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An Introduction To Urban Development Models and Guidelines For Their Use In Urban Transportation Planning

URBAN SYSTEMS MODEL	ACCESS AND LAND DEVELOPMENT MODEL	INTEGRATED TRANSPORTATION AND LAND USE MODELS PACKAGE
PROJECTIVE LAND USE MODEL	ZONAL ALLOCATION PROCEDURE	NBER URBAN SIMULATION MODEL
LAND USE PLAN DESIGN MODEL	EMPIRIC ACTIVITY ALLOCATION MODEL	LAND USE ALLOCATION MODEL

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AN INTRODUCTION TO URBAN DEVELOPMENT MODELS AND GUIDELINES FOR THEIR USE IN URBAN TRANSPORTATION PLANNING

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PREFACE

The subject of this report is the urban development model, an entity that represents a broad class of planning tools which, despite their capabilities, are often not well understood or utilized in transportation and other fields of planning. Our perception of the urban development model and the scope of consideration within this report have been confined to meet limited objectives.

These objectives focus upon the urban development model as an operational tool in the urban transportation planning process. The basic purposes are to provide (1) a general background on the development and use of urban development models, (2) an understanding of the basic principles involved and their operational characteristics, (3) an ability to make enlightened decisions on the evaluation and choice of a model and (4) information on the practical application of the models. Practical considerations are emphasized rather than the more complicated questions of theoretical concepts and techniques which are more appropriate for research and development exercises. Although by nature the urban development model is suitable for many applications in comprehensive planning, research, and other areas, this report will deal primarily with those models and the aspects of the models that are of concern in urban transportation planning.

Therefore our definition and treatment of the models will be in a limited context and should not be interpreted as a comprehensive treatise on urban development models in general.

Additional information on the more diverse aspects of the models is available from other sources, some of which are cited in this report.

Chapter I provides a brief background on model development, a definition of the urban development model, and a clarification of the types of models dealt with in this report.

Chapter II presents a brief overview of land use analysis and forecasting in the urban transportation planning process. Specific topics include a discussion of the general urban transportation planning process, the urban development process, the interrelationship of transportation and land development, the role of urban development models and finally a discussion of the future outlook concerning urban development models.

Chapter III reviews the traditional and modeling approaches to land use forecasting and planning, and discusses some aspects of the plan design and activity allocation techniques as regards transportation planning.

Chapter IV provides an overview of the urban development modeling process including data collection and analysis, model formulation, calibration, forecasting, and evaluation.

Chapter V includes a discussion of items to be considered when selecting and applying an urban development model in an urban transportation planning study.

Chapter VI briefly examines the forecasting accuracy of urban development models, and discusses in general the performance evaluation of such models.

Several urban development models are described and evaluated in Chapter VII. The descriptions touch on the background, theory, capabilities, input and output requirements, calibration, and software of each model, and the evaluations include a discussion fo the model's potential usefulness in urban transportation planning studies.

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CHAPTER I

INTRODUCTION

The urban transportation planning process as we know it today is generally recognized to have had its beginnings in the 1950's and into the early 1960's when some of the major transportation studies were begun in the larger cities of the United States. These studies were the forerunners of later transportation planning studies that were to be instituted in urban areas across the country. It was in these larger urban studies that many advanced and relatively sophisticated planning techniques and procedures were developed and applied. Their efforts were generally supported by government agencies and had the participation of the acedemic and private communities.

One of the major innovations was the acceptance and use of computers on an increasingly extensive scale. The computerized planning programs provided greatly expanded capabilities and changed the character of planning. New techniques and tools were being developed on a rapid scale to meet increasing demands. Planning studies that had previously relied on traditional land use planning and forecasting procedures for their inputs into transportation planning were then developing new automated and computerized procedures which could incorporate both the data processing capabilities of the computer and various theories, relationships and standards relating to land development and locational activity.

Some approaches were theoretically simple, operationally straightforward, and workable. Others attempted to use a complicated theoretical structure and a sophisticated operating system which sometimes proved unworkable. The well known Chicago Area Transportation Study (CATS) used the former approach to develop a landmark transportation-related land use study which was later used as a reference point for many other studies. Other studies working during the same time or shortly thereafter produced the first family of "land use" or "activity allocation" models which now, in a more sophisticated form, are commonly known as urban development models.

To clarify the subject of this report and to provide an initial reference point, a definition of the urban development model is in order. An examination of some of the components of the term "urban development model" will aid in defining it. "Urban" denotes that the model deals with the complex socio-economic and physical system that can be identified with an urban area. The breadth and depth with which the urban development model deals with this complex system varies with each individual model. Some may attempt to focus on particular components of the total urban system (e.g. housing choices and location) and deal in more detail with the forces and interrelationships, which influence that component of the system. Commonly, they will attempt to simulate or describe the forces and relationships involved in the process. Other models attempt to deal with a broader urban system, but on a more generalized, aggregate level. These models may attempt simulation of actual relationships, or they may simply try to reproduce results or effects based on historical trends and anticipated future influences.

The "development" component of the term refers to the growth or changes in the "activiites" and physical facilities of an urban area, spatially defined by analysis zones -- geographic locations similar to the traffic zones.

The spatially defined "activities" may include a variety of measures, but normally they are units of population, employment and land use by appropriate stratifications. As an example, an urban development model may allocate to an analysis zone a certain number of households, described in classifications of income, size and race, and a number of employees classified by job according to Standard Industrial Classification (SIC) codes or some other employment/industry describer. Development defined in this way is, of course, a key element in the trip generation phase of transportation planning.

Many models convert the development "activity" (e.g., persons living in a dwelling unit) to the consumption of a certain quantity of land. In some models the physical "land" development aspect is stressed and land characteristics and environmental concerns are emphasized. Others placed more importance upon the economic and legal dimensions of development such as development cost and zoning constraints.

There are many "development factors" which influence the change in the population and employment "activities" and which are in themselves a type of development. These include those items in the "public service" domain such as: transportation systems/service; water and sewerage; other public utilities (e.g., gas, electricity, telephone); educational and health services (schools and clinics); and police and fire protection services.

The first item, transportation, is an important element in most all urban development models, the others are occasionally used, sometimes in an aggregate measure.

The term, "model," normally evokes a variety of interpretations depending on the context of use and an individual's intuitive responses. Simply stated a model is a device that may describe, represent or present a facsimile or analogy of a situation, phenomena, or system. Some form of mathematical function or quantitative technique is used in the urban development model to accomplish this. An urban development model, is therefore, a mathematical model[1] which attempts to describe or simulate the process of urban development and growth (i.e., the locational process of urban activities). For actual application to an urban area, the models are in computer program form, as are the models considered in this report.

A distinction is usually made between the "descriptive" model and the "simulation" model. However, it is not uncommon to find the terms "modeling" and "simulation" used interchangeably. Simulation has been described as ". . . the reproduction in some recognizable form of a certain aspect of human behavior or of the performance of mechanical systems, or of a combination of these two" (2). In simple terms, simulation recognizes causes and effects and attempts to represent them as such. Descriptive modeling, on the other hand, is primarily concerned with obtaining an accurate solution by means of certain techniques which are reasonable but do not necessarily parallel the logic or processess of the real-world system. The current operating urban development models are generally descriptive in nature.

The type of urban development models with which we are concerned in this report are those that have been developed to act as operational tools in the actual planning process in urban areas. Their purpose is to provide certain required elements (e.g., forecasting and the testing of alternatives) in the planning process. These urban development models can be distinguished from the urban gaming models which also deal with urban systems and are sometimes computerized. The primary purpose of the gaming models is to provide opportunities for education, training, citizen participation, and possibly research. A major feature of such models is the involvement of a number of participants in a gaming situation. These games are not normally designed to represent the characteristics of an actual urban area, nor are they calibrated in the usual manner which results in the approximation of a known condition. Furthermore, gaming models are heavily dependent upon the judgement and choices of the individual participants. The resulting decisions are often reflective of the gaming situation rather than the "real world", and they do not possess a stable, reproducible character necessary for impact testing. Therefore, urban gaming models do not conform to our definition of operational planning tools, and are not discussed further in this report. A description of urban gaming models and an annotated bibliography are contained in Reference 2.

Another significant feature of the models dealt with in this report is the scale and grain of the models' outputs. At one end of the spectrum are some models, such as Jay Forrester's model (3), which deal with the urban area as a single entity without any spatial disaggregation. Spatial

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[1] Mathematical models have been further defined as abstractions presented in the form of symbols which express an aspect of the real world in terms of a sequence of simplified processes or as a complex of relationships among numerical entities.

detail maybe made more explicit as the size of zones are made smaller, until the number of zones begins to tax the limits of reliability of the conceptual framework and the capacities of the computers used. The models with which we are concerned treat the urban area in terms of a number of small analysis zones which are distinct geographical subareas.

The scale of analysis is also significant, for the models described here are comprehensive, encompassing "all of the population of a region, all of the transport flows, all of the flows of goods and so on. An alternative approach is to adopt a strictly micro viewpoint and to focus on the household or the firm" (4).

CHAPTER II

AN OVERVIEW OF LAND USE ANALYSIS AND FORECASTING IN THE URBAN TRANSPORTATION PLANNING PROCESS

General Urban Transportation Planning Process

The urban transportation planning process includes the operational procedures and working arrangements by which short and long-range highway and transportation plans are soundly conceived and developed, and continuously evaluated. The comprehensive nature of the planning process requires that demographic, economic, and land use elements be included; that estimates be made of the future demands for all modes of transportation both public and private for both persons and goods; that terminal and transfer facilities and traffic control systems be included in the inventories and analyses; and that the entire area, within which the forces of development are interrelated and which is expected to be urbanized within the forecast period, be included.

Especially significant are the unique economic characteristics of transportation services. The demand for transportation is primarily for an intermediate service required to bridge spatial and locational barriers that impede the consumption and production processess of households, business firms, and government establishments and agencies. Transportation is a means to an economic end; rarely an end in itself.

Similarly, transportation is supplied by a complex mixture of public and private sources. In addition to households' investments in automobiles, campers, recreational vehicles, power boats, and bicycles, and business firms, investments in trucks, trains, private parking facilities, and loading docks, a vast allocation of public resources matches these private transactions. Rights-of-way purchase, public transit facilities, streets, highways and freeways, and the facilitative control mechanisms are part of the supply side.

The consequences of these unique and special economic characteristics is the need to supplement the automatic guidance usually provided by private market mechanisms with public decision-making and decision-aiding through the planning process. The public sector at all governmental levels has large areas of responsibility thrust upon it by the special character of transportation services.

In addition, the planning process should be closely coordinated with policymaking and program administration and should be organized with the objectives of achieving agreement on interrelated action programs founded on factual information. Also, the data and analyses must be maintained on a continuing basis so that appropriate changes can be made to correspond to urban growth and development at realistic intervals. Figure 1 is a

THE CONTINUING URBAN TRANSPORTATION PLANNING PROCESS

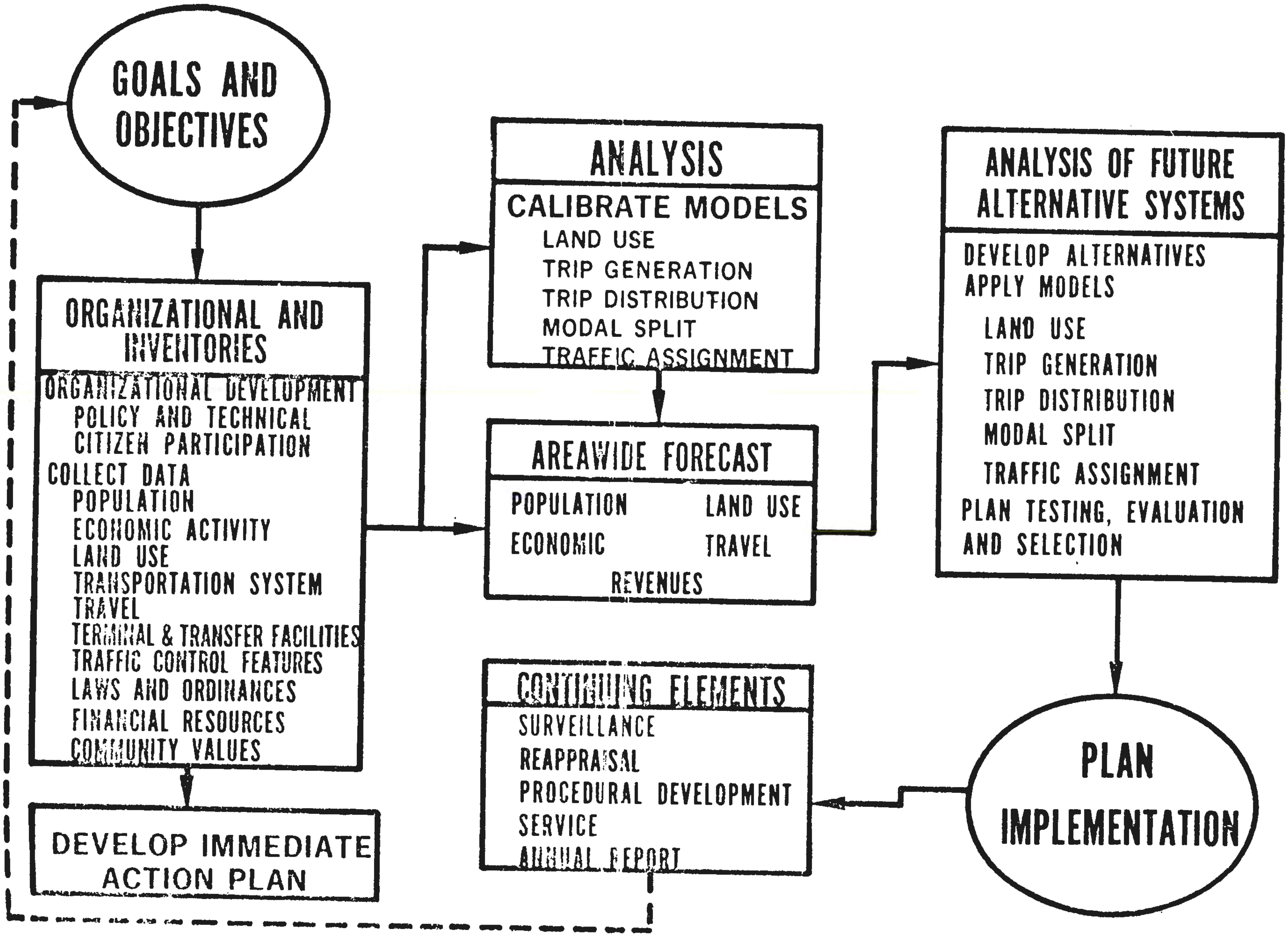


Figure 1

flow chart depicting the general technical phases of the transportation planning process, as well as some of the administrative elements associated with it.

In one of the initial steps, community goals and objectives are determined and continue to play a prominent role throughout the planning process. An important ingredient in the planning of a metropolitan area is the ability of citizens and community officials to relate transportation and land use planning to the needs for housing, employment, social services, other physical services and the impact that all elements have on the preservation of a desirable environment.

Transportation planning requires a knowledge of the existing conditions of a metropolitan area. Thus, inventories are made of the existing socio-economic activities; land use; transportation facilities; travel patterns; terminal and transfer facilities; traffic control features; zoning ordinances; development and building regulations; etc. The data obtained from these inventories describe current conditions, and they sometimes help to identify deficiencies in the transportation system which can be corrected immediately. They are also very useful in developing the various models used as tools in the analysis of transportation problems.

There are several models which are normally developed and calibrated before the appropirate forecasts of land use patterns and corresponding travel demands can be made and analyzed. The seven basic models, each involving analysis, development, calibration and forecasting are:

1. Demographic model
2. Economic model
3. Urban development model
4. Trip generation model
5. Trip distribution model
6. Modal split model
7. Trip assignment model

These represent a set of models, each of which attempts to describe some aspects of the metropolitan area under varying conditions and assumptions. The models form a logical sequence, each successively feeding information to the next model. Since the models are largely computerized, it is feasible to make a series of forecasts based on a variety of assumptions regarding the simulated behavior, land use policies, public facilities and services, and characteristics of the transportation system.

The demographic and economic models provide, as a minimum, estimates of the future population and employment by major category for the metropolitan area as a whole (i.e., with no geographic breakdown within the area). In addition, they will frequently provide, depending on the design of the other phases of the transportation study, information on age, race and sex breakdowns of the population; family size; family income, car ownership; retail expenditures; etc. The demographic and economic forecasts can be viewed as control totals for the land use forecast or allocation.

The urban development model is a tool which is used to allocate metropolitan areawide forecasts of elements such as population, dwelling units, and employment to subareas within the metropolitan area. These subarea activity forecasts provide inputs to trip generation analysis. In addition, the urban development models may be used to illustrate the impact of alternative public policies. For example, they can be used to illustrate the impact of alternative tranportation system improvements on the pattern of urban development. They are also used to illustrate the impact of nontransportation policy alternatives directly on the pattern of population and employment growth and indirectly on transportation demand. Such nontransportation policy alternatives might include water and sewer services, provision for open space, and land development controls.

The transportation analysis comprises several sequential models. This sequence has been commonly used in the Urban Transportation Process. It is appealing to many practitioners since it breaks down the demand estimation procedure into controllable steps. The trip generation model projects zonal trip ends from a number of socio-economic factors. Trip dsitribution is the procedure utilized to connect two sets of trip ends to form zonal interchanges. The modal split model resolves the interchanges into their component modal shares. The trip assignment model produces vehicle and transit volumes on the respective transport systems, and thus provides information for the evaluation of the level of service, the costs and benefits to the community.

Urban Development Process

The urban development process will vary in specifics for each urban area, but the general features of it are fairly consistent. We will briefly discuss the process, with special note of those elements and circumstances which have a special influence on or connection with transportation planning. The basic components of the urban development process are, for our purposes, divided as such:

1. Economic/Market
2. Regulatory
3. Political/Social

Economic/Market

The most basic element in the urban development process is the privately owned parcel of land, developed by the private investor who is normally intent upon gaining a maximum profit from his investment. For larger tracts of land (typical of suburban subdivisions and shopping areas) the commons actors linking the private landowner with the final development are the land investors or speculators and the land developer.

The investor/speculator performs the task of assembling smaller parcels of land to form an area that is suitable for development at a larger scale, which is normally more desirable from a development cost and a marketing standpoint. The land may be purchased outright (fee simple) or the investor may acquire options to purchase the land at a fixed price at a later date if and when certain development privileges are granted by local governmental bodies (e.g., upgrade the zoning, provide utility service, provide access to transportation facilities, etc.). The land investor may either obtain the desired zoning and related changes for his land in its original state, and then proceed to find a developer, or he may first find an interested developer and then attempt to acquire the necessary land development privileges (zoning, etc.) that would be required by the potential developer.

Once the land development privileges are acquired, the transfer to a land developer is possible at a significant profit to the land investor/speculator. The public privileges (e.g., zoning) and services (e.g., transportation) that are allotted to or committed to the investor's land in effect provide a margin of increased value which is recovered as a profit for the investor. The land may also be held, without any change in zoning, until conditions are ripe for development in the area and the land values have increased sufficiently to warrant a worthwhile profit.

The other major intermediary in the process is the land developer. He is the one that conceives of, directs and implements a particular type of development (e.g., housing, offices, etc.) upon available land. Often times the two functions of land speculator and developer are combined. The developer has the responsibility for obtaining or providing services such as these: financing on a long-term and short-term basis (normally through mortgage companies and banks); architectural and landscape design; legal and title services; construction contracts; and marketing and management services. When the development project is completed, the developer may retain the project as an investment or eventually sell it for a profit.

The developer's actions are, of course, utlimately directed at the consumer of his product--whether it be a home buyer or renter, a merchant seeking a retail outlet, a business, professional or service group in need of space, or an industrial organization seeking facilities. It is within the structure of the economic market that the development-related decisions are made and the various interrelationships between supply, demand, and location choice are defined.

These latter decision processes, especially as they relate to locational choice, are of special concern in the basic development of an urban development model. The theory utilized in the model should either explicitly or implicitly account for the locational decisionmaking process. Normally this is accomplished by use of some broad relationships linking transportation service, accessibility to other activities, and the locational attractiveness or feasibility of development as defined by various measures.

Regulatory

Another significant element in the urban development process is the "regulatory" element. This includes the governmental bodies that have the responsibility and power to impose certain controls on land development in order to maintain the public interest, as defined in basic terms by health, welfare, and safety, and also for broader purposes such as the creation or maintenance of a particular standard or mode of community life. An important influence in these matters, especially the latter, are the public policies which emanate from the community's decisionmakers; i.e., those elected officials and responsible appointed officials who are representing the interests of the community.

The regulatory elements which are the subject of our immediate discussion are the product of structured, institutionalized, legislatively mandated bodies, as opposed to the influence groups which we shall treat later as a separate element. These regulatory bodies might include the local planning commission, the board of zoning appeals, the municipal council (elected representatives at the highest legislative level) and the local review agencies such as an architectural review board, or a planning or public works office. The latter would most likely possess advisory powers and in some cases restrictive control or veto power.

Similarly, county, State, and Federal agencies may have a review function and a power to influence the level or character of development. A county or regional water and sewerage commission could, for example, limit development by limiting the provision of the essential water and sewerage services. Or at a higher level, a State water quality control board could limit the outflow of a local sewage treatment plant and thereby force the local agencies to limit new input connections to the plant and thereby affect development.

A typical sequence of actions in the regulatory phase of the urban development process might be as follows. (Note that the example is illustrative only.) For an assemblage of land parcels that had mixed zoning classifications, none of which was sufficient to permit the desired character of the new development, a developer would submit a request to the local planning commission for a change in the zoning (up-zoning) of his land to permit a higher, more intense level of development. With his request, he would normally present materials that would describe and support the intended use. The staff of the planning department would present their findings and recommendations resulting from the preliminary review of the proposal.

At this point, an analysis of the transportation service needs and future impacts should be made. Often this is only a cursory process because of the work load of the planning staff, the time limitations, and the unavailability of adequate tools necessary to provide the answers on both a small area project level and in relation to overall transportation system needs and responsibilities.

Other review and oversight bodies of government would also provide their comments. Both formal citizen groups and individuals along with private interest groups would have an opportunity to contribute their opinions and advice on the development proposal. The planning commission would then vote on the proposal and, if approved, send it to the municipal council for final approval or rejection.

Political/Social

At this time in our discussion it is appropriate to briefly comment on the last component of our urban development process--the political/social elements. The elected officials who eventually vote upon the development proposals represent the political component in its most obvious form. However, there are many other political influences present in the process, such as those felt in the municipal agencies dealing with land development that have direct links to the chief elected officials (e.g., the mayor) through the agency heads.

The social element represents those public interests, beyond the pure economic sector, that could normally be classified as community interests and social services. This element has an interest in development from the aspect of the general community environment, the quality of life, and the social environment. Some specific items that would be included in this element are recreation facilities/services, health care, public housing, educational and community centers. The social influences could derive from a number of sources and for various reasons. Commonly they would entail community concerns as transmitted by the local residents or through citizen organizations. In a broader sense, the social influence could be reflected in consumer preferences and demands regarding development standards and provisions.

