the prospect of mathematical model technique is discussed in reference to the continuing planning process. The city is understood as a composition of systems and sub-systems interdependent but functionally specialized. In order to determine the appropriate future action, the planner must take into consideration all the impacts and repercussions of each action upon such a composition of urban systems and sub-systems. In essence the model technique holds its value in its ability to replication of the real world into a hypothetical abstract where the planner could experiment his alternative planning actions to examine their ultimate outcomes.

CHAPTER II

Principles of model building are the concern of this chapter. Models in use for planning are classified into descriptive models, predictive models and decision making models. The work of model building consists of the identification of persistent relationships among relevant variables, of causal structure and of a logical computational sequence for solution. The model is finalized when all the parameters are given concrete values, adjusted and tested against the observed phenomena in the real world. The basic steps to be taken are, first, the formulation of theoretical framework, second, the collection of necessary data and third, the calibration or the adjusting and testing of the actual formulae of the model.

CHAPTER III

Comprehensive urban development models which consist of population and economic forecast and land use-transportation projection are proposed in this chapter. The models provide the planner with basic information necessary for the comprehensive development plan. First, population and economic growth for the region as a whole is predicted for a certain point in time for the future, usually in terms of the numbers of population and employment. Second, the predicted regional total is allocated to the subareas consisting of the region. Third, transportation requirement of the allocated activities is projected and assigned to the actual facilities. Examples of the various types of models are presented in abstract form.

While the effectiveness of the model technique in land use-transportation planning has been proved the over-all evaluation of the technique is yet to be made. Some attempts of the application of the technique into urban renewal and housing decision making have been reported recently. Peter Cowan of the Joint Unit for Planning Research, London, England, has been carrying out a project to simulate the change and growth of the fringe area of London.

It is not too hard to see the increasingly wider application of the technique to the various facets of planning in coming years. So long as the technique is tamed as a faithful tool, it will provide the planner with a promising help to cope with the immensely complicated urban society of our time.

GLOSSARY

<u>ACCESSIBILITY:</u>

The term which indicates the ease of approach to one location from another location in the urban area. According to the principle of gravity model, the accessibility per unit attraction force at a certain location is measured by the attraction force at another location divided by the distance on travel time between the two locations. The distance or travel time may be raised to some power. The index of accessibility of a certain location is measured by the sum of such accessibilities with respect to all the other locations in the urban area. The index of social or population accessibility employs the number of population, the index of work or employment accessibility employs the number of employment, and the index of commercial accessibility employs the number of commercial employment or the floor area of commercial establishments as the respective attraction force.

<u>ALGORITHM:</u>

The method of solution which describes the concrete steps to be taken from input to output.

<u>ALL-OR-NOTHING ASSIGNMENT</u>: The process in which the total number of trips between two zones are assigned entirely to the path or route with the minimum travel resistance.

<u>ANALYTICAL DYNAMICS</u>: Method of continuous treatment of time in the model. It requires the complete knowledge

of the cause-effect relations over time.

ANALYTICAL SOLUTION:

Method of solution which is applicable to models with complete logico-mathematical closure.

ASSIGNMENT:

Process in which the total number of trips between two zones are allotted to the actual transportation facilities.

AUTOCORRELATION:

A serial correlation of an independent variable with time.

CAPACITY RESTRAINT:

Process in which the travel resistance of a link is increased according to a relation between the practical capacity of the link and the volumes assigned to the link.

CALIBRATION:

Fitting and testing of models.

CENTROID:

The center of a zone, expressed usually in terms of population rather than area.

COHORT SURVIVAL METHOD:

A method of population projection in which the population is disaggregated into a number of "cohorts" according to sex, age, and other factors and, then, each cohort is transferred to next age group at a specific survival rate which is calculated from the specific birth, death, in-and out-migration rates of the cohort.

COMPARATIVE STATICS:

Analysis which compares one static situation to another, assuming a state of equilibrium in a system.

COMPONENT ANALYSIS:

See FACTOR ANALYSIS.

COST-BENEFIT ANALYSIS:

A summation of all the benefits and all the costs which can credited or charged to a given projection in an effort to determine whether the project is the best means available for accomplishing a given object.

DECISION-MAKING MODEL:

Model which incorporates the method of conditional prediction and the evaluation of their outcomes in terms of the predetermined goals.

DESCRIPTIVE MODEL:

Model which replicates the already observed urban phenomena.

DIVERSION ASSIGNMENT:

Process of assigning the total number of trips between two locations into two or more paths according to the relative travel resistance of the paths.

DIVERSION CURVE:

Curve which indicates the relative effects of the travel resistance.

DRIFTING PARAMETER:

Parameter which is designed to change over time.

DYNAMIC PROGRAMMING:

Mathematical technique devised to solve the problem involving the optimization which less restrictions than those imposed by the linear programming.

ECONOMETRIC MODEL:

Term which indicates the model made of a set of regression equations, whether or not it concerns economics.

ENDOGENOUS VARIABLE:

Variable which is determined within the model and read out as output. (cf. EXOGENOUS VARIABLE).

EQUILIBRIUM MODEL:

Model which assumes the state of static equilibrium at any time.

EXOGENOUS VARIABLE:

Variable which is given to the model from outside as input. (cf. ENDOGENOUS VARIABLE).

FACTOR ANALYSIS:

Statistical technique divised to reduce the number of interdependent variables into one or more basic factor(s) by objective treatment of the data.

GRAVITY MODEL:

Model which involves the application of the Newton's Law of gravitation to the social behaviour.

HEURISTIC APPROACH:

Step-by-step approach without delving deeply into the underlying nature.

IMPACT ANALYSIS:

Technique devised to investigate the impact of a given variable when other variables are equal.

INPUT-OUTPUT ANALYSIS:

Economic analysis devised to measure all the economic interactions between different sectors of industry or regions. An input-output table is a matrix which shows such interactions.

INSTRUMENT VARIABLE:

Variable which is manipulable by public officials.

INTERZONAL TRANSFER:

Trip travelling from one zone to another. The term may indicate the process in which the generated trips are given their zones of destination.

ITERATION:

Solution method by successive approximation.

LEAST SQUARE METHOD:

Statistical method of approximation by means of minimizing the sum of the squares of the deviations.

LINEAR PROGRAMMING:

Mathematical technique devised to solve the problem involving the optimization, assuming the complete information of the system.

LINK:

Portion of a highway network connecting two nodes of intersections.

MAN-MACHINE SIMULATION:

Simulation which involves occasional human participation as well as mathematical routines.

MARKET MODEL:

Economic model which presumes the rational judgements based on the full information for all the atomistic decision-makers. The term may indicate simply the model which describes the distribution of the clients whether it assumes the rational choice or not.

MODAL SPLIT:

Term applied to the division of trips according to the means of travel especially into mass and private transportation.

MONTE CARLO MODEL:

Model which involves random process in solution method.

MULTICOLLINEARITY:

Inter-relationship among the explaining variables. When there is a close relationship, the standard errors of the estimated parameters are very large.

MULTIPLE REGRESSION ANALYSIS:

Statistical method performed to estimate the parameters of a relation among three or more variables.

NODE:

Point of intersection in a highway network.

OBJECTIVE FUNCTION:

Mathematical formula which is to be minimized or maximized in mathematical programming.

OPPORTUNITY MODEL:

Model in which the spatial distribution of an activity is viewed as the successive evaluation of alternative opportunities which are rank-ordered in time or distance.

PERFORMANCE TESTING:

Testing devised to evaluate the model's ability of replication by applying it to the already observed phenomena.

POTENTIAL MODEL:

Term interchangeable with GRAVITY MODEL.

PREDICTIVE MODEL:

Model which predicts future urban phenomena.