Modeling the Process

Although the actual process of development is complex and infinitely variable because of the many potential actors and situations, it is not possible for an urban development model to accurately simulate all aspects of the process, even though it may be desirable. In fact, most of the complexities in the process may be ignored and only the basic mechanisms which most substantially influence the final outcome are dealt with. There are certain of these broad principles of economic and social activity which are recognized (usually by some explicit or implicit theory), interpreted, and formulated into a mathematical/logical structure within the model.

As extracted from our previous discussion of the process, one may find, for example, that the actual actors in the economic/market sector may be ignored, or subordinated and only the basic relationships among groups are considered, such as: the desire to maximize the return on an investment (real estate); the desire to capitalize on a locational advantage or a public investment; and the desire to satisfy the highest profitable market needs.

There are various theories of economics and market activity which can be used within a model to simulate the operation of those basic principles and to approximate their outcome. The mathematical representation of the theory within the model often necessitates a further narrowing of the theory which eventually focuses upon some relationships that can be adequately understood and constructed within the model.

A similar situation exists as regards to the regulatory components in the process. The urban development model is not concerned with particular actor-agencies but rather with their products as they have been defined or are most likely to be. The products are the land use regulations and the development policies which affect development. More specifically we are talking about items such as: the zoning ordinance, subdivision regulations, a land use plan, construction regulations, and public utility limitations. Policies regarding the general character and level of development are also part of this component, and as in the case of the other policies, may be formulated in a quantitative context for use in the model.

The political/social elements are probably the most remotely represented in the model except for specific public policies relating to development or transportation. The elements are sometimes represented by surrogate parameters that attempt to measure amenities, environmental conditions, and social attitudes.

Because an urban development model deals with the urban development process in a narrow and abbreviated form, it is important for the user and analyst of the model's output to be prepared to compensate for this situation. As long as we maintain the type of development mechanisms which now exist, it will be necessary to give consideration to the uncertainties and irregularities that may occur and their effects on our quantitative planning tools.

Interrelationship of Transportation and Land Development

There is little doubt in the mind of anyone who is versed in the transportation and land development planning field that there is a "transportation - land development interrelationship" that has significant impacts on both of the individual elements. A large amount of study has been done on certain aspects of this relationship, especially regarding the impacts of transportation development and land development (see 3, 4, and 7). Unfortunately, because of the complexity and scope of the problem, evidence of the causal relationships between the elements has not been available in clear, absolute, quantitative terms. However, there is much in the literature that is expressed in qualitative and descriptive terms which supports the existence of causal links between the two.

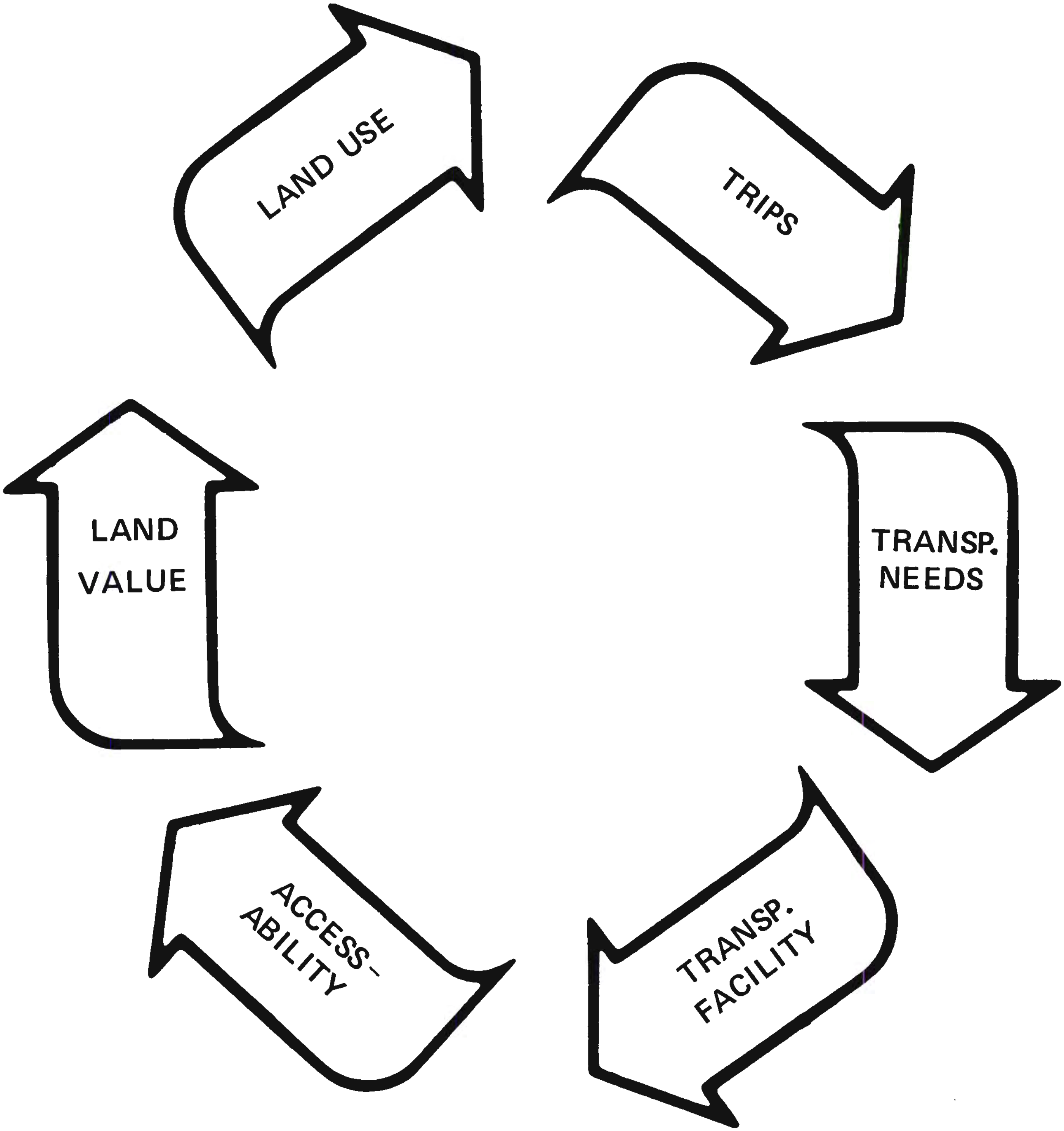
The cycle shown in figure 2 illustrates how the relationship between transportation facility development and land development can be represented in a simple, descriptive form. The cycle indicates that land uses generate a demand for travel (i.e., trips); these trips indicate the need for transportation facilities in order to serve the tripmaking demands; in turn the new or imporved transportation facilities provide accessibility; demand increases for the newly served or more accessible land, causing the land value to increase; eventually the land uses change (usually to a higher density) to reflect the various land market transactions, etc. Although the illustration is a simplified description of only one aspect of the relationship, it does demonstrate the interactive nature of the elements. It should be noted that this cycle does not reflect the external factors that are brought to bear upon the system. For example, land values respond to establishment of new firms based on locational decisions from outside the cycle. Then, land uses also are subject to influences from public decisionmaking independent of land values and the transportation-oriented concepts that precede that arrow in the cycle.

Accessibility

Transportation is readily recognized as a major physical and economic influence on land development just as land development is the prime element in generating transportation service demand (or in other terms, a transportation service need or potential). The influence of land development on transportation is therefore commonly defined in a measure of "demand" while transportation influence on land is often defined by "accessibility". Although accessibility may be defined in various forms (see 5 and 6), in its simplest form it refers to the ability to move from one location to another as measured in travel times or costs. Additional dimensions are often added to account for the number and/or type of people and/or activities that can be accessed. Urban development models normally include some form of accessibility measure as a variable in the model construct. This is necessary to reflect the transportation - land use interrelationship, although simple surrogate measures are sometimes used. However, if a model is to be useful as a tool for testing the impacts of alternative transportation systems, the transportation influence must be adequately represented within the model.

It is important to recognize that accessibility is an attribute of a person's perception, and like most human characteristics, perceptions vary. The economic reflection of accessibility is in the form of travel costs, which include (a) the value of time taken by the trip, (b) the cash outlays involved, including parking, fuel, auto costs, or transit costs, (c) indirect costs such as insurance, taxes, auto maintenance and depreciation, and (d) social costs such as environmental deterioration, congestion, and resource depletion. Although there is little variation in the recognition of costs covered by cash outlays,

FIGURE 2.



The Land Use - Transportation Cycle
(Extracted From Reference 3)

the other classes of costs vary meaningfully in their impact, depending on the income, family status, age, and work relationship of the person. These complexities form the basis for using differing mathematical expressions to reflect the variations in perception of accessibility.

Probably the most direct measure of accessibility in use in urban development models and transportation models is travel time between zones or activities. A more complex representation might be the ratios of activity and travel time (i.e., the denominator of the gravity model formula). Whatever the form of the accessibility variable chosen for the urban development model, it is desirable that it be defined explicitly within the model, in order that transportation policy inputs that change the accessibility can be, to some reasonable degree, traced to the resulting effect on the development pattern.

Because of the importance of accessibility in the model, it has been shown that the characteristics of the travel impedance (e.g., travel time) that is used to calculate accessibility can have a significant impact on forecasted distribution of population and employment. It was demonstrated in a research application that if land use forecasts are based on a free-flow transportation network or a network where flows, and therefore congestion, are significantly less than would realistically be present, the overall spatial distribution of activities can be excessively dispersed. This excessively dispersed pattern of activities can, in turn, produce excessive estimates of tripmaking and network congestion. On the other hand, if land use forecasts are based on over-congested transportation networks, the overall spatial distribution of activities can be excessively concentrated. And, such an excessively concentrated pattern of activities can produce an unrealistically low estimate of tripmaking and network congestion. (7)

If a transportation or land use forecasting method does not adequately account for the interrelationship between the land use and transportation components, faulty results, such as described, could severly impair the value of either. One approach to dealing with this problem is the use of a "linked" or "integrated" land use and transportation model. An example of an integrated transportation and land use models package is discussed in the final chapter.

Role of Urban Development Models

The urban development model is probably one of the more diverse of the advanced tools now available in the field of planning. Its role in planning and the character of its applications have evolved over its short history into some fairly well defined categories. We will examine first in general, and then in more detail the role of the urban development model.

One of the basic premises of model use is that one is dealing with a "system" or some process which can be approached "systematically." Whether it be a transportation system, an economic system, a social system, etc., there must be some definable and predictable interrelationships present which can be approximated or simulated. This is an important factor in determining what the model can be used for and how it can be applied within that use. There are certain systems, such as transportation systems, which are well suited to a relatively narrow range of systematic quantification and analysis. Other systems, such as social systems, are so broad in scope, and the data regarding them is of such a high volume and low reliability that they are usually subjected to modeling only in general form. Therefore, there are limitations to the use of a model which stem from the nature of the system being modeled and the form of the model itself. A simplistic model of an imperfect economic system would, for instance, be severly limited in its use for detailed policy decisions. Mathematical models generally work best at larger scales. Accuracy and reliability decline rapidly in applications involving detailed data and small analysis zones. Because of the characteristics of the urban system with which they deal, urban development models have inherent limitations in the functional role which they may assume.

Urban development models are useful in urban planning from both the theoretical and the practical standpoint. Planning, in a broad sense, involves the selection of alternative policies and programs which are most likely to achieve the community's established goals. The causal relationships between the means (policies and programs) and the goals, which provide a rationale for selection of alternatives, are explained by a combination of theory and understanding.

Almost without exception, every source dealing with the uses or benefits of urban development models cites the understanding of the influences and interrelationships of land development and the urban system as a benefit stemming from the development of a model. This is one reason why it is recommend that the staff of the local agency play a major role in the model construction and development task in addition to the model application task. If the models are developed totally by consultants, the planning staff will lose the experience and understanding obtained from taking part in model development. This understanding results from having to critically examine and separate the vital forces (social, economic, etc.) behind urban development. It would be a significant loss to a local agency if this improve understanding did not accrue to its staff. Understanding the theory and functioning of an urban development model is an important prerequisite to its successful use. Unless a planner has a clear comprehension of the theoretical and procedural framework and operations of the model, he risks using the model in such a manner, or interpreting the output in a way which is inappropriate or erroneous.

A survey of 26 major planning agencies found, in response to a question on the appropriate use of models in planning, that the use of models for analysis and evaluation of policy alternatives was cited as the major purpose by a margin of two to one (8).

The minority position gave forecasting and analysis as the major purpose of models in planning. As an illustration of the type of uses reported in the survey, one agency stated that models should be used "to forecast the effect of alternative courses of action on land development, and the effectiveness of urban systems . . . ." Another indicated that they should be used to ". . .simulate the consequences of selecting actions, and to dimension a general plan and make it internally consistent."

A more recent survey was made by the Fels Center of Government of 782 planning agencies regarding the use of "urban models", a category which included a much broader array of models than the urban development model alone (9). Of the reporting agencies, of which 146 (19%) were currently using a model and 63 (8%) were currently developing a model, it was found that nearly 80% of the models in use were used for projection purposes, while 52% were being used for plan evaluation. The survey results are:

Model Uses	User Agencies*		Developer Agencies*	
Projection only	141	42%	25	28%
Plan evaluation only	48	14	16	18
Projection and Plan eval.	126	37	29	33
Other uses	16	5	12	14
Not reported	4	1	6	7
Total	335	99%	88	100%

Unfortunately, these data do not give an accurate representation of the uses of urban development models since the results included a wide variety of models. The types of models included in the survey were reported in the following manner:

Types of Models	Agencies Using*		Agencies Developing*	
Land Use	61	42%	13	21%
Transportation	71	49	9	14
Population Projec.	31	21	6	10
Employment Projec.	8	6	-	-
Pop. & Emp. Projec.	12	8	1	2
Housing	9	6	8	13
Other	46	32	35	56

*Note: percent is of agencies using = 146 or agencies developing = 63. Totals sum to more than the number of agencies, since one agency may be using or developing several models. Totals also sum to less than the number of models, since agencies using more than one transportation model, for example, were counted only once as using a transportation model.

Despite the broader definitions used in the Fels survey it was found that the potential use in policy analysis (e.g., evaluation of the impacts of alternative policy mixes) was a major influence for supporting the models, especially for non-transportation planners. It is generally recognized that one of the most valuable advantages of urban development models is their relatively efficient and flexible capability to test alternatives - e.g., alternative transportation systems, alternative development plans (including type and phasing of development), alternaitve service system plans, etc. Once the model is calibrated with a set of parameters and variables, the appropriate variables can be changed to represent the alternative condition, and the model run again.

The type and quality of the alternative evaluation will depend primarily on the original character of the model and its ability to represent accurately, by changing the model variables, the test condition desired. Although absolute results are sometimes desired, in many cases the relative changes are sufficient. For example, if alternative "A" produces 1000 dwelling units in an analysis area and alternative "B" results in 600 dwelling units, the important measure may be the decrease of 40% and not necessarily the absolute decrease of 400 units.

The choice of which alternatives to test and how to evaluate them is dependent on the goals and objectives of an urban area as defined implicitly or explicitly in policy statements by the community's leadership. Such a list of goals might look like this:

1. Provide an adequate supply of housing for residents of all income groups.
2. Reduce transportation, utilities, and communication costs.
3. Reduce air, noise and water pollution.
4. Preserve and enhance the aesthetically and ecologically valuable areas in the region.
5. Provide rapid, efficient and reliable transportation service to all sectors of society.
6. Increase the opportunities for personal development, including education and recreation.

The goals would then be defined in terms of alternaitves (e.g., a medium density corridor development plan), and these would in turn be used to define the parameters and inputs used by the urban development model. Some typical input parameters which could be modified are listed below.

Each parameter would be defined for each analysis zone.

1. An accesibility measure between analysis zones. Normally a traveltime and/or cost measure is used.

2. Public service provisions (e.g., water and sewer, schools, etc.)

3. Land available for development (because of zoning classifications).

4. The character or density of permissible development.

5. Population and employment limits (maximum and/or minimum).

The conversion of goals and objectives is not, however, a simple task. A common approach is to define alternatives in terms of physical land development patterns. The major problem with this approach is that the physical form concept does not directly or reliably represent the many aspects of the goals. One must assume causal relationships which may not occur or may be overridden by other factors. For example, the assumption that a high density corridor development pattern will reduce transportation needs may be negated by an unbalanced distribution of commercial and residential development and a lack of adequate public transportation. Also, the development pattern approach limits the variety and the number of possible combinations which can be used, and excludes most of the options which are not definable in terms of physical form. Some models attempt to optimize specific items (e.g., minimize housing costs). When used for the analysis of alternatives, they are subjected to the restriction of optimizing only a few limited factors.

As confirmed by the Fels survey, the other major use of urban development models is for projection and forecasting purposes. Long range planning requires the use of some tool or technique to develop forecasts-whether by simple projections or by more sophisticated and detailed methods such as models. In the case of transportation planning, forecasts are made by small areas (similar or equivalent to traffic zones) for the basic measures of development, which generally are stratified categories of population, employment, and land use.

In the normal planning situation, independent regional forecasts of population and employment (overall totals or by stratifications) are made by one of the conventional forecasting techniques (e.g., cohort - survival and economic base methods). These exogenous (developed external to the model) forecasts are then used as control totals in the urban development model.

Given the control totals, the model is then used to make the small area forecasts. The common operational procedure within the model is to allocate the area-wide forecast on a more detailed scale to smaller analysis zones. This process, which varies with each individual model, is commonly referred to as "activity allocation."

A model may come to its allocation/forecast by means of a one-shot, simultaneous process of equilibrium, or by an incremental approach to equilibrium, or by yet another method. The final result, however, is similar for all models. In chapter IV, forecasting is further discussed in the context of the overall urban development modeling process.

In summary, the purpose of the urban development models' forecast in transportation planning generally focuses upon two areas: (1) the future need for transportation services; and (2) the influence of transportation on urban development and vice versa. The first item is concerned with the normal travel demand forecasting process which defines the need for and character of future transportation improvements. The outputs of the urban development model are normally suitable for use as inputs for the trip generation phase of the travel demand forecasting process.

The second item is of considerable interest to policy makers, planners, and implementors in both the transportation field and in the field of comprehensive urban planning. It is especially evident in this aspect of the models' role that urban development models have an appropriate place within the domain of the multi-functional comprehensive planning process.

Although, in a particular situation the urban development model may be utilized primarily as a transportation planning tool, it is evident that the most valid and efficacious use of the model is in the context of a joint planning endeavor within a comprehensive planning framework.

Future Outlook

As with the discussion of any rapidly evolving planning tool it is appropriate to look to the future state of urban development models. Although there are portents of change for such models, in the near future, one can expect to see the continued use of those models developed in the past if for no other reason than the fact that there is a need for them or something like them. There is, however, a growing potential for more relevant and constructive changes to occur in the future evolution of the urban development models, in part due to the increasing level of understanding and realistic appraisal of the models.

In all likelihood, the future changes to urban development models and the associated categories of planning tools will reflect some of these needs or characteristics:

1. More manageable models that are suited for more diverse applications.

2. More responsive models that are better able to answer the questions of decision-makers.

3. Models that are cheaper to install and operate and which provide quicker results, especially in the testing of various alternatives.

4. Models that can be easily integrated with other components in the planning process.

5. Models that are suited for sub-regional analysis and small area planning.

6. Models that consider the various transportation modes and are sensitive to the particular characteristics of each mode.

7. Models that don't require a substantial data base so as to reduce costs.

8. Models that can be used interactively with advanced graphics and cathode ray tube terminals, so that costs and computer resources are minimized.

9. Models that are easily transferable - the ability to transfer and successfully operate under a variety of different conditions.

EMPIRIC and PLUM, two currently operational models which have been used successfully for land use forecasting and for testing the impacts of alternative public policies on future development patterns, provide examples of some of the types of changes that can be expected in the future to reflect the new needs. Both models use public policies which included those policies directly associated with transportation investment (as measured by accessibility) as well as others (such as water and sewerage services, provisions of open space, and land use control). In the future it may be necessary to alter the form and use of such models in order to deal with a broader specification of policy issues. Transportation system, for example, may need to include cost factors in addition to traveltimes. Further modifications may be necessary to deal more effectively with multi-modal alternatives, environmental issues, and short,range, subregional land use analysis.

There are now some different schools of thought regarding the proper direction for urban development modeling for the future. Of these, two are especially significant. One suggests the creation of bigger, better, more integrated and complex models, while the other recommends a more modest approach. One advocate of the latter approach suggest, in a recent paper, that only very simple models should be built, and that they should address a particular policy problem [10]. This may appear to be backtracking on past developments, but it is a somewhat expected reaction when one observes that all too often in the past the overambitious quests for the complex, comprehensive model have resulted in little more than expended resources and an untested theory.

This approach may present an apparent contradiction to some: the recognition on one hand of the complexity of the urban development process and on the other hand questioning the creation of the large, complex model to treat it. The question is whether the whole urban situation is too complex to be dealt with completely at this point with one model that is both feasible and useful. The alternative question is whether it is better to devise a number of smaller models of narrower purpose which are easier to understand than one large "do-it-all" model which may be a problem to manage properly. However, the natural progression of even the small model approach would be to eventually link together the models into some overall process. That final linking process could, however, be delayed until the integrity of each component was established.

At the present time there are indications that movement is being made in both directions; toward the smaller and more simple, and toward the more integrated and complex. One example of the simplifications and tailoring of functions that are being incorporated in current urban development models is the recent work done on the PLUM model used in San Diego, California. (It has also been modified for its applications in the San Francisco area.) After its initial application there, the planning staff made a number of changes which included: (1) major changes and corrections in some of the basic structural components and procedures; (2) reduction in the overall size (as measured by the number of source deck cards) by approximately 50 percent; (3) reduction in the running time of the model by about 40 percent; (4) reduction of the number of required input datasets; and (5) improvements in the documentation. Some of the changes were required when it was found that the theory was not well represented by the model's operations. Although improved, the revised version of the model still retains the basic principles of the original model.

The Integrated Transportation and Land Use Models Package (ITLUP package), which is described later in this report and is currently in what one may describe as an operating developmental stage, is an example of the movement toward integration of the important elements in transportation planning and urban planning in general. The ITLUP package was designed to directly link the land use and socioeconomic elements (including in this instance the PLUM model) with the transportation models in the trip generation, trip distribution and traffic assignment phases of the planning process. One of the major goals was to systematically (and in a sense, automatically) account for the interaction between land development (resulting in transportation service demands) and transportation system service levels and capacities.

Although the PLUM urban development model utilized in the ITLUP package is not significantly different from other versions of the model, its direct, structured integration with the other transportation models put it in the context of a larger unified transportation modeling effort. A major advantage of this integrated approach is the ability to incrementally (e.g., allocate only a portion of the activity growth per forecast step) modify the transportation system characteristics (e.g., account for increased congestion and traveltime) in accordance with the effects of the land development changes that occurred in the previous incremental run of the urban development model. The next incremental run of the model will then reflect the changes in both the land use and transportation system conditions. Various overall system designs are possible, and as similar techniques are attempted by other planning groups, one can expect to see other system configurations evolve.

One obvious caution in such an integrated approach is to avoid letting the system crank through its whole sequence of operations from beginning to end without an adequate monitoring of the results at each step. These intermediary checks and analysis are necessary to avoid the propagation of uncorrected errors and the use of the system as a "black box" device.