PREFERENCE SYSTEM:

Term which indicates the chooser's system of relative value in a market model.

PROGRAMMING:

Mathematical technique devised to solve the problem involving the optimization within given restraints.

RECURSIVE PROGRESSION:

Progression in which changes occur step-by-step with causal chain over time.

REGRESSION ANALYSIS:

Statistical method devised to estimate a relation among two or more variables. When there are two variables, it is called simple or bivariate regression analysis. When there are three variables or more, it is called multiple or multivariate regression analysis.

SENSITIVITY TESTING:

Testing performed to know the relative importance of a given parameter by varying it in successive runs as to evaluate the difference in outcomes.

SIMULATION:

In the narrow sense, the term indicates the model which involves the random process. In the broad sense, it is applied to all the models which simulate or replicate the actual phenomena.

STOCHASTIC PROCESS:

Term applied to a random process as a solution method.

STRUCTURAL RELATION:

Mathematical formula which describes the relation among variables of a model.

TRAVEL RESISTANCE:

Measure used to state quantitatively the factors considered by a driver in choosing a route.

TREE OF ASSIGNMENT:

A tree is the aggregate of all the minimum path routing from one node to all other nodes in a highway network.

VARIANCE ANALYSIS:

Method of qualified use of regression analysis in an effort to reduce the total variance.

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APPENDIX A

AN INPUT-OUTPUT MODEL FOR ECONOMIC PROJECTIONS FOR THE NEW YORK METROPOLITAN REGION

Berman formulated a model to predict for the years 1965, 1975 and 1985 employment, output, and value added by industry, as well as breakdowns of these magnitudes by type of demand in the New York Metropolitan Region.[1] It will generate also estimates of personal disposable income and population. Its conceptual framework is based on the input-output technique.

First, all the firms in the New York Metropolitan Region are divided into two groups:

1. Those which cater to the national market, that is, which export to other regions (or other nations) a considerable portion of their output, or which are subject to competition from firms in other parts of the country. These firms are termed "national-market" firms, and
2. All other firms, which will be labelled as "local-market" firms, will include not only firms which serve the local population but also those firms whose economic function is to provide goods and services used by the Region's national-market firms.

On the basis of similarity of technology all the firms

[1]B. R. Berman, B. Chinitz, and E. M. Hoover, Projection of a Metropolis, Cambridge, Massachusetts: Harvard University Press, 1961, pp.1-53.

are aggregated into 43 industries, of which 10 are completely local-market, 8 are completely national-market, and 25 have both types of firms.[2]

With regard to the intermixing of local-market and national-market firms, it is assumed that each industry produces two distinct products, one of which is sold in a national market which includes the New York Region, while the other product is sold only locally. The two products of each industry are assumed to be produced in an identical technological setting, which means that the same quantity and quality of labour, raw materials, machinery, etc., are used per dollar of output in the one as in the other.

We have thus divided the output of each industry into two parts, and now we proceed to subdivide the output of the local-market part into three categories based on the source of demand, namely, business purchasers, consumers, and governmental bodies.

(1) BUSINESS PURCHASERS

There are two types of business purchases: one is related to the flow of output on the current account, and the other to the increase of production capacity on the

[2] In this model, governments and households are treated as final demand sectors separate from industrial sectors.

capital account.

With regard to the flow input we assume:

$$a_{ij}\, x_j^t = x_j^t$$

where:

x_j^t : the jth industry's output in dollars in a year t, and

a_{ij} : the jth industry's purchase from local-market firms in the ith industry in the year for a dollar worth of output, or a "flow coefficient".

The flow coefficient (a_{ij}) is assumed to be constant over time. With regard to the capital goods, we assume that the jth industry purchases on the capital account

$$C_{ij}\, (x_j^t - x_j^{t-10})$$

during the ten-year period from local-market firms in the ith industry,

where:

x_j^t : the jth industry's output in dollars in a year t,

x_j^{t-10} : the jth industry's output in dollars in a year t-10, and

C_{ij} : the jth industry's purchase on capital account from local market firms in the ith industry in the ten-year period for a dollar worth of increase in output during the period,

provided:

$$x_j^t \geq x_j^{t-10}$$

If the equality does not hold, we assume that such an industry purchases and sells no capital goods.

Assuming a straight-line pattern for a capital purchase over ten-year period, capital goods purchases in a single year of jth industry from local market firms in the ith industry is equal to

$$\frac{C_{ij}}{10} (x_j^t - x_j^{t-10}).$$

To sum up, in any year t, both local-market and national-market firms in the jth industry will purchase

$$(a_{ij} + \frac{C_{ij}}{10}) x_j^t - \frac{C_{ij}}{10} x_j^{t-10}$$

from the local market firms in the ith industry.

(2) CONSUMERS

We write

$$x_{iC}^t = d_i P^t + f_i Y^t$$

where

- x_{iC}^t : the value of purchases by consumers from the local-market firms in the ith industry in a year t,
- P^t : population in a year t, and
- Y^t : personal disposable income in a year t.

The d_i and f_i are constants which describe the propensity of New York consumers to consume local-market products.

(3) GOVERNMENTAL BODIES

Governmental expenditures are treated as a linear function of the Region's population. A proportion of government purchases from each local-market industry is assumed to be constant over time.

Thus we have:

$$x^t_{ig} = a^t_{ig}\, P^t + b^t_{ig}$$

where:

x^t_{ig} : government purchases in a year t from firms in the ith local-market industry, and,

P^t : population in a year t.

The parameters a^t_{ig} and b^t_{ig} differ for the different projection years according to the propensity for spending of the various levels of government.

Having listed all the sources of demand for output from local-market firms in the ith industry, we can obtain the total demand for the output of such firms, which we shall designate by summing the flow input demand and the capital goods demand from all industries in the ith industry and adding this to the consumer and government demand on the ith industry:

Eq.1.

$$x^t_{iL} = a_{i1}x^t_1 + a_{i2}x^t_2 + \text{---} + a_{i,43}x^t_{43}$$
$$+ \frac{c_{i1}}{10}(x^t_1 - x^{t-10}_1) + \text{---} + \frac{c_{i,43}}{10}(x^t_{43} - x^{t-10}_{43})$$
$$+ d_i P^t + f_i Y^t + a^t_{ig} P^t + b^t_{ig}$$
$$(i = 1, 2, 3, \text{---}, 43)$$

We will have 43 equations in the form of (1), one for each industry. For the eight industry sectors containing no local-market firms, the appropriate equation takes the form:

$$x^t_{iL} = 0$$

We now turn our attention to demand for the output of the national-market industries. The national-market output is derived from the United States employment projection in national-market firms for each of the 33 industries which contain such firms. We have:

Eq. 2. $$x^t_{iN} = \frac{e^t_{iN}}{h^t_i} \quad (i = 1,2,3,---,43)$$

x^t_{iN} : output from national-market firms in the ith industry, in a year t,

e^t_{iN} : employment projection for national-market firms in the ith industry in a year t, and

h^t_i : projected figure for employees per million dollars of annual output by the ith industry in a year t.

For each of 10 industries with no national-market firms, the appropriate equation of (2) takes the form:

$$x^t_{iN} = 0$$

To get total output from both types of firms in each sector, we must add local-market and national-market outputs sector by sector:

$$x_i^t = x_{iL}^t + x_{iN}^t$$

Eq. 3.
$$= \frac{e_{iN}^t}{h_i^t} + \sum_{i=1}^{43} \left(a_{ij} + \frac{C_{ij}}{10}\right) x_j^t - \sum_{i=1}^{43} \frac{C_{ij}}{10} x_j^{t-10} + (d_i^t + a_{ig}^t)P^t + f_i Y^t + b_{ig}^t \quad (i=1,2,---,43)$$

The 43 equations of (3) contain 47 unknowns, therefore, we need some additional equations to solve simultaneously connecting P^t and Y^t with the x's. Four new equations and two new variables are introduced.