One last comment regarding the small, individual model philosophy vs the larger, many, integrated models school of thought. In many respects they are compatible and complementary. For, as one begins to assemble a group of models into a package, it is very desirable to choose component models that have individual integrity, reliability and are well understood and proven in themselves; the type of models supported by the other modeling philosophy. Likewise, once one has developed a group of smaller, special-purpose models for use in a planning situation, there arises a need to deal effectively and efficiently with them in a systematic fashion, which leads to a more serious look at the integration and interfacing aspects of total modeling effort.

Research and Continuing Development

Some of the major indicators of the future of the urban development model are the research projects that are now being conducted and the ongoing development and improvement in the field of urban development models. There is a considerable amount of research relating to urban development models now in progress. Although it is not feasible to comment on each research project,[1] there are certain projects which are indicative of general trends and interests.

One such project,[2] sponsored by the National Science Foundation, is directed toward testing the feasibility of using land use and transportation models for projecting the impacts of alternative policies. The policies to be tested will cover, as far as conditions permit, the full range of measures affecting public facilities, transportation, private development activity location, and environmental protection. The relevant outputs to be sought will be concerned with environmental quality, housing quality, the quality of life, industrial profitability, public costs and similar items. Although the objectives of this project are quite ambitious, it is anticipated that the use of "off-the-shelf" models such as PLUM and EMPIRIC will place severe restrictions on the policies which can be tested and the outcomes which can be measured.

However, the project points out some key areas of concern. First, the desire to use the urban development model as a tool for dealing with broader urban issues other than just transportation and land use. Secondly, the need to develop a capability to test urban policies related to many subject areas and often times without significant historical background or experience. Included in such policies might be a "slow growth" policy of development, or transportation policies related to subsidies and incentives, economic or parking restrictions, and the promotion of new modes or expanded transit usage. And thirdly, the desire to broaden the impact testing capability for more elements (e.g., environment, housing, quality of life) in the urban scene.

[1]Note: Some sources of information on research related to urban development models are listed in the references for Chapter II.

[2]This project, Laboratory Testing of Predictive Models: An Evaluation of Cost Effectiveness, is assigned to the University of Pennsylvania and is under direction of Britton Harris and Stephen H. Putman. A related project at the University, The Use of Urban Models in Urban Policy Making, is under the direction of Janet Pack.

Other related research, some of which is sponsored by the Environmental Protection Agency, is attempting to use models to test specific environmental impacts resulting from future projections and to evaluate alternative policies with respect to items such as transportation, housing, industry location and pollution control.

Beyond the research directly related to the models themselves and their components, there is much allied research related to the theory, relationships, and behavior that are used or dealt with in the models. Some of this research work is intended for use directly in urban development models but much also has applicability outside the fields of urban and transportation modeling. Included in such research would be items dealing with residential choice and housing, patterns of travel and choice of mode, accessibility and mobility, and the economic determinants of locational and travel choices.

Most of the currently operational urban development models are still in a state of continuing development, either by the local planning agency using them and/or through State or Federal agencies, consultants, or the academic community. The Access and Land Development Model (ALD) and the Projective Land Use Model (PLUM) are examples of this phenomena. The ALD model is currently being subjected to research, testing and improvement by the Chicago Area Transportation Study in cooperation with the University of Illinois and the Illinois Department of Transportation. Similarly, PLUM has experienced various modifications by many groups, which includes: The Association of Bay Area Governments/The Metropolitan Transportation Commission (San Francisco); The Comprehensive Planning Organization (San Diego); The University of Pennsylvania; and, new users of the model.

It is worthwhile to note that since the history of urban development models is relatively short, many models still retain some part of the experimental nature that is common to such tools in their developmental periods. Most urban development models will continue to be in an "evolutionary" stage for a number of years (perhaps indefinitely) after they are initially devised. This does not necessarily imply an instability, but rather an increasing body of knowledge and experience which is being used to improve the models and adapt them to changing conditions. Any urban development model that is not adaptable in its operational or theoretical construct will likely have a shorter life span.

CHAPTER III

METHODS AND APPROACHES TO LAND USE FORECASTING

Background

Historically, nearly every large urban transportation planning study incorporated a land use element which was an important part of the total process. The land use forecast that was developed normally required a substantial effort, much of which was devoted to detailed data collection and analysis. Generally each study had a particular attitude or philosophy about locating future land use, and this was reflected in the particular method that they used for their land use forecasting. Some used a manual, judgemental approach, others used a more sophisticated modeling technique, while some used a hybrid approach which included both modeling and traditional judgement. In all cases, there was a need to develop a sufficiently detailed forecast of land activities by stratifications for each analysis zone that could be used for the trip generation phase of the transportation planning process.

Although ideas and practices are changing in this regard, the emphasis in most transportation planning studies had been in a zonal land use forecast (which normally includes socioeconomic variables such as population and employment) and not necessarily a land use plan, although externally produced land use plans were often used to provide data for the forecasts. Today there is a greater likelihood for comprehensive land use planning and the transportation land use forecasting to be integrated into one process. This is due in part to the tendancy to have a comprehensive planning organization as the umbrella agency for both the transportation and land use planning, and due to the clear recognition of the powerful influence of each element (transportation and land use) on the other.

The distinction between the land use forecast and the land use plan is significant. Because of the nature of transportation planning needs regarding land use (i.e., the use of land use activities data in trip generation equations), in the past it was a common objective of transportation planners to simply develop a quantitative measure for land use, aggregated to the level of an analysis traffic zone, for a future year (usually 20-25 years hence). The arrangement, design, service requirements (excluding transportation) and interactions of land uses within or between analysis zones were not of direct concern to the transportation planner.

Problems arose, of course, from this limited approach when conflicts occurred between a forecast of land use that was "trends extended" in nature and a land use plan that was based on the notion of "desired development." The use of certain policy, legal, and fiscal controls were assumed with the "desired" land use plan, but often were not implemented so that the plan could be realized. Likewise, the "trends" forecast often overlooked policy decisions, and even the effects of the transportation system, which would influence the future configuration of land development.

The transportation function is more commonly viewed today as a means of accomplishing broad regional goals, including the shaping of urban land development patterns, and not merely as a service function to whatever development may exist or occur in the future. The urban development model is one of the technical tools available to planners which better enables them to evaluate the "shaping" influence of transportation plans.

Methods and Approaches

Land development forecasting can be approached from a variety of directions, and normally a combination of techniques are employed. The approach is usually closely related to the purpose for which the forecast is made and the special interests or functional responsibilities of the body preparing it. A land use forecast made essentially for transportation planning purposes would generally emphasize the production of trip generation variables by traffic zones, while giving much less consideration to the design characteristics and the more specific and detailed land development interrelationships.

The definition of particular arrangements of development within an analysis zone would not add significantly to highway system planning requirements. However, this would normally be of much higher importance to the general community planner, and would ultimately be of value in affirming the integrity of a land use forecast and its future transportation needs. In the latter case, the planner is concerned not only with gross, aggregated (to analysis zone) measures of activities, but also the "on ground" allocations, perhaps even to the parcel level. The result is a more detailed "land use plan" that deals with land use design characteristics which take into consideration contiguous development patterns, existing arrangements and small scale interfaces.

In the process of making a land use forecast, irregardless of the detail of the final product or its ultimate use, some type of systematic procedure is required which considers the influences on future development. For the sake of simplicity, our examination of the land use or urban development forecasting methodologies will focus on two basic approaches: the traditional (manual) approach, and the modeling approach. Neither of these is, in actual practice, totally isolated from the other.

Traditional Approach

In the traditional land use planning/forecasting approach, one begins with goals and objectives, inventories of land use and public facilities, and forecasts of population and employment. These are normally common to other non-traditional approaches also. Beyond that, there is the application of relevant location and space standards by the planner. The process involves design considerations, public finance, environment quality, and like matters (8). The key element in this process is, of course, the planner who links together the various bits of information using his personal knowledge of the area and his professional judgment. In many cases, intuitive judgment plays an important part. Although the decisions reached by this approach are sometimes of a mixed quality, there is a definite advantage in its ability to permit a broad overview regarding current and future land use.

The early (1955) Washington, D.C. Mass Transportation Study (MTS) is a good example of the judgmental approach to land use analysis in a transportation planning context. In that study, population and employment projections were developed for each county within the study area, and the increments were distributed to the various land uses after a close investigation of trends at the local level.

A group of overall residential density patterns were developed for a general range of likely trends. This process, which took place at the staff level, included a close working relationship between the study personnel and the community leaders. The land use predictions served as a basis for forecasts of population, employment, and retail sales in the smaller analysis zones. (Some urban development models initially allocate population and employment to small areas and then make a land use conversion). The MTS staff felt that although this approach had no rigid systematic form, it was a realistic approach which took account of the variety and diversity among the communities within the region in a way that could not be achieved through reliance primarily upon quantitative relationships (9).

We should note that despite certain advantages to the judgmental approach to land use analysis, there are also disadvantages. One is the fact that although there is much to be gained by the expert judgment of the planner when he makes his decisions, there are also certain items which can be overlooked, misunderstood, or misrepresented. In any event, it is virtually impossible to document all aspects of the land use decisions. Therefore, in the future, when changes or comparisons are to be made, and impacts evaluated, it is not unusual to find that the reason for the originial decisions are forgotten or that the planner has left the agency and taken his first-hand information with him. A process that makes use of an urban development model may reduce some of these problems, although they cannot be totally eliminated.

Modeling Approach

The modeling approach to land use analysis is generally dependent upon a detailed quantification of the land use parameters and variables, and for a systematic analysis, a uniform information base is needed. A vast data base is usually assembled for the planning studies using models. The goal is to develop a data base that has a high level of accuracy, completeness, and detail (most data items have to be defined on an analysis zone basis). In some cases the data is required for two points in time.

It is generally assumed that every operation, interrelationship, and assumption used in the model is to be documented, understood, and taken into account when the model is used. However, this usally is not the case in actual practice, although the potential for such an awareness may exist. One possible criticism of urban development models is that there are often many hidden interrelationships or assumptions in the model which are not understood, let alone documented.

Whether the model is designed by the planner using it or by someone else, a defined logical-mathematical process is utilized which can be reproduced at some future time. This reproducible and consistent nature of the urban development model is of prime value in its use in testing and evaluating alternative situations and policies.

The modeling approach to land use forecasting shares many of the basic principles employed in the more traditional approach. However, there normally exist certain basic assumptions and distinguishing characteristics in the modeling process. These may act to limit or shape the final product and its use. Some of these assumptions and characteristics are listed below:

1. The acceptance of an urban development model implies the acceptance of certain mathematical relationships and the theory that they represent. One further assumes that the urban development and growth process for the area of concern can be simulated, represented or described by a mathematical model in such a way that will produce credible forecasts of the outcome of that process.

2. One assumes that such a model can be reasonably constructed or adapted for the planning area. The measure of reasonability being applied to: the amount of resources required (such as money, time, and expertise); the probability of success (i.e., producing a working, useful model), the ability of the model to produce the required information in the form and time-frame needed.

3. One assumes that the model will be a significant improvement over another approach in both its product and its capabiltieis. One would expect that the output data would be complete and be of a high quality. The model should also provide broader options in testing and manipulating alternative schemes and systems.

4. An urban development model characterisitcally uses discrete analysis zones or districts for its operations and in its outputting of results. The form of these analysis zones is largely determined by the level of geographic delineation which the input data is available for, and by the theoretical and practical constraints which the model places on the size and character of analysis zones. Since the model is highly dependent upon the accuracy of the input data, it is generally desirable to have such data available or collected for geographic units which do not have to

be altered (e.g., expanded or reduced) by some odd unit factor. (Aggregating complete zones is normally acceptable, but subdividing zones is more problematic). The model itself can also dictate analysis district constraints. For example, the theoretical and practical operation of the model may be such and the relationships so defined that the use of very small analysis districts would produce inaccurate or erratic results.

5. A model interrelates all areas of the planning region either in one step or in integrated series of steps. Therefore, except for the most minor of modifications to data, or the system, each change in parameters and data should be arranged in distinct "packages" which can be cranked through the model system for an accurate analysis. These packaged changes are usually classified as alternatives and should be carefully developed so as to conserve the number of model runs and to provide distinct and meaningful alternatives.

A further examination of the modeling process reveals certain advantages and disadvantages to that approach. Some of the advantages of using an urban development model in transportation planning would include:

- the ability to handle a large quantity of data and complex relationships.

- the ability to reproduce systematic consistent small area forecasts for various comparisons among the effects of varying public policies.

- the requirement that the assumptions underlying the land use forecasts be explicit (i.e., normally quantified) and documented. This permits an analysis of the assumptions at some point in the future to see if they are still valid.

- the ability to provide fairly quick and easy testing of alternative land use and transportation policies once the model is calibrated.

Likewise, certain problems that may arise when urban development models are used include:

- the requirement of a large and accurate data base. Most Models require time series cross-sectional data while a few require only cross-sectional data for one period in time.

- the requirement of personnel with a high level of technical capability and the willingness to commit a large amount of their time to the initial application of the model, at a minimum.

- the requirement of sufficient time to install, calibrate, apply and evaluate the model output prior to the need for its use in decision making. Normally the minimum time required would approximate 9 months provided the input data is in fairly good condition.

- the requirement of a computer system for which the model has been developed or made operational or the commitment to modify the model to make it operational on the user's computer system.

Another influence on the capabilities and operating characteristics of a model is the type or classification of the model. There are numerous classifications of urban development models, and many of these classification schemes are discussed and evaluated in the references (2-6). One classification that is useful for our purposes is a breakdown of the existing models by "level of complexity" and "model theory." Following those basic criteria, and relating them to a developmental progression, the urban development models may be classified as "first," "second," or "third generation." The first generation models are representative of the earliest efforts in the development of operational urban development models and continue to serve (either in their original or modified form) a great number of transportation planning organizations. These models are quite simple, generally deal with aggregate relationships, are based largely on accessibility indices, and deal primarily with the location of residential activity. Swerdloff and Stowers (7) describe the results of a test of five first generation models and contains sufficient detail to provide a basic understanding in order to permit the selection of one for more detailed investigation. The five models consist of the (a) Density-Saturation Gradient Method, (b) Accessibility Model, (c) Regression Technique, (d) Stouffer's Intervening Opportunity Model, and (e) Schneider's Intervening Opportunity Model. These models can be applied without the use of a computer, or simple programs can be prepared for use on a computer.

The second generation models draw upon notions and fundamental concepts which either originated with or were adapted from the first generation models. Improvements introduced in the second generation models include more complex statistical estimating procedures, consideration of more than residential activity, stratification of residential locations into several distinct groups, and incorporation of behavioral relationships in the model formulation. Models which can be classified in this group include the EMPIRIC Activity Allocation Model and the Projective Land Use Model.

The third generation models are more comprehensive and come closer to simulating the process of urban development, as opposed to the fitting of statistical models to the results of this process. One type of third generation model is concerned with more complex model concepts which require a knowledge of preference structure and individual utility functions in various forms. An example of a "preference" type of model is the Equilibrium Model of Metropolitan Housing and Locational Choice being developed at the University of Pennsylvania. Another type is concerned with simulating several of the key phases of transportation planning (i.e. population, employment, land use, generation, distribution, modal split, assignment) in one model operation. Thus an equilibrium between transportation and land use development can be achieved. Examples of the "equilibrium" type models include the Access and Land Development Model and the Integrated Transportation and Land Use Models Package. These two models along with several second generation models are discussed in more detail in the last chapter.

Planning versus Forecasting

One of the significant questions as regards land use planning and transportation planning arises when one separates the forecasting of land use from the planning design aspects. Traditionally, land use planning looks at what should be, or is desired to exist, at some future point in time. There is an attempt to design a pattern or arrangement of land uses (normally with appreciable detail) that is compatible with needs and development conditions, which promotes the public good and an orderly development, and which leads to a high quality of life. Development controls, such as zoning usually have a major impact in the planning decisions, but it is not unusual for actual development patterns to be altered by variations in the development controls or changing conditions. In some cases certain areas of the land use plan are predicated upon the use of controls which are never actually implemented.

One of the major difficulties of land development controls has been that they stem from a philosophy and practice that views the controls only as being prohibitory in nature (preventing the worst) and allowing the owners of land to use or develop their land as they wish except as specifically restricted by State or local legislation. More recent land development legislation reflects a more positive role of the public interest, but the development process still retains a strong determination by the individual, private developer. The problems in predicting the individual development decisions are obviously difficult.

The activity allocation process that is favored as a land forecasting input to transportation planning bypasses the detailed arrangement of land uses and focuses upon specifying the amount, type, and location (by analysis district) of activities (e.g., households and jobs) which compose the land development. This approach generally supports the dominance of the "market forces" in the process, and views land development controls as one moderating or prohibitory influence on land development.

The weakness in this approach is that it does not consider (except in the most general terms) the actual site conditions and the microlevel considerations that should be given to development, that is, to serve people in a way that surpasses purely household and employment delineations. In planning the physical development of land one is concerned with the proper location and intensity of activities (which is also involved in activity allocation),and the type, design, and location of structures and facilities that serve these activities. The latter are normally considered in activity allocation only in terms of large regional systems of facilities such as highways or water and sewer systems.

In each of the various approaches to land development planning there is often a weakness in the consideration of social and economic objectives. Land planning should, as a minimum, identify the physical factors which can significantly influence the realization of social and economic objectives. The activity allocation process normally confines itself to broad economic or social principles that are often treated in terms of some numerical weight, by some economic optimization technique, (e.g., minimize rents or development costs), or by means of an external manipulation of the results (e.g., interject public housing into select districts). The traditional process of analysis and design offers somewhat more flexibility concerning social and economic matters, but does not necessarily insure that such considerations are actually made.

Although trade-offs must be made with whatever approach is used to land use forecasting, it is important to consider the characteristics, benefits and constraints of each in relation to the present and future needs of the transportation planning process.

CHAPTER IV

URBAN DEVELOPMENT MODELING PROCESS

The basic objectives of an urban development model application are to forecast activities by small areas and to evaluate alternatives and test for impacts.

Specific forecasting outputs include items such as population or households, stratified by income or other measures, and employment stratified by an industrial class or similar measures. The forecasts are made for small areas or analysis zones which may vary in size from that of a traffic zone to something larger than a census tract.

Land use is also an important component in the forecasting process. Either directly or indirectly, a desired output from an urban development model is the change in future land use. By various techniques, the activity levels are transformed in terms of land consumption or land use changes. Usually, land can be classified according to broad categories (e.g., low density residential; heavy industrial; open space) in each analysis zone and inventoried by areal units.

One of the basic goals of the modeling process is to make available an accurate, calibrated model in which the developers, the immediate users and those who are dependent on its output, have a high level of confidence. The model should be able to do the job for which it was intended (e.g., forecasting, etc.) in a manner and form that meets the criteria of the overall planning process.

Data Collection and Analysis

Data collection and analysis is a major element, regarding both time and use, in the urban development modeling process. The old phase in the computer business "garbage-in, garbage-out" is very applicable for urban development models. No matter how sophisticated or theoretically sound a model is, it cannot operate very effectively with poor data.

Despite the recent increase in information sources, data collection and analysis is still a large portion of any modeling effort and may consume more than half the project resources. In some past transportation studies data collection and processing absorbed about 60 percent of the total budget (1).

One current consideration in data collection which is gaining broad support is the use of secondary sources (i.e., rather than the modeling group collecting the data themselves or essentially for their own needs, the data is acquired from another source which collects the data for a specific or varied purpose.) The advantage from secondary sources is not only in the savings from the elimination for individual data collection for a certain data item, but also from the possibility that this information will be continuously collected into the foreseeable future. This latter situation facilitates the updating and reevaluation of the model at a feasible cost. The availability of the same data in the future, from whatever source, adds value to the whole modeling process.

If the data are to be used properly, the user should have some measure of the accuracy and reliability of the data base. Some errors in the data used in modeling propagate and could have a significant impact on the overall accuracy of the model.

The data base for a modeling process often results from a group of inventories or datasets assembled according to the character of the data. An important item for most all urban development models is the transportation inventory. A survey of past, present, and future transportation facility characteristics provides the information needed for an accessibility construct on which most models heavily depend. The accessibility factor usually involves the use of interzonal traveltimes, travel costs, some combination of the two, or a related function.

The inventory of socioeconomic data contains some of the key elements normally required by an urban development model--population and employment. These are subject to various stratifications. A common stratification for population would be households by income class. Other descriptors such as age, family size, and residential density may also be used to define the population component.

The employment data are commonly stratified by industry groups such as are defined by SIC codes.

Other items in the socioeconomic datasets may include auto ownership, school enrollment, race, and similar information.

The land use dataset may include data on a zonal basis or on a smaller parcel level. The largest component is normally the classifications of land use by type. Land area, floor space, housing types, service provisions (e.g., water and sewerage) are other like items to be found in this dataset.

Beyond the simple numerical measure or count of the data, there is the slightly more involved task of determining the various rates and relationships between the data. In this category, one would consider such things as the employment participation rate; the average number of autos per dwelling unit; the amount of land consumed per industrial or residential category; and the amount of land consumed per occupied floor space.

Following the determination of data rates and relationships is the anaylsis aspect which involves an examination of datum both as an individual entity and as it relates to other data. Statistical anaylsis is the approach normally used and, within the array of available mathematical techniques, regression analysis is most commonly utilized. The degree and precision of analysis depends largely on the type of data involved and its use in the model. Critical data items to which the model is especially sensitive will probably receive the greatest analysis if required.

It is not uncommon to begin with a large array of data in the initial analysis process and systematically reduce the data to the most meaningful and useful items. The development of variables for models such as EMPIRIC by the regression technique would follow such a process.

Most urban development models are data hungry, but it is advantageous to reduce the data which is used to the most essential and meaningful items. Quality of data is normally a more valuable criteria than quantity. Efficient use of data will also be helpful in the future as the model is reapplied, compared or evaluated.

Model Formulation

Model formulation is that step in which the model is actually shaped or formed into a particular operational tool suited to specific needs. This step applies whether a model is designed and built for a particular study or if a pre-existing model is chosen, although the former circumstance might present an overlap in design and formulation.

A basic first step in model formulation is to define what is expected of the model regarding specific data outputs. Inputs and outputs are, of course, directly related and should be considered together. But the output from any particular model can vary according to the action of the user.

A second step is to define the basic structural and logical linkages of the system if it has not already been done. This entails a more refined system design in which subsystems, programs or operational blocks are linked together. In the case of a model such as EMPIRIC (which is composed of 17 discrete programs), it would mean defining the systematic arrangement of the various programs within each subsystem. In more unified models, such as PLUM, this step would probably deal with linking of submodels (such as BEMOD), data interfacing programs, or graphical display programs.

A third step would entail the formulation of major operations within the model which can or must be specified by the user. A prime example of this would be the formulation of the regression equations in the EMPIRIC model. Actually, the major portion of this is done in a fairly routine calibration process, but there is also much that is left to the user regarding the input of data, the analysis of the variables, and the selection of the final variables and the form of the equations.

In other models there are major items such as mathematical functions or routines, probability functions, accessibility computations, and major operations which are dependent on specific study area characteristics which need to be formulated. The specification or formulation of these items may require, in some instances, changes or additions to the software of the model.

Some other items to be considered in model formulation are those input parameters which specify options or control operations. These parameters define the detailed character and operation of the model for a particular application. These items can normally be read into the model on parameter cards or otherwise be input in some relatively expeditious manner. Included among these parameters are things such as: 1) The number or type of time periods, iteration steps, income ranges, housing types, etc; 2) standards or rates of consumption such as the land used by certain categories of residential households or by commercial activities with specified floor space usage; and 3) weighing factors, measures and indicies related to items such as development potential, residential attractiveness and accessibility.