Personal disposable income depends in great measure upon the economic activity of the Region. As the total employment in the Region as an indicator of such an economical activity, we have:

Eq.4. $$Y^t = k^t E^t$$

where:

Y^t : total disposable income in a year t,

E^t : total employment in a year t, and

k^t : constant which describes a relation of disposable income to total employment in a year t.

We next have an equation relating population to total employment:

Eq.5. $$P^t = m^t E^t$$

where:

P^t : population in a year t,

E^t : total employment in a year t, and

m^t : population to employment ratio.

Three per cent unemployment is assumed for the estimation of the population to employment ratio.

As in the case of government expenditure, government employment is a linear function of population;

Eq.6. $$e_g^t = q^t P^t + s^t$$

where:

e_g^t : government employment in a year t.

The parameters q^t and s^t describe the relation in a year t.

Finally, we have an accounting identity which says that total employment E^t is the sum of employment in all the industry sectors, plus government, plus employment of domestic servants in households (e_h^t).[3]

Eq.7. $$E^t = \sum_{i=1}^{43} h_i^t x_i^t + e_g^t + e_h^t \,.$$

[3]The e_h^t is projected exogenously.

This completes the system, which consists of 47 equations with 47 variables. Therefore, we can solve simultaneously these equations once all the parameters are determined exogenously from census and other materials.

APPENDIX B

PROCESSING AND RECORDING SYSTEM OF PLANNING DATA

Major problems in dealing with the collection and maintenance of a large volume of planning data and statistics arise from:

1. Difference of systems of areal unit.
2. Difference of systems of classification categories.
3. Difference of the time of data collection.

The system must be developed to complement the current planning concept, to assist in the formulation of urban simulation models, and to be suitable for large-scale computer manipulation, as well as to overcome the above problems. The planner must also keep the data up-to-date to provide the information for the continuing planning process.

(1) AREAL IDENTIFICATION

Various authorities divide the urban area into various systems of sub-areas as their own objectives require. One can cite a handful of these areal units with no difficulty, for example:

1. Municipal jurisdiction,
2. Census tract,
3. School district (public and separate),
4. Fire protection district,
5. Water district,

6. Enumeration district,

7. Hospital district,

8. Electoral district.

Sometimes the planning agency creates new systems for its own purposes, for example:

9. Planning district,

10. Transportation district.

The endeavour to consolidate these various units into a coordinating system will have a certain advantage. However, it is true at the same time that there is always the most appropriate areal division for certain purposes. The consolidation might be difficult because of historical traits as well as the functional reason.

The ideal system is the one which accepts data by any areal division and outputs it by any desired areal division. The solution takes the following steps;

1. To subdivide into fairly small basic <u>statistical units</u> which is deemed to be homogenous for all the purposes,
2. To develop a method to specify the location of each unit,
3. To develop a method to assemble the recorded data by desired areal units.

(a) <u>Statistical Units</u>

Consideration should be given first to homogeneity within a unit in reference to the objective of the data collection and, second, to correlation with other units defined by some other authorities for their data collection but useful as the planning statistics as well. A unit should be homogenous not only at the time when the survey is made but also during the foreseeable future.

The basic unit for any urban land use study is a lot or site, legally defined in a land title. In most cases a lot has a street name and a house number as its identification tag.

A study has been done by Professor E. M. Horwood and others to develop a technique which automatically converts a street address into grid coordinates and collects grid coordinates to form a set or sets of polygons. Since a polygon can approximate any areal unit, this technique provides a means for specifying an activity's location and for collecting data by any areal unit.[4]

(b) Location Specification

The simplest way to specify the location is to draw a reference map which shows boundaries of units and to name each unit by the serial number or letter. By referring to a conversion table, the data can be assembled according to any areal unit.

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[4] Robert B. Dial, Street Address Conversion System, Proceedings of the 1965 Joint Conference of A.S.P.O. and T.P.I.C., Toronto, 1965.

To facilitate the presentation of data on a geographical basis, the principle of coordinates in geometry is useful. An abstract grid system of two perpendicular sets of numbered, equally spaced, parallel lines is superimposed on the study area, in a north-south and east-west direction or rotated so one set of lines is parallel to the principal streets. The centroid of each unit is then assigned a set of grid coordinates of the nearest intersection of the grid lines. The required accuracy determines the spacing of the grid lines. One thousandth of a mile or 5.28 feet is considered satisfactory for the planner's purposes.

In view of the general practice of the grid street system, the Cartesian coordinates are usually appropriate in North America. The polar coordinates may be of value where the radial street system is overwhelming.

Once a parcel of land is assigned coordinates, it can be exactly located without reference map. Apart from this advantage for geographical presentation, the coordinate system keeps its validity over time. It will not be affected by construction of new thoroughfares, new subdivision, replotting, etc. Its mathematical nature permits the sophisticated manipulation. A contiguous group of units, such as a city block, a census tract, etc. can be described as a polygon by listing the coordinates of its vertices.

As compared to the street address system, the assigned coordinates has little visual appeal for understanding the immediate relative disposition. For example, it is impossible to tell directly from the coordinates whether or not lot (211, 145) and a lot (218,148) are on the same street.

Another complaint against the coordinates system is the difficulty of referencing data to a grid system. In the past the referencing has been accomplished by using aerial photos of the study area. Grid lines are drawn on the photo and a conversion table is compiled.

(c) Assembly by Areal Units

When a unit is registered by number on a reference map, the sorting of the data by a group of such units is accomplished by putting an identification tag into the original number to specify the group the unit belongs to or by referencing to the conversion table manually prepared.

When a unit is referred to by coordinates, an areal unit can be described as a polygon specified by the coordinates of its vertices.

(2) CLASSIFICATION CATEGORIES

For statistical treatment, the data has to be categorized according to the standard criteria. Difficulty occurs when such criteria are not consistent for various surveys done by different agencies.

For example, the classification of land use survey- the most standard planning survey - varies from one planning agency to another, though there is a certain broad agreement.

When the breakdown of the classification of each survey is available, a conversion table can be prepared. The procedure is comparable to the areal identification system previously discussed. The data are classified into sub-categories and assembled by a group of such sub-categories by means of the conversion table.

(3) UPDATING

The rapid change of our urban community necessitates the busy up-dating of the planning statistics and, hence, the efficient maintenance of the past records as well.

Problems in this line occur in relation to:

1. the recording system of change,
2. the administration of the continuing data up-dating (how to detect change).

While some changes may be detected as they occur, a building permit for the change of land use for example, some are perceptible only through periodic checking.

APPENDIX C

THE DESCRIPTION OF THE GROWTH ALLOCATION MODELS FOR THE BALTIMORE METROPOLITAN AREA[1]

The 579 transportation zones of the Baltimore Metropolitan Area are aggregated to 99 "Transportation Districts", 24 "Subsectors", and 16 "Jurisdictional Subsectors". The study area outside the city limit is divided into 13 "Analysis Areas". The appropriate areal unit is chosen according to the characteristics of the model and the availability of the necessary data. Projections made to these aggregated areal units are further distributed to each transportation zone by means of expanded use of the corresponding model or subjective judgments or of both.

(1) MANUFACTURING GROWTH MODEL

This manufacturing model and the following two residential models are termed growth models because in these models the corresponding growth increment during a specific period of time is taken as dependent variable, while in all other models the total figure at a specific year is taken as the dependent variable. Theoretically growth or flow models are more favourable than cross-sectional or stock models, though the availability of historical data is usually the determining factor of choice.

[1]Baltimore Regional Planning Council, A Projection of Planning Factors for Land Use and Transportation, 1963.