Often times in urban development models one must use external considerations and controls regarding allocations to specific zones. This sometimes occurs because of large-scale development or other special types of development which require independent allocation. A large shopping center or a military base may fit into this category. Likewise, there are often zones which have specific limits or ranges under which any future development may occur. This could be because of the dominance of a one institution such as a university or because of legal or natural controls. In any case, the model formulation must give special treatment to these situations.

Not to be ignored in model formulation are those items which, although not directly used by the model, have a direct influence on those parameters and data which are inputs into the model. We speak here generally of policies related to urban development. These policies relate to growth, to the scale of development, to environmental controls, and to similar matters. A policy to limit growth in a certain area, for example, may have a direct representation in the model in terms of the amount of population and employment that can be allocated there, the amount of land that can be consumed, and the amount of services that will be available.

When the model is formulated, it is important to insure that the effects and implications of any policies can be considered by the model as far as is desirable or practical; otherwise, one may find late in the modeling process that the policy evaluation options of the model are overly restrictive.

Calibration

The calibration of an urban development model is basically the adjusting of the model to fit its intended purpose. It normally consists of two phases: 1) Defining the model's variables and parameters; and 2) comparing the model's output with a know situation.

There is normally a difference in scale between the calibration required in the process of building a model and in the process of using an existing model. We shall discuss the calibration process in general, and distinguish between the "build" or "use" situation as is necessary.

Borrowing from an approach to calibration by Lowry, we can distinguish two types of transformation involved in the initial step of the calibration process: First, the model's variables must be given precise empirical definitions; and secondly, the model's parameters must be assigned numerical values (2). The calibration of an existing model would be concerned primarily with the second item.

Compromises are usually involved in the defining of the variables, the first transformation. Variables which are included in a model because of their theoretical significance may not be available in a real world situation, causing a more readily available proxy to be substituted for it. Faced with data definition and availability problems the model-builder may be forced to revise the model's logical structure to lessen its sensitivity to bad data or to make better use of the data that is actually available.

An example of the variable definition and availability problem could be a variable which is conceived in general terms (e.g., household income) but must be related to an available statistic (e.g., the median income of families and unrelated individuals as derived from a 25 percent sample by the Bureau of the Census). Any restrictions or qualifications surrounding the data would have to be examined to insure that the proposed role of the variable in the model was not seriously undermined.

The second transformation, the fitting or parameters (the numerical constants of relationship), is normally common to the build and use situation. Parameter fitting is necessary for two reasons: 1) Theoretical principles and deductive reasoning therefrom are seldom sufficient to indicate more than an appropriate sign (positive or negative) and probable order of magnitude for such constants; and 2) since these constants are measures of relationship between numerical variables, the precise empirical definition of the variable affects on the value of the parameter. For example, a labor force participation rate may be dependent upon whether the participants are chosen from a 15-60 age group or a 14-65 age group.

Parameter fitting is usually accomplished by some statistical method. Regression analysis is the most common tool. Another way to fit parameters is by use of a linear equation (or econometric) technique. This latter technique has the disadvantage of using the best <u>overall</u> fit of the model as the criterion for the selection of individual parameter values. The resulting values for individual parameters may be difficult to explain or accept.

Other methods, generally categorized as "heuristic," deal with the model as a partitioned group of subsystems. In these cases, the parameters of the subsystem can be fitted independently. This may involve a variety of techniques which vary from a "best fit" approach to trial-and-error methods.

In some situations, where it is difficult to find a mathematically exact expression for a relationship, model developers resort to "human parameters." This is simply one way of saying that in some instances a person of respected judgment is asked to alter the preliminary outputs of the model to conform to "...an intuitive standard of plausibility based on their experience in the field" (2).

The second item in the calibration process is sometimes considered as model validation, testing or evaluation. What it entails is the actual application of the model under test conditions. Each model should be given a test appropriate to its designed function. For example, a descriptive model of urban form might be tested for its ability to replicate the details of an existing urban pattern on the basis of limited information concerning the area in question. Ordinarily, there is detailed data on the area's characteristics available against which the model's output may be checked. This test may not, however, give any indication as to the suitability of the model for use in any city but the one for which it was designed.

For a predictive model the most appropriate test is to use it for a forecast and verify its output. The most desirable situation is to forecast from the base year to a distant time in the future, but since verification is impossible the most commonly used approach is an *ex post facto* technique. In that case, one would use a point in the past as the base year (e.g., 1965) and apply the model by forecasting to a know point in time (e.g., 1975). Data for both points in time would be necessary: the early data for use as input to the model and the later data for comparison with the model's output. The model should be calibrated for a different time period (e.g., 1960-1970).

In the EMPIRIC model the use of data for two points in time is a requirement for determining the equation structure and coefficients. In other models where this is not required, there may be greater difficulties in obtaining some range of data that is available for the base year.

Other specific measures of performance such as sensitivity testing are sometimes included at the time of calibration in order to evaluate a model. These items are dealt within a later section of this report.

Forecasting

Forecasting is the process by which the model develops one of its prime objectives--a prediction of select future conditions. The basic operation of forecasting is to make judgments (in quantitative terms) about the future, given reliable information about the past and present, and estimates of certain future circumstances.

In some models the forecast is heavily dependent upon past information and trend extensions. Others require much externally generated information relating to the forecast year(s). The latter is combined with data on present conditions to develop the forecast.

Future influences or information may be in the form of: (1) separate forecasts (e.g., basic employment for select areas or population control totals); (2) independent occurrences of high reliability (e.g., a "new town" development or a large institutional or industrial development); or (3) policies which usually result from decisions by governmental bodies, but may also include business and other sectors of society. Examples of the latter are: investment and location policies regarding investment in and location of public facilities and services such as water and sewerage, transportation, schools; taxation rates and schemes; and development and investment controls and incentives.

Depending on the type of model, it may operate over one long time period (e.g., 20-25 years) or it may proceed in smaller time increments (e.g., 2-5-10 years.) In the later case, the model produces a forecast at the end of each minor time period which acts as an input to the model for the succeeding forecast period. If certain required model inputs are exogenous to the model and not part of the output, it may be necessary to produce these by means of submodels or some method of external generation.

The forecasted variables vary for each individual model, but usually include stratifications of population and employment and some indication of land consumption by land use categories. Normally the forecasts are allocated to distinct small areas.

As with any model output, the forecasts should be checked to discover if they are reasonable and consistent. This may be required for both the aggregated and disaggregated output data.

Evaluation

After the model has been calibrated and run through its forecasting operation one is left with the output(s) of the model. The generation of some type of forecast outputs is not, however, the end state of the modeling process. These outputs need to be subjected to an evaluation process whereby their validity is ascertained, and they are translated into meaningful planning options.

Since the urban development model is only one tool in the planning process, its product must be examined and evaluated before the process continues along using the model's results. Some of the basic questions one should ask on initial examination of the model's output are:

(1) Is the output reasonable and logical?

(2) Is there an overall consistency in the output?

(3) Are there any particular analysis zones or data categories which display unusual or questionable values that should be subjected to special examination?

(4) Have those restrictions, limits, ceilings, etc., that were used in the model on a zonal or some other basic, worked properly? Have some been overlooked?

These questions and others address the quality of the model output and bear on the value and use of its product. A more detailed discussion of the accuracy and validity considerations are contained in Chapter VI.

If one can assume or satisfy the requirements for an acceptable level of accuracy and validity from the model, the final step is to examine and evaluate the output as a representation of alternative policies, plans and systems.

CHAPTER V

PRACTICAL CONSIDERATIONS IN URBAN DEVELOPMENT MODEL SELECTION AND APPLICATIONS

There are numerous decisions that must be considered prior to the selection of an urban development model for use on a continuing on-line basis in any comprehensive transportation planning study. Some of these have been touched upon in earlier chapters of the report. The decisions can be categorized into those concerning (1) the desired uses of the model, (2) the acceptability of the model theory or construct to the prospective users of its output, (3) the availability of adequate staff resources to install and operate the model, (4) the availability of input data for operating the model, (5) the availability of adequate model documentation, (6) the accessibility to a computer system on which the model is designed to operate, (7) the choice of using an existing model or developing a new model, and (8) the time frame in which the model output must be used in on-line decisionmaking. Each of these items will be discussed in this chapter. It should be noted that all are equally important and should be given serious consideration prior to any final decision to select a model. Many of the urban studies that previously used urban development models did not give adequate consideration to many of these items and subsequently their experience in using the model was not as successful as it might have been.

Desirable Model Uses

It is very important that any prospective model user first identify what the intended uses of the model are. Models that do not provide output that can directly or indirectly be used for these intended purposes can then be quickly eliminated from further consideration. It is, of course, understood that an urban development model cannot possibly serve all needs. However, certain basic outputs such as small area population and employment forecasts as well as the capability for illustrating impacts of several public policies on these forecasts go a long way toward satisfying many planning tasks. For instance, these forecasts play an important part in transportation planning, land use planning, testing alternative plans and policies, health planning, environmental planning, urban drainage and solid waste disposal, housing planning, police and school planning, public utility planning, etc.

Acceptability of Model Theory or Construct

It is easy to criticize and find fault with most of the existing urban development models. It should be remembered that the process of urban development which is being modeled is very complex and the various elements of this process are extensive and ill-structured. Modelers which have attempted to undertake this task should be commended. In the development of any model, whether it concern transportation, urban growth, or both, many relationships must be left out or models would become to unwieldly to be of any use. No model construct can be held up to the light of reality without finding flaws, gaps, and inconsistencies. This is the nature of the modeling process (i.e. there is continual compromise between operationality and descriptiveness). The models which are most widely used today have successfully approached the acceptable balance between operationality and descriptiveness.

Based upon this knowledge care must be taken to determine the acceptability of the model theory or construct to the several expected users of the model output. The local decisionmakers, planners, and citizen groups should have a basic knowledge of the model if they are to be expected to accept and use the model output. This will require some training and public relations work on the part of the urban study staff. If wide acceptability is not reached then the use and acceptance of model output will not justify the models use.

Any proposed use of the model in a "black box" approach should be avoided. Many will recall the "old school" planners objections to using earlier models for doing a job which they were already quite good at, and had been doing for years. They failed to realize that the urban development model was simply a tool that would cut down on some of the tedious and repetitive jobs that are encountered in activity allocation, and most evident in alternative policy testing. This probelm is not as great today since many planners have realized that the model output must be tempered with their professional judgement and that ample opportunity is provided for their input at appropriate points in the model application.

Availability of Adequate Staff Resources

The initial installation of an urban development model is a large task and requires considerable personnel time and technical capability in computer programming, statistics, data manipulation and forecasting. Urban studies that have an adequate technical staff in addition to the required computer facilities and data have successfully developed or used an existing model. Other studies having an adequate staff but found they could not commit them to a long term project have used a consultant to install and apply the model. When a consultant is used care should be taken to insure that the consultant has an adequate technical staff available, and is sensitive to the output and time requirements of the study. Also, the consultant should be required to train the staff in the use of the model. In cases where a consultant is used it is desirable for at least one staff personnel to work closely with the consultant for a continuing staff capability with the model.

Availability of Input Data

As discussed in chapter IV the collection and analysis of data plays a large role in the overall time and cost of urban development model applications. Generally the input data required for calibrating most models are time-series cross-sectional data at the analysis unit (i.e. zonal) level. However, a few require zonal data for only one point in time. If all other considerations were equal then it would be less demanding overall to use the model with fewer input requirements. Since in most instances this will not be the case, it is recommended that model input requirements hould be compared against what data is available or obtainable by surveys, secondary sources, or estimation. It is much better to determine from the start that data problems cannot be overcome (if this is the case) rather than at a later date when considerable expense has been expended in installing the model on the user's system. In addition, the availability of a data manipulation system is desirable for use in shaping raw data into the required model format. The EMPIRIC Model has a good manipulation system as part of its model package. This system could be used to shape input to other models.

Availability of Adequate Model Documentation

The availability of adequate documentation on the theory and use (i.e. User's Manual) of each particular model under consideration is a major concern in selecting a model. While the documentation problem is not as prevalent as in the past it is important that the study staff determine whether the existing documentation is sufficient for a model application, especially if the model is to be applied without the assistance of a consultant. The brief description of several models in chapter VII should provide an indication of the available documentation for them.

Accessibility to a Computer on Which Model Operates

The computer facilities which an urban study uses can have a significant impact in narrowing down the models under consideration. While most of the models operate on an IBM 360, an examination of each models specific system size requirements should be undertaken. Good turn-around time should be available for the model application. It should be noted that in a few instances where a model has been considered highly desirable the urban study has funded a reprogramming of the model for use on their computer system. However, cases such as this are fairly rare.

New Model Development vs Existing Model

In most instances the use of an existing model is recommended. In a few cases urban studies have decided that the existing models were not adequate and then undertook the development of a new model. Usually the rejection is on the basis that the accessibility component of the model will tend to exert too much influence on the forecast. In many of these cases the land use work was on the study's critical path and the development work was too rushed resulting in an inadequate model. In these cases it was not uncommon to find that accessibility was a component of the new model. Based upon past experience it appears best to take a proven existing model and if necessary make minor improvements or modifications rather than to undertake a new model development.

Time Frame for Model Application

Sufficient time should be allowed for the installation, calibration, and application of the model. In addition sufficient time should be allowed in order to evaluate the model output prior to its use in decisionmaking. Experience has shown that at the minimum nine months should be allowed provided the input data is in good shape. If data is not readily available the total application could run almost two years.

It is generally recommended that the initial work with the urban development model be done off-line (i.e. that the model output not be required for input to other work phases on the study critical path).

If this work cannot be done off-line then it is recommended that a backup should be available. This backup procedure could then be implemented in the event the model application falls toofar behind schedule (i.e. during initial model applications problems can arise due to inexperience in its use, which will not prevail during future applications.)

Application Considerations

In addition to some of the above items which can also be characterized as application considerations, several other problems may arise during model applications. Many application problems are fairly specific to the individual models, such as, the need for defining basic and service employment and the requirement for the user's location of basic employment prior to the use of the Projective Land Use Model (PLUM). Model specific application problems are described in detail in the model documentation. Three problems most common to all applications involve the level of zonal aggregation, the allocation of activities to the zonal level, and the decision to forecast recursively or non-recursively.

Zonal Framework

The selection of zonal framework for any particular model application will largely determine the cost of using the model. More important is the influence of the zonal framework upon the cost of preparing the data base for the model. In general, the larger the zone sizes (i.e. the smaller the number of zones) in any study area, the cheaper and simpler it is to use the model. The potential model user should be concerned with the recommended limits of zonal numbers associated with each model (if any have been set). For instance, PLUM can be run with 1000 or more zones. However, the model developer, Dr. William Goldner, and other users report that for operational purposes, this may be much too large a number.

District to Zone Allocation

From the experience of past model applications it is clear that models perform better when they are used to forecast growth for larger analysis units. In most cases the larger analysis units are called districts and consists of aggregations of several zones. Since transportation models require zonal level input the study staff must further allocate the forecasts from districts to zones. During their application of the EMPIRIC Model, the Washington Metropolitan Council of Governments (WMCOG) and the Denver Regional Council of Governments (DRCOG) made use of a zonal allocation procedure (ZAP) to allocate districts forecasts to zones. A brief description of ZAP as prepared by Peat, Marwick, Mitchell & Co. is contained in Appendix A.

In general, the allocation procedure should be selected based on the availability of data at the zonal level, the available financial resources, and the required accuracy of the zonal forecasts. For instance, the more detailed the procedure, the greater is the forecast accuracy and the zonal data required. An allocation procedure that is to be used in a study of the impact of highways or transit on selected zones must necessarily be more detailed than one that is allocating growth to all zones.

The allocation procedure should not be solely based on a systematic weighting of existing zonal population. This procedure should also consider a weighting of factors such as:

1. Distance to convenience shopping.
2. Available residential and employment capacity.
3. Distance to the major street system.
4. Percent of industrial development in the zone.
5. Percent of residential development in the zone.
6. Location of major population and employment generators.

When the analyst is intimately familiar with the study region the allocation procedure can be based on a systematic, but subjective, weighting of these type factors. However, much of the activity allocation work is being done by consultants, and they do not have this perspective. Therefore, the allocation procedure should be based on a systematic, analytical weighting of the various factors.

Specifically, the simple first generation models discussed in chapter 2 are considered appropriate for this type of allocation.

Recursive vs Nonrecursive Forecasting

Recursive forecasting is usually done by five year increments and consists of two or more forecasts in which the forecast of the distribution of activities for any time period is explicitly a function of conditions at the previous time period (i.e. the output from one forecast increment is used as input for the next forecast increment). Nonrecursive forecasting involves only one forecast. The use of recursive forecasting in transportation planning provides for the consideration of feedback between scheduled (i.e. staged) transportation improvements and land development. Many urban studies feel that the accuracy or sensitivity lost by not using recursive forecasting will not be as great as the accuracy lost in trying to forecast what the transportation network (skim trees) and other required model inputs will be for every five-year increment in their 20 year forecast period. While it is difficult to argue the point, experience has shown that the error associated with the PLUM forecasts are due in large part to making a forecast in one large interval (nonrecursively) as opposed to several shorter intervals (recursively).

CHAPTER VI

MODEL ACCURACY, VALIDITY AND PERFORMANCE

A key consideration of any model is its accuracy, validity and performance characteristics. These considerations are probably even more important for an urban development model which plays a prominent role in both the forecasting and evaluation stages of transportation and land use planning. The urban development model should, therefore, be able to meet performance criteria on the theoretical, technical and practical levels that support its credibility with those who must accept and utilize its product.

It is normal for a model to be calibrated (which may include various degrees of adjustment, fine tuning and massaging) so that it can adequately describe some past and existing situation in a time frame of perhaps 5, 10 or 15 years. However, the proper evaluation of the accuracy and performance of a model generally requires a more detailed examination.

For evaluation purposes it is convenient to examine accuracy, validity and performance in terms of two individual aspects of the model which in actuality are closely interrelated, but provide for a more simple analysis when considered separately.

The first involves the design of the model itself, i.e., the logic, the theoretical construct and the operational structure. The validity and accuracy of this aspect of the model are largely influenced by the accuracy and interpretation of the basic information used in the design of the model. The second aspect refers to the accuracy and performance of a model in terms of its product (e.g., the output forecasts.)

Regarding the first aspect, model design, Alonso (1) has identified two types of errors to be considered: specification error and measurement error. Specification errors result from the incorrect formulation of relationships within the model, e.g., the identification or specification of a linear relationship that in reality is nonlinear.

Measurement errors result from incorrectly assessing a magnitude of a parameter or variable, e.g., rounding each measurement to the nearest whole number. While a specification error is inherent in the model, a measurement error can change and vary with the quality and accuracy of the data used. From a practical standpoint, Alonso's research has indicated that a model should be formulated so as to:

1. Avoid intercorrelated variables

2. Add variables where possible

3. Multiply or divide variables if you cannot add

4. Avoid as much as possible taking differences or raising variables to powers

5. Avoid as much as possible model configurations which proceed by chains.

Both of the cited errors relate to the accuracy of the data which is used in the modeling process. Alonso (1) argues that the design and use of models must not exceed the accuracy of the input data. He concludes that simple and proven models are the best choice for operational agencies, and that universities and other research groups should be investigating complex models. Although opinions may vary, others in the field have also concluded that simple models are preferred for on-line applications (2), and that a balance is required between data accuracy and model sophistication (3).

Two significant items, therefore, for an operating agency to consider regarding an urban development model would be the level of accuracy of the input data, and the level of simplicity of the operational model. One should note that although simplicity may suggest a low specification error and a high degree of validity, this is not <u>necessarily</u> true in all cases. That is one reason to make an adequate investigation of the various models and modeling techniques before coming to a final evaluation conclusion. The descriptions and evaluations of various urban development models in Chapter VII should provide some indication of the level of sophistication of the models and their past or potential operational success and utility.

Chapter IV discussed some of the considerations in data collection and analysis for use with an urban development model. The normal quality checks would be applied during the data collection process.

The second aspect of our discussion in this chapter, the accuracy and performance of a model in terms of its final product, poses one of the most common questions regarding urban development models. It is also one of the most difficult to answer. But the potential user of a model has a natural interest in its past performance and the probability of it working well in a different application.

The testing of a model's accuracy and performance characteristics is usually first attempted (for the model as a whole) in, or following, the calibration process as was described in Chapter IV. Once the variables and parameters are properly fitted in the calibration process, the model can be tested in order to determine whether it works as designed. The character of this test depends on the function of the model, but in general it involves the application of the model with some available data base and the comparison of its output with a know situation.

For a model that is predictive in nature, a test can be made using data from a point in the past for the base year input. The model then produces a forecast for the present or some point in the immediate past for which verifying data is available. Since the model is operating in a period of the past, its performance under those circumstances does not necessarily insure that it will perform in the same manner under a set of circumstances occurring in the future. It is this unknown element--the future--which presents the greatest difficulties.

However, even if one could examine a model that was initially calibrated and applied at some time in the past, the evaluation of it could still be a problem. The most obvious approach--a simple comparison of what the model predicted and what actually ocurred--does not necessarily produce immediate conclusions as to the validity or the overall value of a model. Sometimes a model produces poor results because it wasn't used properly. This could include both measurement and specification errors, e.g., certain policy or physical-change inputs were inaccurate or were omitted in the original running of the model, and therefore caused a less accurate output. The implication is that if the proper data were used at the time of the original application, the results would have been better.

In an investigation of ways to verify and evaluate land use forecasting models, Boyce and Cote (4) observe that these models "...cannot be verified in a strict sense because their formulation does not provide a confidence statement about the relationship between the observed and predicted values." They maintain that in order to verify point forecasts, which are the type usually made in urban studies, it is necessary to specify the distribution of error around the point forecast. Although verification procedures and data requirements are identified, they conclude that the verification procedures depend heavily on much more data than are currently available. These demanding data requirements have evidently reduced the priority of model verification in past and current studies.

It would appear that models that were applied in the past within planning studies and are still in use, would present an opportunity for the evaluation of such models within their respective study. Such evaluations, which might entail the comparison of the models past performance with present conditions, would be a valuable addition to any individual evaluation that a potential user may make. However, urban studies have not generally engaged in such evaluation exercises.

Some of the possible reasons for this situation are:

1. The data required for a test of the model may not be readily available at the present time.

2. Such a test requires an expenditure of resources which the planning staff or decision makers may see as being better used for immediate problems rather than for an "academic" test.

3. The model may have changed (i.e., improved) since the original application and may not even be available in its original form.

4. The new, revised model has already been applied and has produced future forecasts which are different from those provided by the "old" model. Therefore, the old forecasts have been superseded and are no longer being used.

5. The length of time that has elapsed since the model was first applied may not be long enough to make a fair appraisal of the model's performance.

6. Not many modeling advocates or those who have made a commitment to their use are anxious to focus on possible past deficiencies in the modeling process.