Through an analysis of time-series data (1948-1957) of growth in manufacturing employment outside the city of Baltimore, the following model is finally accepted:

$$x_{12} = 0.8x_2 + 1.7x_3 + 31x_4 - 1839x_5 - 625x_6 - 6493$$

where

X_{12} : growth in manufacturing employment,

X_2 : land value,

X_3 : available industrial land,

X_4 : index of sewer service,

X_5 : index of rail service, and

X_6 : index of port service.

Coefficient of Determination (R^2) = 0.76

Sample size: (n) = 13

Areal unit = Analysis Area.

The accessibility to the labour force was believed to be a significant factor in plant location but upon testing it fell in significance below acceptable level in the mix of factors. Thus it was discarded from the model partly because of the lack of confidence in the collected data and partly because of its high correlation with land values.

This model is only applied to sub-areas outside the city of Baltimore, where the projection is made separately. Outside the city, it is assumed that the growth is always positive but does not exceed the limit density of twenty workers per acre.

Index of sewer service is measured by the percentage value of the area served by sewer per unit industrial land. Index of rail service is the mileage of railway per 100 acres of industrial land. Likewise, index of port service is the mileage of coast line per 100 acres of industrial land.

(2) RESIDENTIAL GROWTH MODELS

Two models of residential growth are adopted; one refers to the suburban area outside the City of Baltimore and the other to the City. It is believed that there is a considerable difference in locational decisions made in these two areas.

Through the analysis of time-series data (1948-1960) the following model is accepted for the subareas outside the city;

$$x_{11} = 36089x_2 - 1.5x_3 + 0.5x_4 + 0364x_5 + 283x_6 - 34837$$

where

x_{11} : growth in population

x_2 : relative income level

x_3 : land value,

x_4 : available residential land,

x_5 : index of accessibility to employment, and

x_6 : index of sewer and/or water service.

Coefficient of determination (R^2) = 0.88

Sample size (n) = 29

Areal unit: Transportation District.

Index of accessibility and index of sewer and/or water service are excluded from the model for the city, because there is no significant change of these indices from location to location within the city.

In the suburban residential model, a gross density of ten persons per acre for future growth (increment) is assumed. When these capacities are filled up, the residual amount is allocated to the remaining sub-areas iteratively. Although negative growth is predicted by the model, it is assumed that the suburban area will hold present population. In the city, the negative growth or decrease of population is accepted when it occurs. A density constraint within the city is assumed to be twenty persons per acre for future development since it is believed that the future development will have to compete with the suburbs as a living environment. The relative shift of population predicted by these models allows for this relatively low density for the residential development within the city. The negative growth is limited by the existing population. Its residual is redistributed to other sub-areas iteratively.

(3) RETAIL EMPLOYMENT MODEL

Because the historical data for the retail employment is not available for analysis, only a cross-sectional as opposed to a growth or flow model is constructed through the analysis of the 1962 retail employment survey data.

The area unit chosen for allocation of the population-oriented employment such as the retail, service, and governmental activities is a Jurisdictional Sub-sector. This is done because the areal unit must be large enough to sustain the major hypothesis of orientation of these activities to resident population.

The projection made for these Jurisdictional Sub-sectors is further distributed to the transportation zones by separate procedures, which may be called commercial market analysis.[2]

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[2] It has been suggested that competition between regional centers is susceptible to a "gravitational" type of analysis.

The basic formula of this "law" is as follows:

$$S_{ai} = P_a \frac{\dfrac{F_i}{(D_{ai})^3}}{\displaystyle\sum_{i=1}^{n} \dfrac{F_i}{(D_{ai})^3}} \qquad (i=1,2,---,n)$$

where S_{ai} : the amount of goods and services at regional center i purchased by the residents of zone a,

P_a : the purchasing power of the residents of zone a,

continued

The model of retail employment for the Jurisdictional Sub-sectors outside the Central Business District is given by,

$$x_1=2898x_2 + 2.69x_3 + 23.8x_4 + 357x_5 + 1434$$

where

x_1 : retail employment,

x_2 : relative income level,

x_3 : index of accessibility to population,

x_4 : resident population (in thousands) and,

x_5 : percent of total employment in the Jurisdictional Subsector to total employment in the study area.