Although the state of practical knowledge and guidelines concerning the validity and accuracy of urban development models is somewhat limited, there are certain steps that the user of these models may take in order to provide a more reasonable forecast. First, the model should be judged logical (i.e., the model formulation must not include any inconsistent and irrelevant relationships). Next, the model should be calibrated, and if possible applied to see if it actually replicates the actual development. Finally, if time permits, various experimental runs or sensitivity tests should be undertaken. It is important to test not only the sensitivity of the forecasts of land use, but also the forecast of trips. Questions that usually arise relating to forecasts are of the kind, "How much error is acceptable?" Such questions could be answered in terms of how much of the model's projection of land used is affected by changes in inputs, and whether planners consider of the resulting variance to be significant. Changes in the level of parameters could also indicate the strength of a model's design.

CHAPTER VII

SELECTED URBAN DEVELOPMENT MODELS

A. EMPIRIC Activity Allocation Model

B. Projective Land Use Model

C. Urban Systems Model

D. Access and Land Development Model

E. Land Use Allocation Model

F. Land Use Plan Design Model

G. NBER Urban Simulation Model

H. Integrated Transportation and Land Use Models Package

EMPIRIC Activity Allocation Model

Background

The EMPIRIC model originated in 1963 when an urban development project was initiated for the Boston Regional Planning Project (later know as the Eastern Massachusetts Regional Planning Project). The project was created for the purpose of preparing a comprehensive development plan--elements of which included transportation planning and land use activity forecasting.

The Traffic Research Corporation (TRC, now Peat, Marwick, Mitchell & Co., (PMM) was contracted to develop a land use forecasting model that was sufficiently sensitive so as to permit the testing of alternative sets of public policies. As a result, TRC developed two prototype allocation models--EMPIRIC and POLIMETRIC--which they tested and evaluated with calibration data. The EMPIRIC model provided a number of advantages over POLIMETRIC and was, therefore, chosen for further development by the project.

After its application in Boston, EMPIRIC became one of the more popular urban development models. It has subsequently been applied in Southeastern Massachusetts, Washington, D.C., Minneapolis-St. Paul, Denver, Seattle, Atlanta, Winnipeg, and Toronto.

Description and Theory

The model is designed to perform three major functions, essentially similar to those of other activity allocation models such as "PLUM" and "USM". They are:

- To allocate regional projections of future population, employment and land use (subcategorized) between a set of smaller subregions or zones;
- To assess the probable impact of alternative regional planning policies on the future distribution of regional growth; and
- To provide a foundation for the evaluation and coordination of future policy decisions in a variety of different functional areas.

"Activities" are defined within the model as classified, small-area counts of households and employment stratified, for example by income, size or industry type, coupled with parallel estimates of land use acreages classified by type. Planning policies are expressed in terms of regional accessibility and opportunity measures derived from conventional highway and transit network analyses; water- and sewer-system service-areas; zoning, open-space and environmental/land conservation controls; the projected location of major development, and region-wide housing and employment location policies. The model is calibrated using small-area activity and policy data assembled for two separate points in time, usually approximately

10 years apart. It is then applied recursively to generate forecasts of the future distribution of activity for points 10, 20, 30, etc. years into the future, conditional upon the pursuit of specific regional planning policies.

EMPIRIC is essentially composed of a system of simultaneous linear regression (difference) equations which quantify relationships between the output (dependent) and causal (independent) variables. The simultaneous nature of the equations permit more than one dependent variable per equation. The equations are formed by hypothesizing relationships among activities and by applying statistical techniques to historical data. The final form of the model is calibrated (i.e., variables are specified and coefficients are estimated) using historical data for two points in time.

The theory on which the EMPIRIC model is based is quite simple. Bascially, it recognizes: (1) that the location of different activities are interrelated; and (2) that the location of these activities is affected by public policies, facilities and services. Quantification of the relationships between activities and locational influence is based on the statistical analysis of changes in activities over time (differences between data from two points in time are compared). Whether or not a certain locational influence (variable) is used in the final scheme of equations is determined essentially by the contribution it makes in explaining the past changes in activity levels or land use as measured by statistical analysis.

Model Structure

An EMPIRIC model is developed by combining the individual programs into a chain that is built around four major components or "modules" which define integrated functions within the model. Figure 3 illustrates how these modules are linked together in a forecast chain. These four modeules are:

Module 1 - Simultaneous Equation Module;

Module 2 - Land Consumption Module;

Module 3 - Supplementary Sub-Models; and

Module 4 - Forecast Monitoring Module.

The Simultaneous Equation Module forms the heart of the model. It consists of a set of simultaneous equations relating changes over time in the sub-regional distribution of population and employment one to the other, to their original distribution in a given base year and to the effects of specific planning policies implemented over a specified forecast interval.

The module is calibrated using data on the sub-regional distribution of activity developed for two separate points in time, usually approximately ten years apart, together with parallel information on the imple-

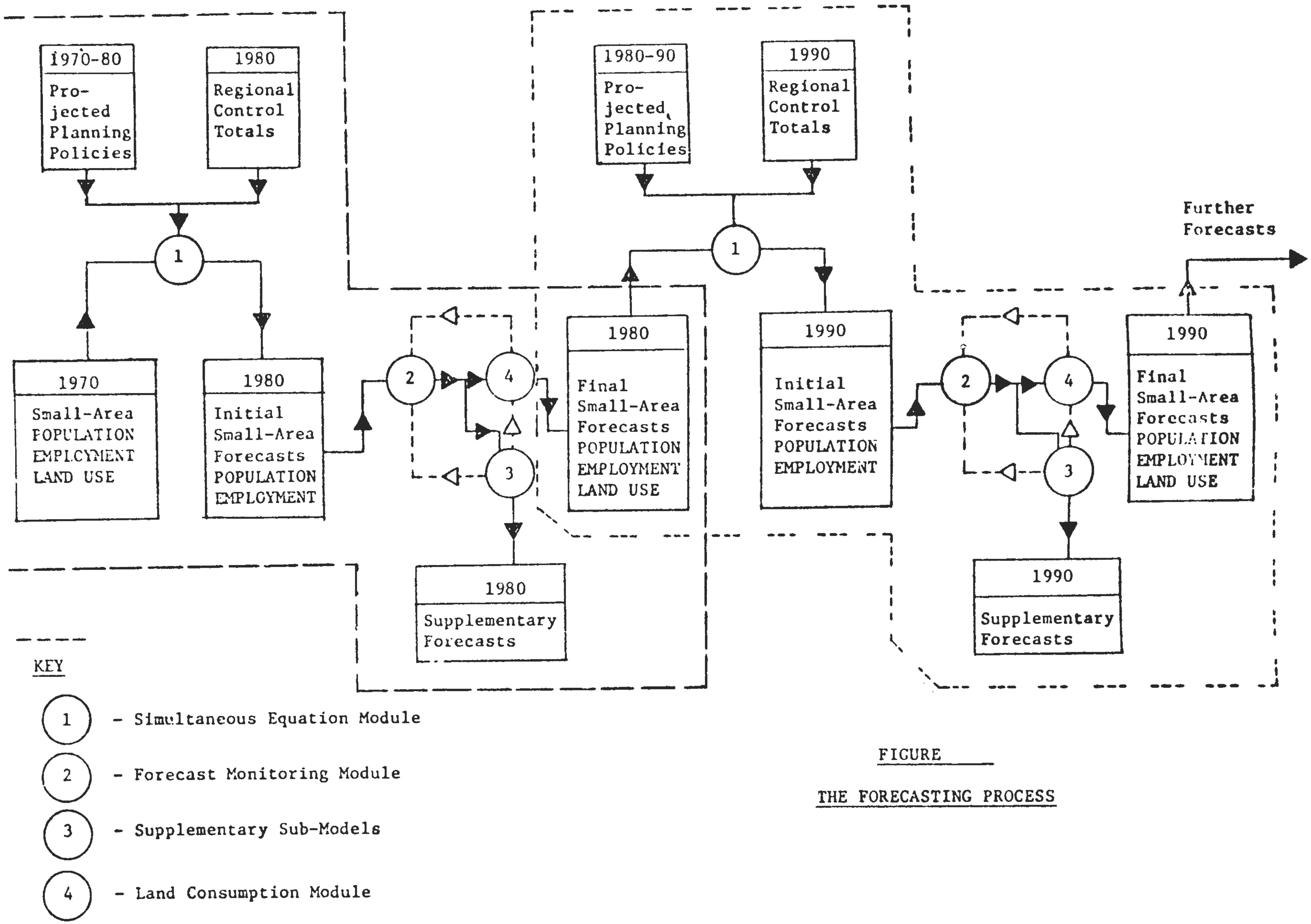


FIGURE 3 STRUCTURE OF "EMPIRIC" MODEL

(Extracted From Reference 4, Page 35)

mentation of selected planning policies over that period. It is then applied recursively to generate forecasts of the future distribution of "activity" by solving the set of equations successively for each individual sub-region and each successive forecast interval.

All variables are typically expressed as sub-regional "shares" of "changes-in-share" of a regional total. Population estimates are typically expressed as sub-regional counts of households, broken down by type and income level. Employment variables are similarly expressed as sub-regional counts of employees by place-of-work, broken down by type of industry. Policy variables are typically expressed as projected future levels of transportation or utility service and the availability of vacant land for development.

The <u>Land Consumption Module</u> translates the set of initial activity forecasts generated by the first module into equivalent changes in sub-regional land use at the end of each successive forecast interval.

This module, again, is calibrated using data from two points in time, corresponding to those used in the calibration of the simultaneous equation module. It accepts as input, in addition to the projected changes in sub-regional activity, a statement of the base-year distribution of land use acreages within each sub-region at the start of the forecast interval, together with a set of permissible development densities and an estimate of the land area available in each sub-region for specified types of development. Its output is a simple, updated accounting of the status of land use development within each sub-region at the end of each successive forecast interval.

The third module consists of a set of <u>Supplementary Sub-Models</u> designed to supplement the initial set of projections generated by the first two modules. The structure of these sub-models may vary considerably at the option of the analyst. They are typically designed to build directly on the outputs of the first two modules to generate estimates of sub-regional population broken down by age, households broken down by size, average automobile ownership, etc. They may be based on data assembled for either one or two points in time.

The fourth and final <u>Forecast Monitoring Module</u> consists of a series of "monitoring" routines which permit the analyst to impose exogenous constraints upon the forecasting process. These constraints may be of several different types, ranging from pre-specified minimum and maximum levels of activity in any sub-region, to limitations on the use of land within particular sub-regions or isolated variations in permissible development densities.

These four modules are supplemented by a family of data assembly and statistical analysis programs which are used to support the process of model calibration and application.

Inputs and Outputs

EMPIRIC requires the development of a comprehensive, small-area dataset for two points in time for use in calibration. The model also requires regional forecasts of allocated activities (population and employment), and specific policy inputs, by small-area, for each forecast policy alternative. Common policy inputs are the transportation system, land development controls, and public utilities.

The full set of data inputs required for model calibration and one single chain of forecasts are summarized schematically in Figures 4 and 5. A typical set of model outputs are summarized in Figure 6.

Calibration

The calibration of the model, in simple terms, entails the determination of the coefficients for the dependent variables in the equations, using known data from two points in time. In actual practice there is a considerable amount of statistical analysis required to determine which variables should be retained and what the final form of the equations should be. Sometimes the basic data base must be altered or certain data items need to be recategorized or corrected.

Those familiar with developing regression equations will appreciate the type of work involved with the use of tens of equations and hundreds of variables. There are various options or programs within EMPIRIC to accomplish these tasks.

A step-wise regression procedure is available in EMPIRIC which produces statistics for each equation and each variable in the equation. The step-wise procedure first selects the single independent variable with the highest correlation with the dependent variable, then successively adds additional variables until all variables are exhausted or a control is reached. Some of the statistics which are available and can be used in evaluating the equations and variables are: standard error; multiple correlation squared; unbiased multiple correlation; t value; residuals; and the Von Newman statistic.

There is also an ordinary least squares regression option which can be used to develop preliminary relationships. A two stage least squares regression is available for developing the final relationships.

For analysis and evaluation purposes, a factor analysis program (FACTOR) and a program to check reliability (RELIAB) are available.

Forecasting

The forecasted future activity levels for each sub-region are derived from the solution of the set of simultaneous equations used in the final calibrated model. The equations do not directly yield activity levels, but computed changes in the shares of the activity level for each sub-

	CALIBRATION INPUTS		FORECASTING INPUTS FOR ONE POLICY SCENARIO			
	YEAR		YEAR			
	1960	1970	1970	1980	1990	2000
<u>INTERNAL ACTIVITY DATA</u>						
. Demographic	●	●	●			
. Employment	●	●	●			
. Land Use	●	●	●			
<u>EXTERNAL ACTIVITY DATA</u>						
. Demographic	●		●	●	●	
. Employment	●		●	●	●	
<u>POLICY DATA</u>						
. "Direct" Policy Variables (e.g., Transportation, Utilities, Developable Land, Nominal Development Densities, etc.)	●	●	●	●	●	●
. "Indirect" Policy Variables (e.g., Development Controls, Density Overrides, Conservation and Open-Space, Land Suitability, Major Developments, Fair-Share Housing, etc.)			●	●	●	●
<u>REGIONAL ACTIVITY FORECASTS</u>						
. Demographic				●	●	●
. Employment				●	●	●

FIGURE 4 TYPICAL SET OF DATA INPUTS FOR "EMPIRIC" ACTIVITY ALLOCATION MODEL

(Extracted From Reference 4, p. 47)

A) INTERNAL ACTIVITY DATA

1) DEMOGRAPHIC INPUTS
(All data required at District Level for 1960 and 1970)

- No. Families in Households x Income Category (3-6 classes)
- No. Unrelated Individual Households
- No. Households x Size (4-8 classes)
- No. Households x No. of Workers (2-4 classes)
- No. Households x Race (2-3 classes)
- No. Households x Auto Availability (2-4 classes)
- Population in Households x Age (6-8 classes)
- Population in Group Quarters
- No. Households x Housing Unit Type (2-4 classes)

2) EMPLOYMENT INPUTS
(All Data required at District Level for 1960 and 1970)

- No. Employees at Place of Work x Industry (4-8 classes)
- No. Employees at Place of Work x Land Use (4-8 classes)

3) LAND-USE INPUTS
(All Data required at District Level for 1960 and 1970)

- Land-Use Acreages x Use (4-8 classes)
- Area of Developable Vacant Land
- Area of Undevelopable Land
- Total Area

B) EXTERNAL ACTIVITY DATA
(All Data required for each external district for 1960, 1970, 1980, and 1990)

- Total Households
- Total Employment

C) POLICY DATA

1) 'DIRECT' POLICY INPUTS
(Transportation Data required for all Internal and External Districts; All Other Data required for Internal Districts only. All data required for years 1960, 1970, 1980, 1990 and 2000)

- Transportation, a) Highway - District-Level Travel Time Matrices x Trip Length Distribution
  b) Transit - District-Level Travel Time Matrices x Trip Length Distribution
- Water Service - Area Served
- Sewer Service - Area Served

2) 'INDIRECT' POLICY INPUTS
(Data required for Appropriate Activity/District Combinations only for selected years 1970, 1980, 1990, 2000)

- Modifications to Nominal Development Densities
- Developable Land Withholdings
- Release of Land Previously Unsuitable for Development
- Size of Major Developments, Renewal and Redevelopment Projects
- Activity-Balance Requirements
- 'Fair-Share' Housing Requirements
- Minimum and/or Maximum Activity Levels

D) REGIONAL ACTIVITY FORECASTS
(Data required for Internal Study-Area only for 1980, 1990, and 2000)

- Regional Total Families in Households
- Regional Total Unrelated Individual Households
- Regional Total Employment x Industry (4-8 classes)
- Regional Total Group Quarters Population
- Regional Total Population x Age (6-8 classes)

FIGURE 5 ILLUSTRATIVE DATA INPUTS FOR CALIBRATION AND FORECASTING

(Extracted From Reference 4, Page 50)

(n.b.: Policy Inputs based on one Policy Scenario for the Years 1970-80, 1980-90, 1990-2000)

- TOTAL NO. OF HOUSEHOLDS
- NO. OF FAMILIES IN HOUSEHOLDS x INCOME
  (3-5 classes)
- NO. OF UNRELATED INDIVIDUAL HOUSEHOLDS (URI)
  (1 class)
- GROUP QUARTERS POPULATION
  (1 class)
- NO. OF HOUSEHOLDS x SIZE
  (3-8 classes)
- NO. OF HOUSEHOLDS x NO. OF WORKERS
  (2-4 classes)
- POPULATION IN HOUSEHOLDS x AGE
  (6-8 classes)
- NO. OF HOUSEHOLDS x HOUSING UNIT TYPE
  (3-4 classes)
- POPULATION IN HOUSEHOLDS x RACE
  (2 classes)
- NO. OF EMPLOYEES AT PLACE OF WORK x INDUSTRY
  (2-8 classes)
- LAND USE ACREAGES x TYPE OF USE
  (6-10 classes)

NOTE: ALL OUTPUTS PREPARED FOR EACH DISTRICT AND EACH FORECAST YEAR

FIGURE 6 TYPICAL EMPIRIC MODEL OUTPUTS

(Extracted From Reference 4, Page 13)

region. The changes in shares are then added to base year shares for that sub-region and activity. These new shares are multiplied by the exogenously forecasted regional totals for each activity to produce an absolute sub-regional activity level (e.g., the number of households and employees in a sub-region).

The equations are of the following form: The dependent variable on the left hand side of the equation is a measure of the change-in-share of an activity level. The independent variables on the right hand side of the equation may include concurrent change-in-share dependent variables from other equations and also other variables which represent various land use and accessibility characteristics, some of which are classified as "policy variables" since they are to some degree under the control of a government unit. Examples of these are: highway and transit accessibilities; public open space; zoning restrictions; and public utilities service such as water and sewerage.

Land use considerations were limited in the early EMPIRIC applications, although various studies used simple procedures to convert forecast activity changes into equivalent acres of land use changes. In later applications of the model a land consumption program (designated LU) was added to handle some of the land use accounting tasks.

It is possible for a study to develop two (or more) versions of the EMPIRIC model--one being an extensive, fine-grain version and the other a simplified, aggregated version. The former is the "full" and final forecasting tool which contains up to the maximum number of dependent variables and analysis zones. The latter usually uses aggregated sub-regions and deals with a smaller number of dependent variables in simplified equations. This simple version is usually used to make a rough evaluation of potential alternatives so as to limit the number of alternatives used with the "full" model. The simple model provides for faster, more economical testing and allows for the initial consideration of more alternatives.

The Boston project used two versions of the EMPIRIC model (as did Washington, D.C.). The first was the "full" operating model which forecasted nine activities for each of the 626 traffic zones comprising the region. The nine activities consisted of four categories of population (number of families) by income and five categories of employment by industry group.

These EMPIRIC forecasts were then used in single equation submodels (external to EMPIRIC) to forecast four other activities by zone: total population; automobile ownership; and two categories of school enrollment.

The second model used by the project forecasted three activities (total population, manufacturing employment, and nonmanufacturing employment) for 97 sub-regions which were aggregations of the 626 traffic zones. Four alternative plans were tested using this simpler model and, after analysis of the results, two of the four plans were selected for further testing and analysis with the full 626 zone model.

Capabilities and Characteristics

Policy inputs to EMPIRIC must be defined by some quantifiable measure, and may be expressed in basically two ways: 1) as variables incorporated within the main model structure, such as accessibility; 2) as some exogenously specified analysis area constraint or activity level. An example of the first case, accessibility, depends on transportation system improvements as reflected in changes in interzonal traveltimes. Another variable could be a measure of an analysis area level of a public service such as water and sewerage. In such a case, the level of the service would need to be defined for both the calibration points in time and also for each forecast year.

The second situation, the use of exogenous constraints, would commonly be used for representing land use controls, housing policies, and unique developments. Either a maximum/minimum constraint is applied to an analysis area activity level, or a specific level is applied for a particular point in time. In the case of low-income housing, for example, a minimum level might be set for the number of low-income families in a zone. Land use/zoning controls might be represented by a zonal limit on land consumption for a particular land use category. The EMPIRIC program, MONITO, is designed to impose activity level constraints to an analysis area and to automatically reallocate excess levels of activities.

The sensitivity of the model to policy inputs depends on whether they are the "variable" or "constraint" type. If expressed in term of an equation variable, the sensitivity to these policies is dependent upon the form of the equation structure and the significance of the variable within the equation.

EMPIRIC normally uses small-area geographical units which are sometimes referred to as districts or analysis zones. These districts are sometimes larger than the traditional traffic zone because of the need to reduce the number of analysis units or the problems of small-area abberations and calibration inaccuracies. Larger size districts tend to produce more accurate and more reliable model forecasts, but they also require the use of some type of zonal disaggregation procedure if the models' output is to be used on a smaller zonal basis. The Washington, D.C. study, for example, developed a Zonal Allocation Procedure (ZAP) which was designed to produce forecast year values by zone, specifically for the creation of zonal level work-trip tables. The process basically makes a distribution of households and employment based upon zonal percentages of suitable land available as determined from the Master Plan.

The transferability of the EMPIRIC model is generally limited to concepts, basic model structures, and adaptable technical procedures. Since each model must be devoloped to meet an individual study's output requirements and data availability, there is not much direct transfer of equation form and program linkage between different applications.

Software and Documentation

The EMPIRIC model consists of a series of 17 computer programs which are primarily written in FORTRAN, but require other assembly language subroutines, one of which is used for dynamic core allocation. Consequently, in its present form, the software is limited to use with the IBM 360/OS or equivalent system. The programs and documentation are in the public domain and are available from the Federal Highway Administration among other sources. Documentation for EMPIRIC which has been maintained by the prime consultant, PMM, was revised for FHWA in 1973-74 and included a series of illustrative applications for the individual programs. In early 1974, FHWA began distribution of the revised software package ("EMPIRIC Package") and the EMPIRIC Users' Manual.

Resource Requirements

Experience with the development and application of the model in a number of different metropolitan areas has indicated that a minimum of between 9 and 12 months is required for successful development and application of the model. By far the largest proportion of this time is required for data assembly activities. These typically consume at least 6 to 12 man-months of professional time together with up to 1-½ to 2 times that amount of technical support. Model calibration, depending upon the detailed structure of the models to be calibrated, typically consumes approximately three months and involves some 4 to 6 man-months of professional time. Creation of a single set of forecasts for three separate forecast-years requires between 1 ½ to 2 months for each "policy scenario" to be tested including 2 to 3 man-months of professional time and approximately the same amount of technical support. Computer requirements generally range between 15 to 25 hours of IBM S/360 (Model 65) time or its equivalent. Costs for technical assistance in an average application would approximate $75,000 or more. These latter requirements are only generally estimates which may vary considerably for a particular application.

Evaluation

EMPIRIC is one of the most widely used of the major urban development models. It is essentially a statistically based econometric model of urban change. It does not depend on a single, well-defined theory of urban development, but rather relies on some very general hypotheses concerning the processes underlying urban growth which are implicit in the statistical approach. By standard econometric techniques (regression, et. al.) it identifies the major factors influencing past development and extrapolates these into the future. The "trend-based" approach of the model is commonly recognized. One resulting problem is the difficulty in representing a situation that is not supported by adequate historical data. Also, the lack of a strong theoretical structure is one of its main weaknesses.

Examination of EMPIRIC reveals that in many ways it is more a package of techniques for model building rather than a model itself. This provides for some its flexibility.

The form of the equations used in EMPIRIC, a linear combination of varaibles, accounts for certain limitations regarding land use, such as the inability to constrain the solution of the equations so as to prevent an allocation of activities which result in the overdevelopment of a sub-region. Normally, land use considerations such as holding capacities, reallocation and land consumption are dealt with after the solution of the equations by means of special purpose EMPIRIC programs such as MONITO and LU. However, in most such models the land use accounting is accomplished in the latter stages of operations.

The lack of a strong, unique theoretical foundation, such as that found in PLUM or USM, places a heavy burden on the ability of the analyst to develop his own conceptual structure and to translate into a set of meaningful, valid statistical relationships. The effective calibration and application of EMPIRIC require a significant degree of familiarity with both the development process, and particularly with the fundamental principles of econometric techniques. The model can very easily be misapplied. Any application of EMPIRIC by a planning agency should include a significant amount of staff training.

The data requirements for the model are normally extensive and demanding in quality. As with most modeling efforts, a large portion of the allocated resources should be allowed for data requirements. For calibration purposes, historical data is required for two points in time, and certain data items are needed for each forecast year. Unlike PLUM and USM, however, the model does not require estimates of future small-area distributions of "basic" or "primary" employment.

PROJECTIVE LAND USE MODEL (PLUM)

Background

The emergence of PLUM as an operational planning model at the Bay Area Transportation Study Commission (BATSC) is just one item in a continuous sequence of developmental activities beginning several years before the BATSC experience and still underway at San Diego, California.

The developmental process of PLUM including its antecedent models and the current version of the model (NPLUM) illustrate the incremental growth pattern of PLUM expanding from one version to the next while continuously retaining complete operational capability as an urban development model.

The path of development leading to the present version of NPLUM is relatively short. The fundamental innovative product grew out of the trail-blazing work of Ira S. Lowry for the Community Renewal Program at Pittsburgh, Pennsylvania during 1963 (1). Subsequent revisions of his approach were made in 1964 by CONSAD Research Corporation personnel and incorporated into the overall Pittsburgh Urban Renewal Simulation Model (2).

In the meantime, a group of scholars at the University of California's Center for Real Estate and Urban Economics (CREUE) were reviewing current activity in the field of urban development modeling. In 1964, this group decided to develop and implement a Lowry-type model.

The initial attempt at modeling, named BASS (Bay Area Simulation Study), was a pilot study by William Goldner and Ronald S. Graybeal for the county of Santa Clara (3).

The Bay Area Transportation Study was underway by this time, and the plans for its extensive 9-county data coverage were coordinated with plans to expand the CREUE pilot study model geographically. This expanded version became BASS I.

The final design version of BASS I was fixed in March 1966, and steps to program the model with a meaningful number of modifications were initiated. As the CREUE work program solidified, it became apparent that experimental modifications would more easily be developed on a separate model which retained the BASS acronym. The original pilot model with more emphasis on immediate operationality, led to the development of PLUM. And, perhaps most important, the BATSC effort provided much of the data required by PLUM.

For BATSC, PLUM was run in two stages to produce a forecast of regional development for the period 1965-1980 and then for the period

1980-1990. This forecasting process provided valuable experience in linking comprehensive planning with traditional transportation analysis. In 1969 the Federal Highway Administration contracted with Dr. Goldner, Univ. of California, to modify, reprogram, and document PLUM in order to facilitate its use by other urban studies (4).

During 1971, PLUM was used to study the economic and spatial impacts of alternative airport sizes and locations in the San Francisco Bay Region. This study was one segment of a comprehensive planning effort conducted for the Regional Airport Systems Study Committee (RASSC) and conducted by the Institute of Transportation and Traffic Engineering (ITTE) at the University of California, Berkeley.

In the RASSC study, PLUM was used for the first time to evaluate the developmental impact of a set of alternative locational policies. Also, for the first time, income and tax projections were developed to supplement the basic employment, population, and land use variables, and the initial formulation and application of attractiveness factors as a key refinement of the model's residential and shopping allocation functions (which previously consider only travel time as the relevant variable) was accomplished (5).

ITTE and the San Diego County's Comprehensive Planning Organization in a joint effort applied the PLUM model in the San Diego Region (6). The joint effort constituted the third stage of PLUM's development in which a set of refinements enlarged the model concept even further and the model was referred to as PLUM/SD. In August 1973, operational revisions were made in PLUM/SD in response to conceptual changes that were tested with new data in a more rigorous fashion, and with local knowledge and judgment providing significant input. After these revisions, the model was referred to as "NEW PLUM" and was used to generate and test San Diego's alternative transportation and land use plans for the year 1995.

It is evident that others will take "NEW PLUM" from San Diego and will continue to improve on the model or revise it to suit their area or needs. Example: "PLUM 74" by the Association of Bay Area Governments with its own improvements and those of San Diego.

The San Diego CPO supplied FHWA with computer programs for "NEW PLUM", documentation and revisions to PLUM/SD in October, 1973. FHWA made minor changes to "NEW PLUM" in order that it be included in the FHWA Battery as "NPLUM" to replace the March 1972 Version of PLUM. FHWA has revised portions of the PLUM/SD documentation to incorporate the "NPLUM" Capabilities, however, other portions of the documentation remain to be updated. The "NEW PLUM" Version was taken by Baltimore, Maryland and the program was internally documented with a large number of comment cards but with no significant modification. The Association of Bay Area Governments (ABAG) has made modifications and reprogramed "NEW PLUM" for the CDC Computer and they refer to this version as "PLUM 74." The FHWA supplied a copy of NPLUM to Dayton, Ohio. Dayton modified NPLUM to enhance model calibration, and to make it possible to run NPLUM without local-serving employment disaggregation. The Dayton version is called "PLUM-MG".

Model Description

The best detailed descriptions of the model are provided by references (4) and (6). "PLUM" is designed to yield projections of the future small-area (i.e., zone level) distribution of population, employment and land use within an urban area based upon information on the distribution of these characteristics in some base-year, coupled with a series of simple and intuitively appealing allocation algorithms. In the PLUM/SD, NEWPLUM, PLUM74, and NPLUM versions, allocation incorporates auto and transit modes separately, and disaggregated local-serving categories allocated by differing processes.

The allocation algorithms are based upon two fundamental concepts. The first of these relates to a distinction between "basic" and "local-serving" employment, and the second employs the notion of an "allocation function." Both concepts are derived directly from the original Lowry model (1).

"Local-serving" employment is that for which a local market or service area may be identified based upon the location of the households which it is intended to serve. Typical examples might include retail stores, schools, and the bulk of local government activities. "Basic" employment includes all other employment activities - that is, all that employment whose location is relatively less dependent upon the precise location of households within the urban region but rather on other factors such as proximity to transportation facilities or space availability.

"Basic" employment is located exogenously prior to the operation of "PLUM". A series of three spatial allocation functions are then used to distribute the remaining "local-serving" employment and households around these "basic" employment centers. This process proceeds in three steps(7):

1) An initial set of <u>households associated with persons employed in "basic" employment activities</u> is distributed with respect to the exogenously specified locations of "basic" employment;

2) <u>"Local-serving"</u> employment is then distributed with respect both to this initial distribution of households and to the previously specified locations of "basic" employment; and

3) Finally, a second set of households associated with persons employed in "local-serving" employment activities are distributed around those latter employment locations.

The allocations in each case are based upon descriptions of the spatial relationships between the activities involved, based primarily on existing, base-year tripmaking behavior and forecast year transportation networks. Empirical evidence suggests that trip frequency by traveltime conforms closely to a distribution similar in nature to the log-normal. In figure 7, a plot of traveltime frequencies from the San Diego O & D survey shows a close resemblance to the log-normal distribution. For this reason, the log-normal distribution is used as the probability function. Its shape indicates the desired property of decreasing trip frequency with increasing traveltime. The calculation of trip probabilities is based upon two parameters: the mode (β) of the distribution of trips by time, and the standard deviation (S) of the logs of the distribution. Figure 8 illustrates curves corresponding to various S's for 9 minutes. These figures also include the curve of the probability function used by PLUM/SD (the reciprocal log transformation function) corresponding to the appropriate B-value (8).

The allocation of employees from place-of-work to residence is dependent upon the probability of each zone in the study area receiving employees from a given zone of origin. This probability is dependent upon accessibility and opportunities. Accessibility is determined by converting traveltime to probabilities using the probability function. Final determination of the allocation probability is achieved when opportunities are considered. The home-to-shop and work-to-shop allocations are handled in essentially the same way as the work-to-home, and have as their purpose the generation of local serving employment at place-of-work.

For any given target year, the model iterates to a single forecast, based upon the achievement of balance between the projected exogenously specified location of basic employment and the resultant distribution of local-serving employment and the set of households associated with both employment categories. These allocations are subjected to a set of constraints, including an upper bound capacity constraint for households within each zone, and a set of land-consumption constraints reflecting the manner in which vacant land is consumed by development. The result is a final, internally-consistent set of projections of employment, population and land use by small-area for a given target year. For purposes of forecasting over a series of time intervals the model is applied recursively, with the outputs for each forecast year serving as the base for the next set of forecasts. The outputs of the model include basic estimates of zonal-level households, population, "local-serving" employment and land use for each forecast year along the path of development.

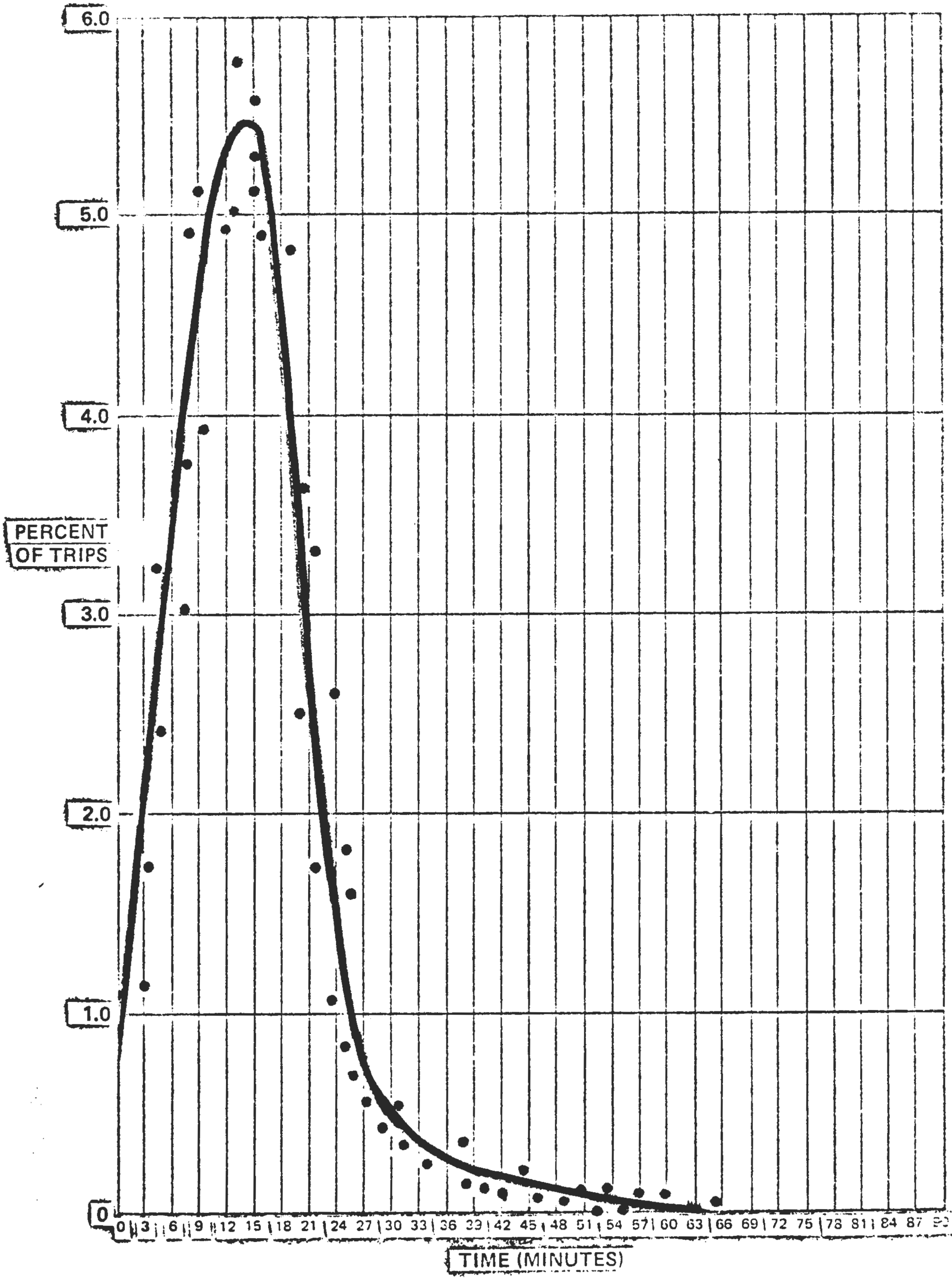


Figure 7 DISTRIBUTION OF TRIPS BY TRAVEL TIME
WORK–TO–OTHER TRIP TYPE, MAJOR STATISTICAL AREA NO. 1
SAN DIEGO, COUNTY (Extracted From Reference 8)

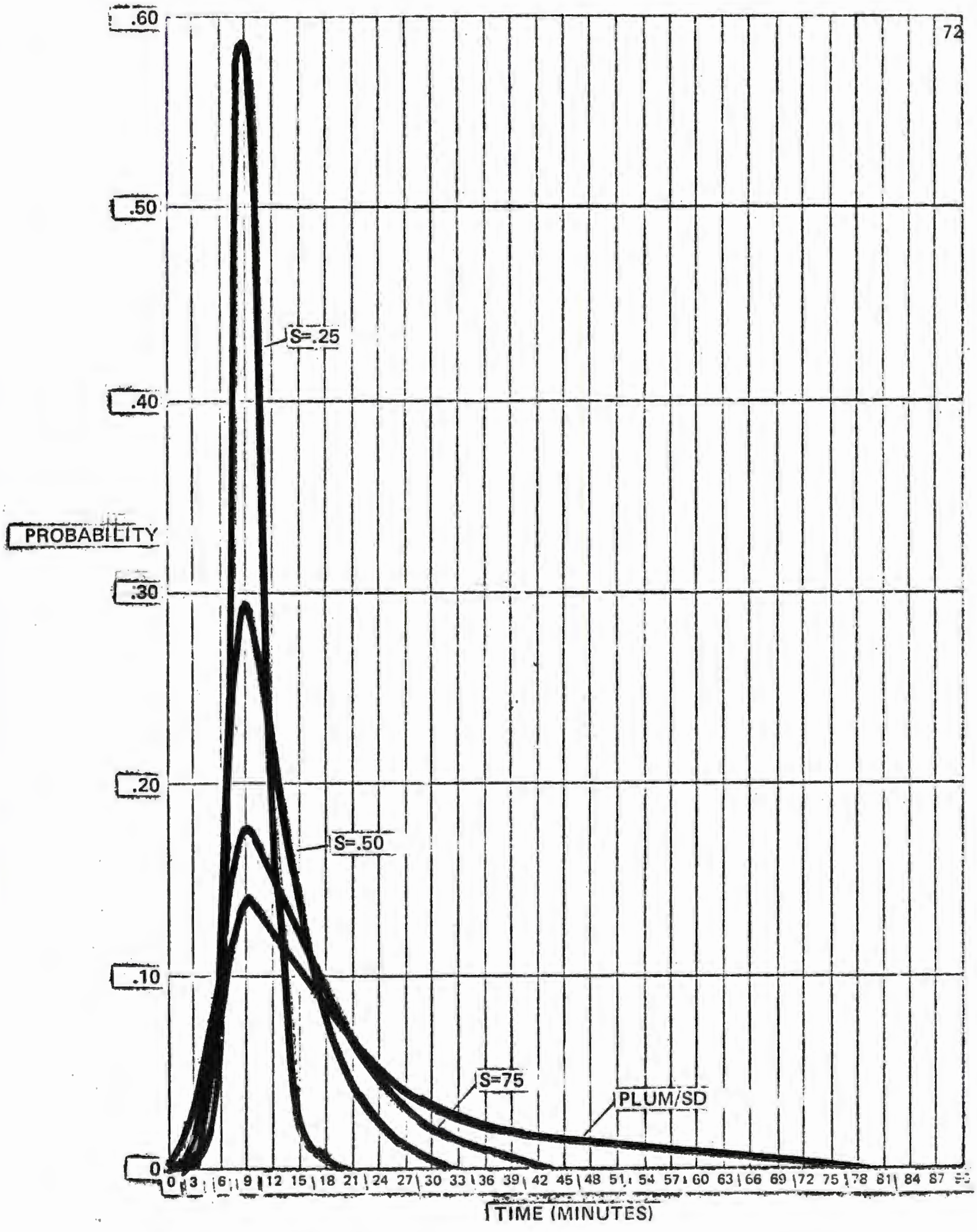


Figure 8 LOG–NORMAL AND PLUM/SD PROBABILITY FUNCTIONS (MODE = 9 MINUTES).
(Extracted From Reference 8)

Program Organization

The PLUM Program is written totally in FORTRAN and is very large (around 3000 FORTRAN cards) with substantial data storage requirements, depending primarily on the size of the system. The program is divided into five separate phases. The phase (0), "Program Initiation", uses base-year land use file, population, and employment data, etc. Projection area ratios and coefficients are calculated from the data, as are various control totals.

The Phase (1), "Initial Allocations", deals with the basic allocation function and calculates "work-to-home" allocation probabilities and others. Pre-emptive land changes required to satisfy basic employment changes, and major road construction programs are first satisfied. Basic employees are allocated to residential locations. They are then converted to residential population to provide indicators of residential market potential for incremental local-serving employment. Local-serving employment is then allocated to projection areas based upon demand factors from places of residence and places of work.

Phase (2), "Revised Allocations of Incremental Employment", calculates the ratios for residential land absorption and the employed residents per household. Initial increments of employed residents are calculated for each travel mode. Mode-specific reallocation pools are forned. The consumption of vacant served, and vacant unserved residential land is itemized.

Phase (3), "Reallocations and Increments". New residential locations for the pools of transit-using and auto-using employees to be reallocated are treated separately. The reallocations are first based upon proximity to the original residential locations and then upon the availability of vacant served and unserved residential land. During this phase printed summaries of all reallocations are prepared and finalized incremental projection area data are listed. Also, a summary of mode-split (work and home trip ends) is output.

Phase (4), "Projections". Estimates mean incomes for the projection year. Projection year values, base-year plus increments, for the assorted activity and land use variables are calculated. The projected usage of land is reconciled with each area's gross land area. Street and highway acreages are estimated. An output land use file is generated and finalized projections are listed.

Input Requirements

The data input requirements of the model are described in Reference 4. The input requirements include detailed, small-area population, employment and land use data assembled for a given base year, together with information for auto and transit networks on base-year inter-zonal travel times, projected increases in small-area "basic" employment levels for each forecast-year, inter-zonal travel time matrices for each forecast-year, and regional population and employment control totals for each forecast-year. In addition, if externally determined constraints are to be imposed upon the use of particular areas of land within the forecasting process, these need to be identified in advance.

The inputs to PLUM can be classified into four categories or files: (1) inventory, (2) target year control totals, (3) policy-related inputs, and (4) times file.

The base year inventory is a demographic, economic, and land use profile of each zone for which allocations are to be made. There are 27 specific "variables" which must be specified for each zone. These include:

1. Occupied housing units
2. Single family housing units
3. Multiple family housing units
4. Total population
5. Household population
6. Group quarters population
7. Employees at place of residence
8. Total employment
9. Basic employment
10. Retail employment
11. Business service employment
12. Retail service employment
13. Education-related employment
14. Other employment
15. Households by income category
16. Average housing value
17. Total land area
18. Unusable acreage
19. Net residential acreage
20. Acreage used for basic employment
21. Acreage used for local-serving employment
22. Acreage used for streets and highways
23. Acreage vacant and available for development, industrial
24. Acreage vacant and available for development, other than industrial, served by infrastructure
25. Acreage vacant not served by infrastructure
26. Fraction of employees using transit
27. Fraction of employed residents using transit

Target year control totals, reflecting total regional growth, must be specified for several variables. The control totals for the target year include:

1. Total Population
2. Occupied housing units

3. Retail employment
4. Retail service employment
5. Business service employment
6. Education employment
7. Other employment

The primary function of the model is to simulate urban development under different policies. Therefore, the most important inputs are those that represent local or regional development policies. It is through these policy-related inputs that the model is able to supply the policymaker with the likely impacts of various policies before the policies are actually implemented.

There are five types of policy-related inputs which may be quantified to represent alternative policies in the following areas:

1. Transportation
2. Industrial Location
3. Densities
4. Constraints on land use
5. Provision of urban services

The times file is an N x N matrix of the travel times, in minutes, from every zone to every other zone in the system. Depending on the option taken in a particular PLUM run, a transit set and an auto set of times are needed for a modal split run.

Model Outputs

The output or product of PLUM is a demographic, economic, and land use profile of each zone for the forecast year. The general set of inputs and outputs are shown in figures 9 and 10. The basic set of outputs are:

1. Tot. Housing Units
2. Tot. Res. Pop.
3. Group Quarters Pop.
4. Tot. Number of Employed Residents
5. Tot. Non-Working Pop.
6. Tot. employment
7. "Basic" employment
8. "Local-serving" employment
9. Total population
10. Total land area
11. Unusable acreage
12. Acreage used for streets and highways
13. Acreage used for basic employment
14. Acreage used for local-serving employment
15. Net residential acreage
16. Acreage vac. and avail. for industrial development
17. Acreage of other vacant land

These basic outputs may, if desired, be further broken down to provide estimates comparable with the list of input variables.