Coefficient of Determination (R^2) = 0.91

Sample size (n) = 16

Areal Unit: Jurisdictional Subsector.

The model verifies the hypothesis that resident population is the most important factor in determining retail activity. The location of employment and the accessibility to population are next in importance. It should be recalled that the index of accessibility is not concerned with the level of activities within its own area.

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2 continued

F_i : the gross square feet of regional center i, and D_{ai} : the driving time between regional center i to zone a.

The exponent constant was suggested by Walter Hansen for shopping trips. See, Walter Hansen, ibid.

For purposes of projection, the interelated variables such as the number of population and employment are estimated iteratively. For the first round, the simple extrapolation of the past trends may be substituted to the more sophisticated projection by the models. The output of the first-round is then fed into the models for the second-round. This procedure is repeated until the acceptable level of convergence is obtained.

(4) SERVICE EMPLOYMENT MODEL

The service activity is also recognized as consumer-oriented. The framework of the service employment model is accordingly similar to the retail employment model. The following model is finally accepted;

$$x_1 = 6.7x_2 + 56.8x_3 + 114.8x_4 - 7653$$

where

x_1 : service employment,

x_2 : index of accessibility to population,

x_3 : resident population (in thousands) and

x_4 : total employment in the Jurisdictional Subsector.

Coefficient of Determination (R^2) = 0.60

Sample size (n) = 16

Areal unit: Jurisdictional Subsector.

(5) TRANSPORTATION EMPLOYMENT MODEL

The following model is accepted:

$$x_1 = 0.01x_2 + 2.2x_3 + 8.7x_4 + 154.6x_5 - 1585$$

where

x_1 : transportation employment in the Subsector,

x_2 : land value,

x_3 : index of accessibility to population,

x_4 : index of accessibility to commercial employment, and

x_5 : percent of manufacturing employment in the Subsector to the total manufacturing employment in the study area.

Coefficient of determination (R^2) = 0.68

Sample Size (n) = 24.

Areal unit: Subsector.

The model indicates that the amount of manufacturing activity in a Subsector is the most important determinant of transportation employment location.

(6) WHOLESALE EMPLOYMENT MODEL

The accepted model for estimating wholesale employment in each Subsector is given below:

$$x_1 = 20x_2 + 0.66x_3 - 840$$

where

X_1 : wholesale employment in the Subsector,

X_2 : index of accessibility to commercial employment, and

x_3 : transportation employment in the Subsector.

Coefficient of determination (R^2) = 0.69.

Sample size (n) = 24

Area unit: Subsector.

(7) CONSTRUCTION EMPLOYMENT MODEL

The model for estimating construction employment for each Analysis Area is given below:

$$x_1 = 16x_2 + 26.4x_3 + 3.1x_4 - 181$$

where

x_1 : construction employment,

x_2 : resident population (in thousands)

x_3 : total employment (in thousands), and

x_4 : change in population (in thousands) all in the analysis area.

Coefficient of determination (R^2) = 0.98

Sample size (n) = 13

Areal Unit:Analysis area.

(8) GOVERNMENT EMPLOYMENT MODEL

Government employment category is the least homogenous in its behavioral pattern of all the employment categories considered in the Baltimore models. Though the following model was constructed, it was not found statistically significant.

$$x_1 = -1.5x_2 + 28.8x_3 - 17x_4 + 2814$$

where

x_1 : government employment in the Jurisdictional Subsector,

x_2 : index of accessibility to population,

x_3 : resident population (in thousands), and

x_4 : index of accessibility to commercial employment.

Coefficient of determination (R^2) = 0.30

Sample size (n) = 16

Areal unit: Jurisdictional Subsector.