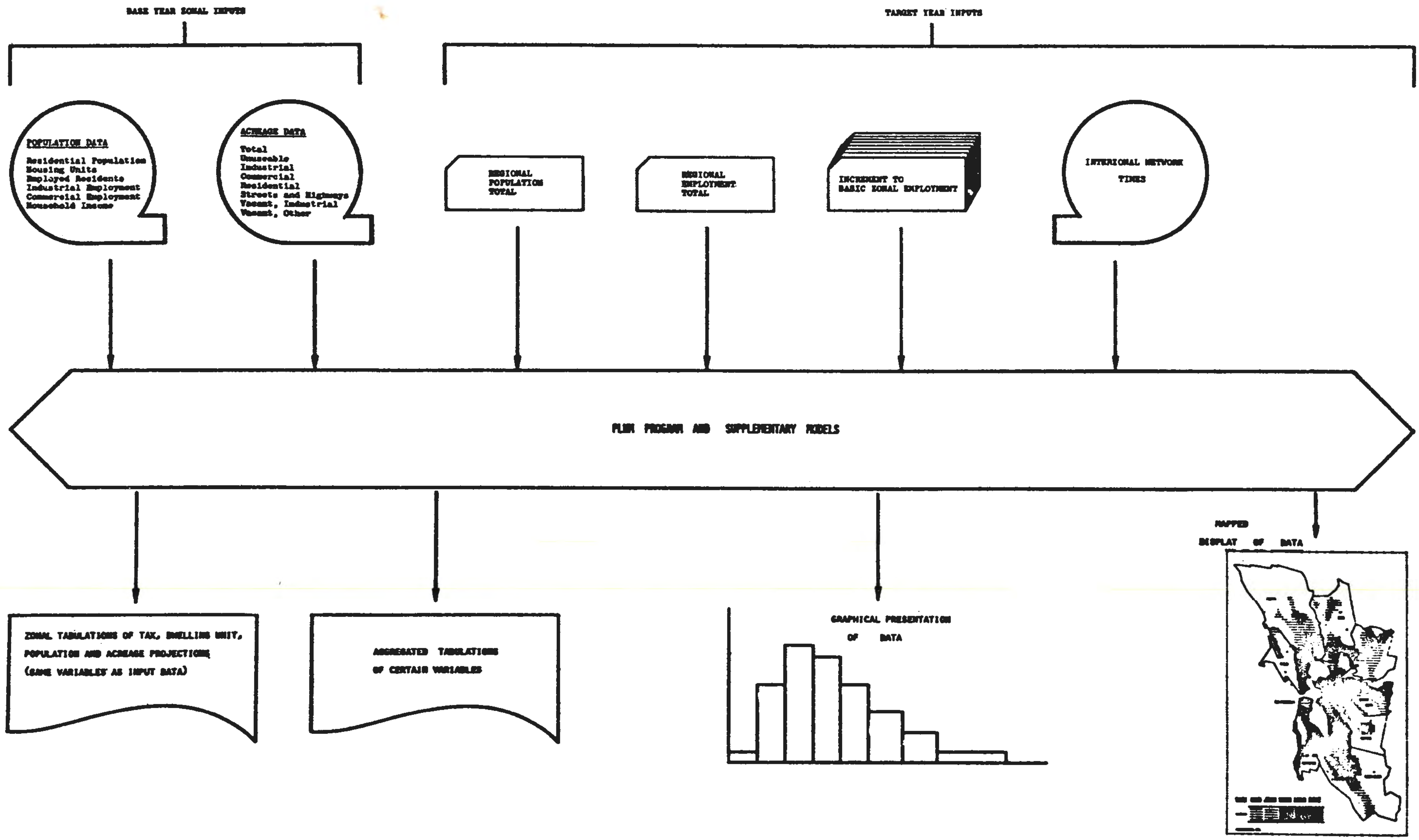


Figure 9 PLUM Input Requirements and Output Capabilities
(Extracted From Reference 4; Vol. I, page 40)

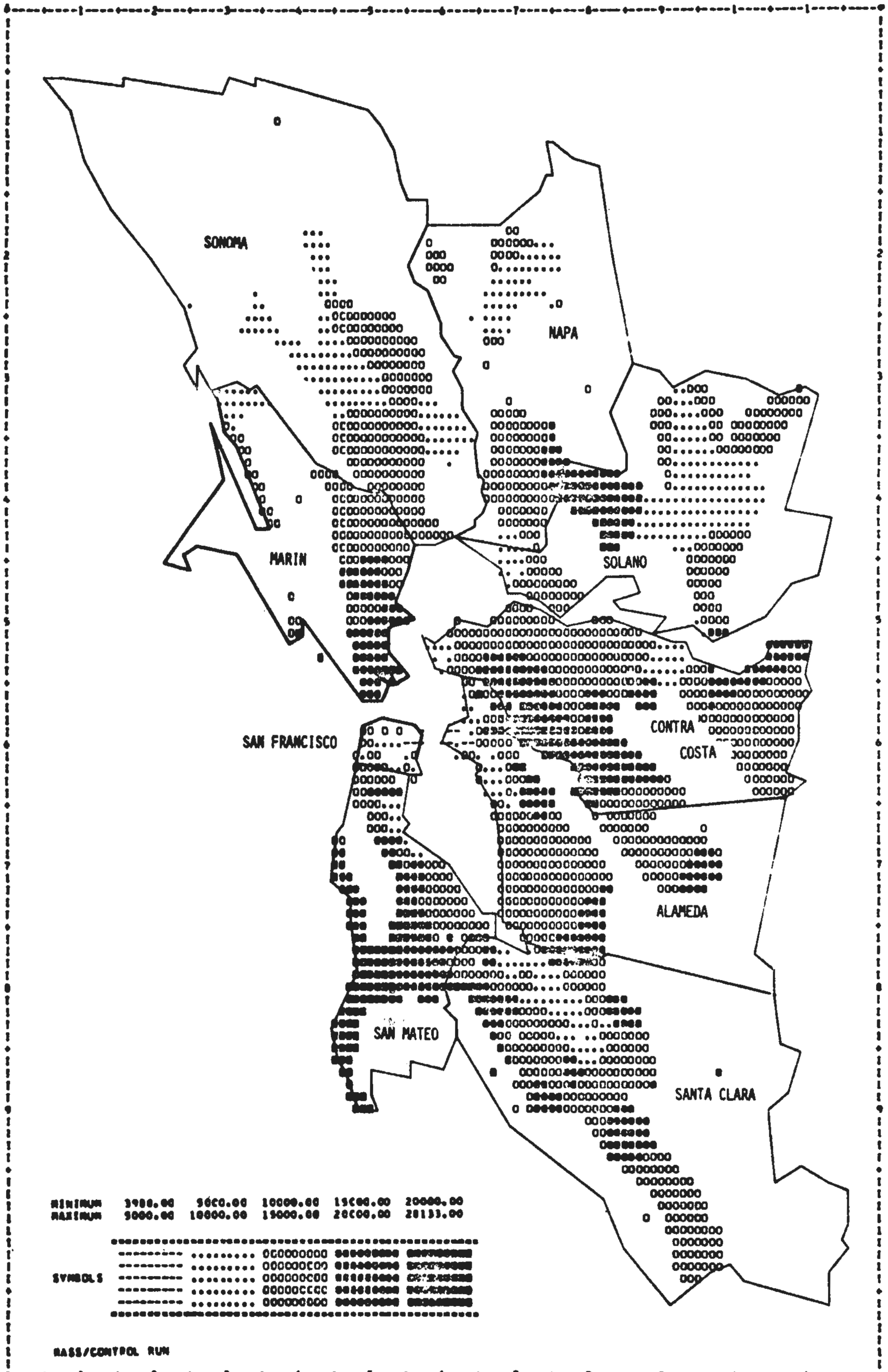


Figure 10 Sample Graphic Display of PLUM Projections.
(Extracted From Reference 4, Volume I, page 63)

Several methods of aggregating and displaying the PLUM output data have been developed. The simplest method of display is a tabulation of data done by a program called PLAN TAB which compares more than one set of data at a time. The printer plot displays data values on a geographic framework, a three dimensional representation is necessary. One such printer plot program is SYMAP. Others are: (1) time rings plots, (2) histograms, and (3) others. If hardware is available one might use incremental plot displays, cathode ray tube photographs, microfiche, and microfilm displays.

Capabilities

PLUM takes a regional population and employment growth forecast and allocates it to small geographic areas throughout the region according to specified growth assumptions, development constraints, and transportation policies, thus simulating the possible future development patterns for the region.

PLUM is an incremental model. That is, it deals primarily with the change (increase or decrease) between a base and target year, adding this change or increment to the existing base year development. The result is the forecasted target year development (6).

In addition to providing small area forecasts PLUM can be used as a tool to aid in testing alternative policy choices, such as:

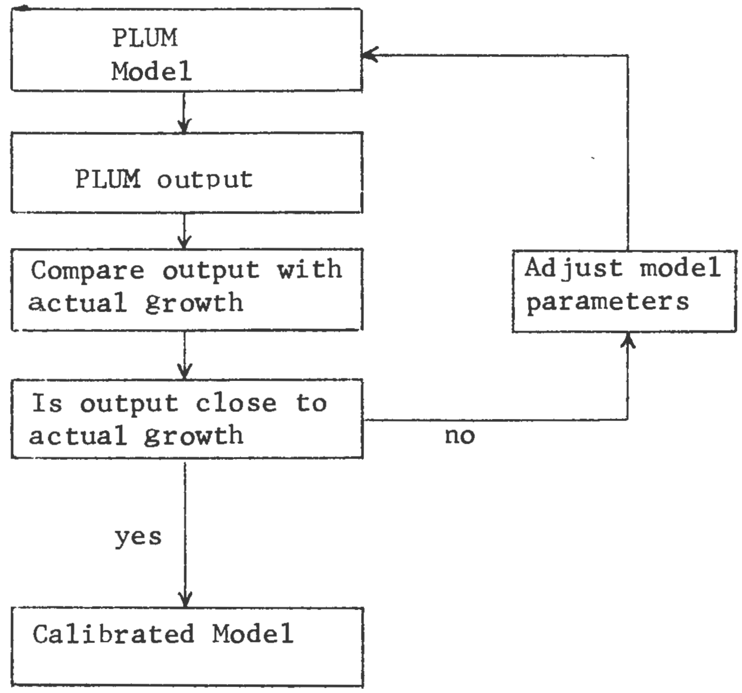
1. Transportation Policy - PLUM can be used to test the impacts of various transportation strategies and mixtures of travel modes on the physical and economic development in the region.

2. Land-Use Policy - PLUM has the capability to accommodate a wide variety of Land-Use Policies including open-space, flood plains, density and redevelopment options, and to assess their potential impact on future development in the region.

3. Other policies - PLUM can be a significant aid in examining alternative patterns of industrial facilitiy location, important aspects of airport location, major office, industrial site and public facility location, central business district and regional shopping center expansion or contraction.

Calibration

The calibration process for the PLUM model is not as well defined as is the case for certain other Urban Development Models. However, since the PLUM Model is not a highly statistical model, but rather a algorithmic model in which only a few parameters control the allocation, this lack of a rigid calibration requirement does not present a serious problem. Basically the calibration of the PLUM model can be characterized as follows:



Parameters which have a basis for estimation in real world data but also can be systematically adjusted for calibration, policy, or imperfect data reasons are: the mode and standard deviation of the probability function (i.e. log-normal distribution) discussed in the model description section; the beta coefficients; the density adjustment coefficients; and, the over-riding land absorption coefficients.

Preliminary values of the mode and standard deviation can be determined from the related trip length frequency distributions for the area. Reference 8 provides a general framework for determining the mode and standard deviation based on empirical data. Adjusted values of the mode may be used to modify the probability function assumed for each trip type from each zone. The relevant trip types are work-to-home, home-to-shop, and work-to-shop. Variations in modal values control the dispersion of the allocation functions. The mode of the related trip length frquency distribution will assist in making PLUM conform to the base year allocation. A disaggregated set of modal values may be used to allow for spatial differences in allocation, and a well formulated set of hypotheses has to be brought to bear if the modes are to be adjusted to reflect allocational conditions in the future. In the present version of PLUM the introduction of the "opportunities" concept compliments the unique influence of the modal values. Now allocations are substantially influenced by the availability of developable land and its holding capacity. In practice it is easier to estimate a single set of system wide modes and standard deviations for allocation and adjust the "calibrated" fit to holding capacities under varying density and land availability assumptions.

In addition to all of the above, a check should be made to insure that "target year" exogenous calibration levels for total population and housing are consistent with comparable base year subregional data.

Additional information on the calibration procedure for PLUM is contained in References 4 and 6 (especially volume II). It should be noted that improvements to the PLUM calibration procedure have been developed in connection with the ITLUP (see later section of this chapter) and other methods are described in Wilson's book on Models (9).

Computer Software

The PLUM model is operational on both the IBM 360 Computer (NPLUM Version) and CDC 7600 Computer (PLUM 74 Version). The NPLUM Version is written in FORTRAN with substantial data storage requirements, depending primarily on the size of the zonal system, and is available from the FHWA, Urban Planning Division.

Evaluation

Systems using PLUM are confronted by two problems which are common to all Lowry-type models:

a. Separating employment data classified by industries into the two categories of basic and local-serving employment. The problems are (1) local-serving industries, focused on local markets and service areas, frequently sell their products and services to customers outside the region; i.e., they are partially basic; (2) locally produced intermediate goods (partially basic) that are sold through local-serving establishments and should be classified local-serving; (3) basic industries (factory outlets) selling their products locally and therefore should be partially local-serving.

b. The spatial allocation of basic employment in the target year. This is perhaps the most difficult area in locational modeling, and the few models available for this task operate at minimum thresholds of acceptability. Alternatives to these models are Delphi methods, judgmental and hand allocations, cataloging plans for major developments as far in advance as possible, and combinations of these with location models.

The selection of a zonal framework for any particular application of PLUM will largely determine the cost of using the model. The most important influence of the zonal framework is upon the cost of collecting and preparing the data base for the modeling system. In general, the larger the zones in any study region (i.e. the smaller the number of zones), the cheaper and simpler it is to use PLUM. Although the costs in computer time increase roughly as the square of the increase in the number of PLUM zones, computer costs are less significant than data collection and preparation, staffing and personnel costs, and evaluation and analysis of output. The following chart provides data on "core processing time" as a function of computer type and zonal number.

Core Processing Time

No. of Zones	CDC 7600	CDC 6400	IBM 360/40	IBM 360/50
85	6 sec.	-	-	-
300	-	3 min.	40 min.	-
312	12-15 sec.	-	-	-
440	20-25 sec.	-	-	-
663	30-33 sec.	-	-	-
825	-	-	-	38 min.

PLUM can be run with 1,000 or more zones. However, the model developer, Dr. William Goldner, and other users report that for operational purposes, this may be much too large a number. From a technical standpoint, the error terms grow larger in proportion to output values as the sizes of zones are smaller. In addition, the sheer magnitude of long lists of numbers makes identification, evaluation, systems verification, and ultimate use beyond personal comprehension. Therefore, a resort to aggregation, generalization, and graphic and tabular summarization are needed. Inorder to reduce the number of zones used during a PLUM application, the zones could be grouped into superzones or districts which contain from 4 to 9 of the original zones. The allocation from districts to original zones could then be done by some simple allocation rule. This would substantially reduce the computer time and input data requirements for the PLUM application.

Research and usage has shown that one type of error associated with the PLUM forecasts are due in large part to making a forecast in one large time interval in contrast to several shorter intervals. Therefore whenever possible, PLUM should be applied in a recursive manner.

URBAN SYSTEMS MODEL

Background

The Urban Systems Model (USM) is a "Lowry Type" Model which had its basic development in Britain (1). The USM was further expanded, refined, and applied to the North Central Region of Texas and to other planning situations by Alan M. Voorhees & Associates, Inc. (AMV), (2,3,4). In addition the USM forms the basis of a Statewide Activity Allocation Model that was developed by AMV for the Federal Highway Administration, Program Management Division (5) and (6). Research and evolution of the model continues.

Model Description

The USM (illustrated in Figure 11) operates as an integrated set of submodels which distribute forecasts of areawide activities totals to a group of small analysis zones. The regional activity level forecast totals are derived from sources outside the model. Each of the submodels and their function is as follows:

a. Primary Employment Activity System Submodel (OPTIONAL) - distributes primary employment to analysis zones.

b. Residential Activity System Submodel - distributes total primary employment from workplace locations to residential locations.

c. Service Activity System Submodel - distributes service demand from residential and workplace locations to service centers.

d. Accessibility Submodel - calculates activity system accessibilities.

e. Market Potential Submodel - calculates activity system market potentials.

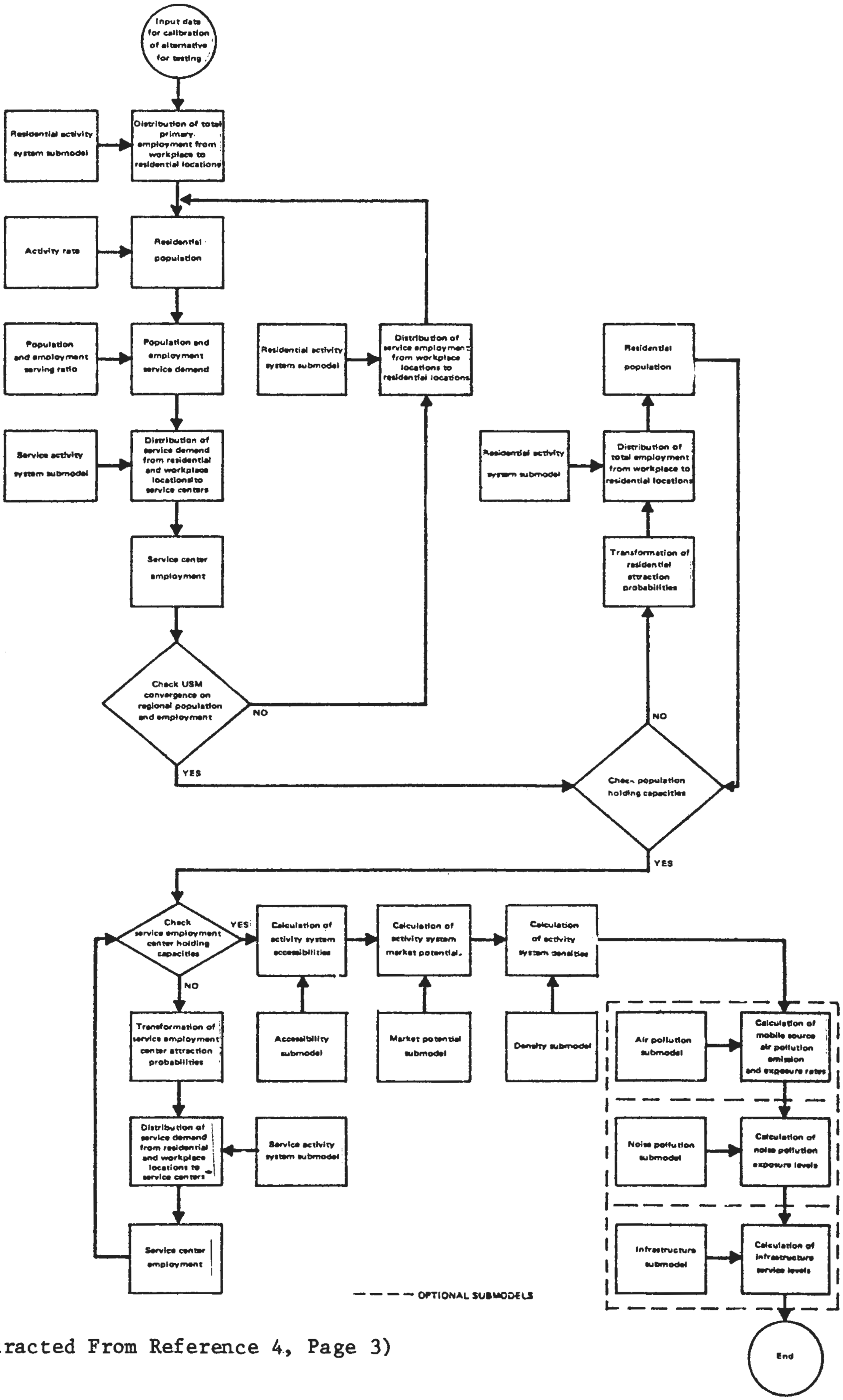
f. Density Submodel - calculates activity system densities.

g. Air Pollution Submodel (OPTIONAL) - calculates mobile source air pollution emission and exposure rates.

h. Noise Pollution Submodel (OPTIONAL) - calculates noise pollution exposure levels.

i. Infrastructure Submodel (OPTIONAL) - calculates infrastructure service levels.

Figure 11 USM STRUCTURE



(Extracted From Reference 4, Page 3)

In many respects USM follows the basic Lowry Model theory, and therefore is similar to PLUM. Like PLUM, the residential population and service employment distributions are determined by the distribution of regional "growth generating" (primary or basic) employment. Primary employment is distributed to metropolitan area zones either by an independent, external analysis or by use of an optional primary employment activity system submodel which is outside the main structure of USM.

Given the forecasted spatial distribution of primary employment the model first distributes the households associated with this employment. Then the model forecasts the distribution of service or nonbasic employment with respect to these households and the original distributio of primary employment. Finally the model distributes the households associated with that service employment to residential locations and the model proceeds iteratively towards a convergence with the total regional forecasts of population and employment for the particular forecast interval. Once the regional convergence has been satisfied, the model checks to insure that small-area holding capacities and constraints have been met, and makes any necessary re-allocations. Optional submodels provide the capability of determining various environmental effects. The optional submodels are designed to build on the outputs from the main submodels, however, they may be used independently of the main submodels.

Input Requirements

The general input data requirements of the USM for each forecast year include: as major items, regional population and employment, highway and transit networks, the small area primary employment, commercial and residential holding capacities based on one or a combination of planning, institutional, physical, or environmental constraints, and small area total acreages.

Specific data items required are:

1. Highway or composite highway/transit skim tree.
2. Small area residential attraction index (e.g., base year net residential floorspace).
3. Optional small area residential attraction index (e.g., base year recreational amenities, neighborhood socioeconomic status, school quality).
4. Small area population.
5. Small area population ceiling (holding capacity).
6. Small area primary employment.
7. Small area service employment.
8. Small area total employment.
9. Small area service center attraction index (e.g., base year small area service employment).

10. Base year small area primary employment.
11. Base year small area total employment.
12. Base year small area population.
13. Base year small area service employment.
14. Small area service employment ceiling (holding capacity).
15. Small area recreation attraction index (e.g., base year recreational demand at facilities, net recreational floorspace).
16. Total small area acreage.
17. Zone-district equivalence array (optional)
18. Regional population
19. Regional employment

If the optional submodels are used the following inputs are required:

Air Pollution Submodel

1. Emission (grams) per freeway vehicle mile of travel (VMT) for a. carbon monoxide, b. hydrocarbons, c. nitrogen oxides, d. sulfur oxides, and e. particulates
2. Emission (grams) per arterial VMT for a through e as listed above.
3. Emission (grams) per collector VMT for a through e as listed above.
4. Emission (grams) per conventional bus VMT for a through e above.
5. Emission (grams) per rapid bus VMT for a through e above.
6. Emission (grams) per rapid rail VMT for a through e above (stratified by power source (e.g., coal or oil).
7. Freeway VMT in each small area.
8. Arterial VMT in each small area.
9. Collector VMT in each small area.
10. Conventional bus VMT in each small area.
11. Rapid bus VMT in each small area.
12. Rapid rail VMT in each small area.
13. Small area population or population density (use only if this submodel is used alone).

Noise Pollution Submodel

1. Small area noise emission array, coded in order of increasing noise emission levels as: blank, 1,2,3,4.
2. Zone - district equivalence array.
3. Small area population.
(Items two and three are used only if this submodel is used alone)

Infrastructure Submodel

1. Small area sewer service index (e.g., m.g.d.)
2. Small area water service index (e.g., m.g.d.)
3. Zone - district equivalence array.
4. Small area population.

5. Small area primary employment.
   (Items three through five are used only if this submodel is used alone)

Primary Employment Activity System Submodel

1. Interindustry characteristics (e.g., base year small area total primary employment; base year small area total service employment)
2. Economies of scale (e.g., base year small area primary employment by type, for example, aggregate SIC Code)
3. Accessibility characteristics (e.g., base year accessibility to the labor force; to service employment; to CBD's; to airports; to truck terminals; to rail sidings.
4. Development potential characteristics (e.g., base year small area infrastructure service; base year small area vacant land; small area geological and topographical characteristics)
5. Antipathetic characteristics (e.g., base year small area net residential floorspace; base year population density)

Model Outputs

Figure 12 illustrates the output of the USM. Specifically, the model forecasts the following information for each forecast year:

1. District, and small area population
2. District, and small area population density
3. District, and small area population change over the forecast period
4. District, and small area service employment
5. District, and small area service employment density
6. District, and small area service employment change over the forecast period
7. District, and small area total employment
8. District, and small area total employment density
9. District, and small area total employment change over the forecast period
10. Work to home trip length frequency distribution, mean trip length
11. Home, work to service center trip length frequency distribution, mean trip length
12. District, and small area accessibility to urban areas (population)
13. District, and small area accessibility to primary employment centers
14. District, and small area accessibility to total employment centers

Figure 12

USM OUTPUT INFORMATION

1. Activity Information For:
   - Population
   - Service Employment

Zone	Actual	Estimated	% Diff	Absolute Diff	Estimated Density
1					
⋮					
504					
Total					

District	Actual	Estimated	% Diff	Absolute Diff	Estimated Density
1					
⋮					
25					
Total					

2. Travel Information For:
   - Work–home travel
   - Home, work–service travel

Units of Travel 'Cost' (Distance, Time, Utilities, Money)	Incremental		Cumulative	
	Person Trips	% Trips	Person Trips	% Trips
1				
⋮				
140				
Mean Trip Length				

Optionally:
Work–home peak person trip table

3. Accessibility Indices For:
   - Primary Employment Centers
   - Service Employment Centers
   - Total Employment Centers
   - Population Centers

Zone	Accessibility	Proportional Accessibility	Weighted Accessibility
1			
⋮			
504			
Regional Average			

District	Accessibility	Proportional Accessibility	Weighted Accessibility
1			
⋮			
25			
Regional Average			

4. Market Potential Indices For:
   - Primary Employment Centers
   - Service Employment Centers
   - Total Employment Centers
   - Population Centers

Zone	Market Potential	Proportional Market Potential
1		
⋮		
504		
Regional Average		

District	Market Potential	Proportional Market Potential
1		
⋮		
25		
Regional Average		

(Extracted From Reference 4, page 14)

Figure 12 (cont.)

5. Sewer and Water Infrastructure Indices for:
- Residential population
- Primary employment

Zone	Per Person Sewer Service Index	Deviation From Mean Regional Sewer Service Index	Per Person Water Service Index	Deviation From Mean Regional Sewer Service Index
1				
⋮				
504				

District	Per Person Sewer Service Index	Deviation From Mean Regional Sewer Service Index	Per Person Water Service Index	Deviation From Mean Regional Sewer Service Index
1				
⋮				
25				

6. Mobile Source Air Pollution Emission and Exposure Rates for:
- Carbon monoxide
- Hydrocarbons
- Nitrogen oxides
- Sulphur oxides
- Particulates

Zone	Highway Emission Rates				Transit Emission Rates				Total Transportation Emission Rates	Total Transportation Exposure Rates
	Freeway	Arterial	Collector	Total	Conventional Bus	Rapid Bus	Rapid Rail	Total		
1										
⋮										
504										
Total										

District	Highway Emission Rates				Transit Emission Rates				Total Transportation Emission Rates	Total Transportation Exposure Rates
	Freeway	Arterial	Collector	Total	Conventional Bus	Rapid Bus	Rapid Rail	Total		
1										
⋮										
25										
Total										

7. Noise Pollution Exposure Levels for:
- Residential population

Zone	No. Residents Exposed To Noise Level A	No. Residents Exposed To Noise Level B	No. Residents Exposed To Noise Level C
1			
⋮			
504			
Total			

District	No. Residents Exposed To Noise Level A	No. Residents Exposed To Noise Level B	No. Residents Exposed To Noise Level C
1			
⋮			
25			
Total			

15. District, and small area market potential for population
16. District, and small area market potential for primary employment
17. District, and small area market potential for service employment
18. District, and small area market potential for total employment

Optionally, the program produces:

19. Regional and district air pollution emissions of:

    Carbon monoxide
    Hydrocarbons
    Sulphur oxides
    Nitrogen oxides
    Particulates

    for the following highway types:

    Freeways
    Arterials
    Collectors

    for the following transit modes:

    Conventional bus
    Rapid bus
    Rapid rail

20. Regional and district exposure of the population to air pollution for:

    Carbon monoxide
    Hydrocarbons
    Sulfur oxides
    Nitrogen oxides
    Particulates

21. Regional and district noise pollution exposure levels from large stationary sources (i.e., airports)

Capabilities

The USM can be used as a straight forward tool to forecast the future small area distribution of population and employment within a region. In addition it allows the analysis and evaluation of the impacts of various public and private policies regarding transportation and land development.

Policy inputs and system alternatives are expressed in terms of:

- Travel costs, for highway and transit networks.
- Land development potential.
- Levels of water and sewer service.
- Zoning and open-space controls, in terms of small area constraints on the use of land.
- Air and Noise pollution constraints.
- Industrial, commercial, retail, residential, and recreational development policies.

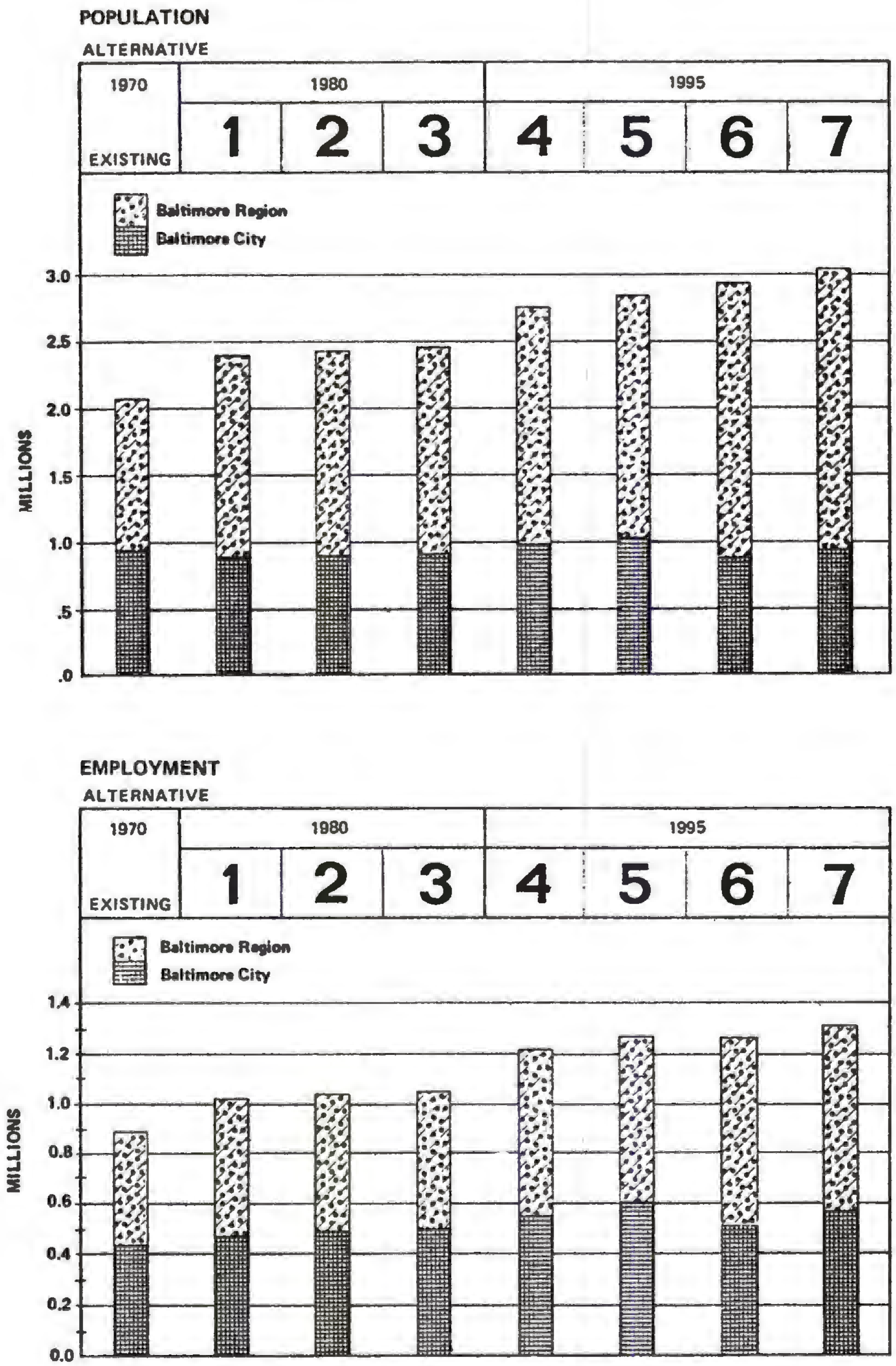
As part of the Baltimore Regional Environmental Impact Study, the USM was calibrated and applied in order to produce the activity-related impacts of seven alternative transportation systems. Population and employment forecasts were produced by the USM for each transportation alternative at the 100 zone level of analysis. The activity levels associated with each transportation alternative are presented in figure 13 for Baltimore City and the region. The population and employment distributions produced by the USM were used in the evaluation of the air, noise, water, and ecological effects associated with alternative transportation systems in the Baltimore region.

Calibration

The USM is calibrated by estimating the parameter "β" in a negative exponential travel "cost" expression for each of the three major activity combinations (i.e., "home-to-work", "home-to-shop" and "work-to-shop"). The process is similar to estimating a parameter for each of the three spatial allocation functions employed in PLUM. The method used to estimate these parameters involves the comparison of observed and estimated trip length frenquency distribution and the regional mean trip length associated with the activity system.

Specifically, calibration is achieved by using an initial estimated value of the "β" parameters to obtain an initial model output. This initial model output is used to adjust the "β" parameter of the residential and service activity system submodels to improve the model estimated results. Changes in the value of the "β" parameter result in changes in the perceived "cost" of travel, and in the overall amount.

Figure 13 A COMPARISON OF ALTERNATIVE ACTIVITY LEVELS PRODUCED BY THE USM



(Extracted From Reference 4, Page 13)

of travel generated in the region. The maximum likelihood of "B" is that which makes the real world and estimated trip lengths equal. Thus, the "B" values of the residential and service activity system submodels can be derived by simulating the actual work-to-home, and the home and work-to-service mean regional trip lengths. Figure 14 illustrates the fit obtained between the observed and estimated trip length frequency distributions (TLD) and mean trip lengths (MTL) of the residential activity system in the North Central Texas Calibration. In addition, the USM calculates the coefficient of determination and root mean square error to provide statistical measures of the overall quality of the calibration results. The USM calibration procedure also provides a comparison of the actual and estimated levels of population, service employment, and total employment by small area. Figure 15 illustrates the 1970 calibration results of the North Central Texas study at a district level for each of the above activities. References three and four contain more detailed information on the USM calibration procedure.

Computer Software

The USM is operational on the Burroughs 5500 and the IBM OS 360/50 or larger hardware with approximately 250 K bytes of storage. For an area with 100 zones or less the average CPU execution time is less than one minute and the average core size required is 120K bytes. The model is programmed in FORTRAN IV. The program is modular in format and the set of optional submodels which are designed to build on the outputs from the main submodels utilize a standard multiple linear regression program which may be operated independently of the main algorithms. The IBM 360 program source deck is available from the FHWA or Alan M. Voorhees & Associates, Inc. (AMV). The Burrough's version is available from AMV.

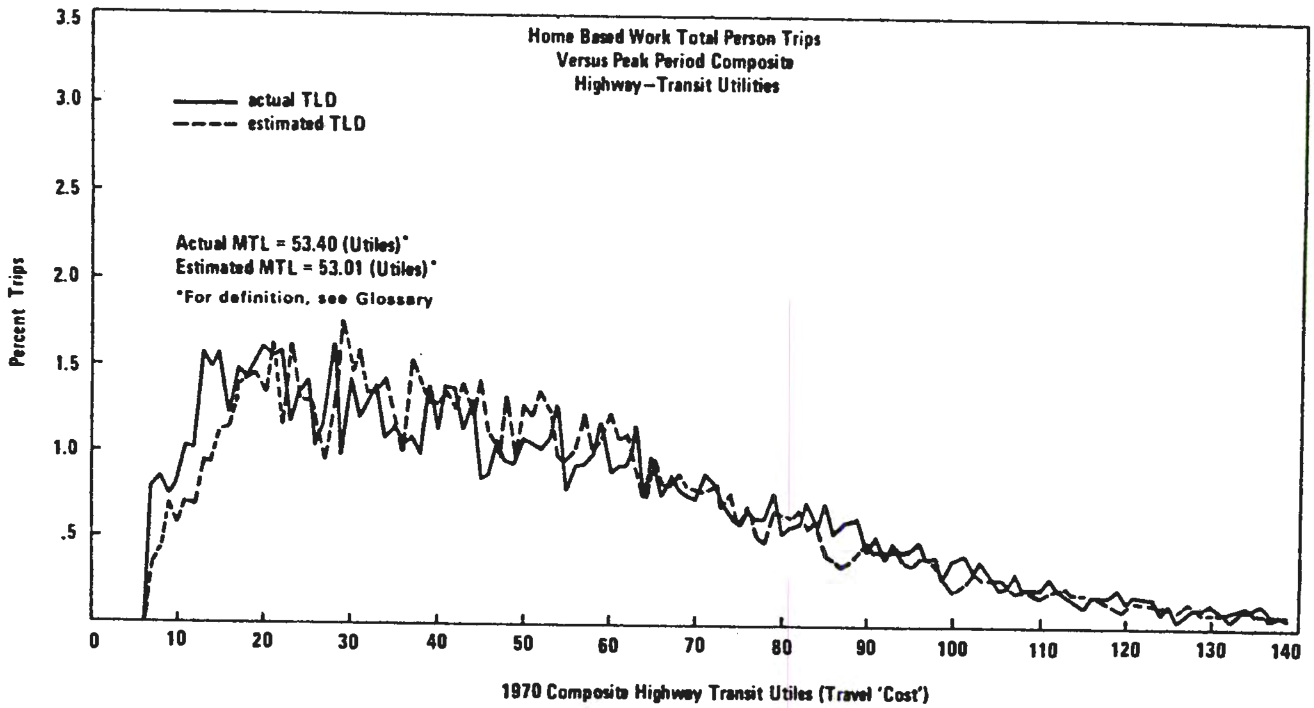
Evaluation

The first major application of the USM in the United States consisted of its use to forecast the impact of alternative public transportation systems on the future distribution of urban activities and on the environment in the North Central Region of Texas. As part of this application the USM system was installed on the urban studies computer facilities in order to provide a continuing operational capability (2, 3, and 4). Discussions with the study staff after this applicated indicated that additional work on the model structure was needed in order for the model to provide data in the form that would be of most use to their study.

Systems using the USM are confronted by two problems which are common to all Lowry-type models:

Figure 14

1970 DALLAS - FT. WORTH CALIBRATION RESULTS



(Extracted From Reference 4, page 10)

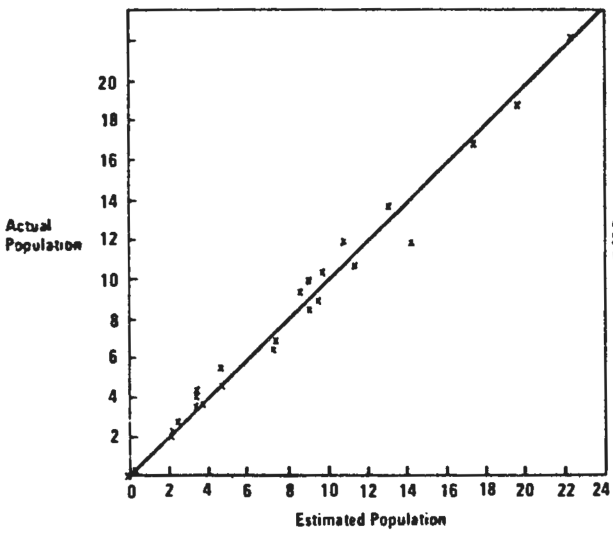
Figure 15

1970 DALLAS - FT. WORTH CALIBRATION RESULTS

(Extracted From Reference 4, page 11)

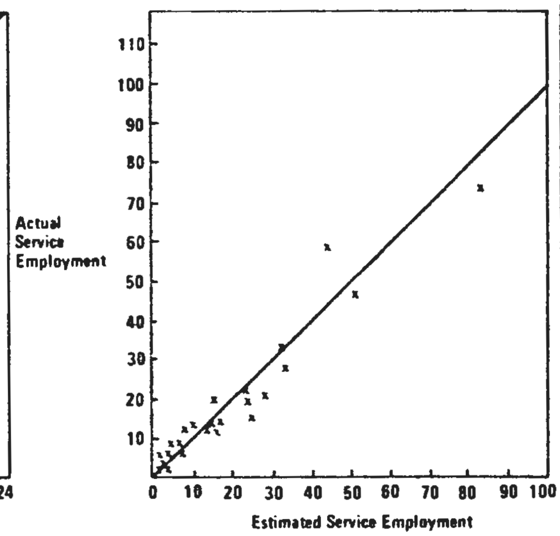
Actual v Estimated Population (10,000's)

$R^2 = .96$



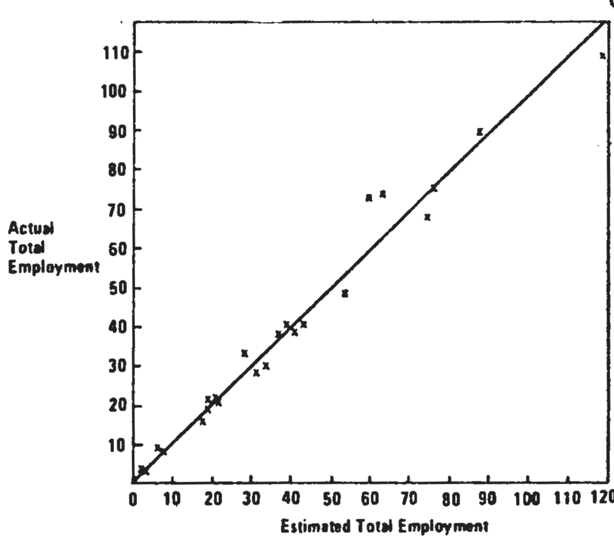
Actual v Estimated Service Employment (000's)

$R^2 = .95$



Actual v Estimated Total Employment (000's)

$R^2 = .99$



where:
X = districts (aggregations of regional analysis zone)

a. Separating employment data classified by industries into the two categories of basic and local-serying employment. The problems are (1) local-serving industries, focused on local markets and service areas, frequently sell their products and services to customers outside the region; i.e., they are partially basic; (2) locally produced intermediate goods (partially basic) that are sold through local-serving establishments and should be classified local-serving; (3) basic industries (factory outlets) selling their products locally and therefore should be partially local-serving.

b. The spatial allocation of basic employment in the target year. This is perhaps the most difficult area in locational modeling, and the few models available for this task operate at minimum thresholds of acceptability. Alternatives to these models are Delphi methods, judgmental and hand allocations, cataloging plans for major developments as far in advance as possible, and combinations of these with location models. It should be noted that the USM offers an optional submodel for performing the primary employment allocation.

In contrast to these general problems the USM offers the advantage of a clearly defined and well documented calibration procedure.

ACCESS AND LAND DEVELOPMENT (ALD) MODEL

Background

The history of the ALD Model started with a paper given by Morton Schneider at the Dartmouth Conference on Urban Development Models (1). The paper, entitled "Access and Land Development" presented a theory relating the amount of development expected to occur at each site in a region to the accessibility of the site provided by the region's transportation network. The paper contained a proposal for further work needed to transform the theory into a working model.

Under a one-year contract between the Federal Highway Administration (FHWA) and Creighton, Hamburg, Inc., (CHI) a prototype model was developed and a computer program written to implement the model. While this program was capable of accepting only a generalized "grid" representation of transportation networks, the development patterns produced by the model were in general agreement with experience. The work carried out under this contract was reported in a two-volume report to FHWA (2,3) and in two papers given before the Transportation Research Board (8,9).

Under a further contract between FHWA and CHI certain deficiencies of the prototype model were corrected, and a second version of the program was written (4,5,6).

Up to this time the ALD Model had been applied using only hypothetical data. Recognizing the desirability of testing the ALD Model in an actual urban environment, another contract was initiated with CHI. This contract was jointly sponsored by FHWA and the NY Tri-State Regional Planning Commission and provided for a test demonstration of the ALD Model in the New York Tri-State region. This study is documented in a final report published in 1974 (10).

Several months after the initiation of the New York ALD demonstration the Chicago Area Transportation Study (CATS) became interested in the concepts underlying the ALD Model and considered it to be of potential use in their study. The CATS in cooperation with the Illinois DOT, University of Illinois, and CHI initiated an on-going project whose long range goal is to develop the ALD Model as an aid for Urban Transportation Planning in the Illinois urban areas. Several working papers from this study are available from CATS (11 through 22, and 25 through 30).

The discussion up to this point has summarized the development and testing history of the ALD Model. There were two additional applications that were undertaken using the ALD Model which were not developmental in nature. One of these studies used the ALD Model to measure the land development impact of proposed transportation facilities at the National level (23). The other application involved the use of the ALD Model as part of a New York State sponsored study of the transportation needs of the 14 counties of the New York Appalachian region. The ALD Model was used to study the distribution of activities within the fourteen-county Appalachian region as affected by changes in the transportation system, and also, to study whether improvements in the transportation system could increase the amount of activities obtainable by the fourteen-county region from the much larger region including most of New York and Pennsylvania (24).

Model Description

A complete description of the ALD Model is contained in the series of reports listed in the reference. Basically the ALD Model is a computer program that attempts to interrelate land use patterns, density of development, travel, trip generation, choice of mode, and access provided by transportation facilities. Generally, the model is designed to distribute a given amount of development among a group of analysis zones in such a way that the resulting development in each zone is in equilibrium with the accessibility of each analysis zone. Since accessibility is taken as a function of travel time and cost and the development in each zone, the model must undergo several iterations before the final equilibrium value of development for each analysis zone is reached.

There are two operational versions of the ALD Model. They are the ALD Version B, and the ALD Version E. The basic difference is that Version E accepts coded travel networks while Version B requires grid networks. The E Version also utilizes a minimum path tree builder (included in the program battery), a path time and cost program used in selecting alternative paths, the land development model itself, and output print routines necessary or useful in analyzing model inputs and results.

Input Requirements

The input data required by the ALD Model are as follows:

1. Description of the transportation networks.
2. Definition of the region in terms of 2500 grid squares (50 x 50) (Version B)
3. Coded Travel Networks (Version E)
4. Development constraints which may apply in any or all zones.
5. Amount of development and land in each zone.
6. Total amount of development in the region.

The network description includes for each mode of travel the speed, cost per mile, time penalty (waiting time, if any), cost penalty (fare, parking charges, etc.) if any. Using this network data the travel time and cost between each zone is computed using a tree-building algorithm developed for this purpose (10). The linkage or connection between each mode of travel and location (zone) is also specified. Version B may run with one, two or three distinct modes of travel, while Version E permits any number of different modes to be represented in the network description. The grid squares are also of specifiable size. Each square or zone is identified in-terms of coordinates and is given an index of relative desirability. This index permits the user to designate a portion of the zone as undevelopable. These development contratints may be expressed as a requirement that development be less than, equal to, or greater than a specified amount no matter what the zone's access is to the region.

Model Outputs

Given this information, the model produces three sets of output. They are as follows:

1. A set of "F" tables
2. Site development
3. Travel by mode

The set of "F" tables represent the values of the travel distribution function for the specified networks. These values are used to calculate the potential travel patterns between zones. The site development information provides the expected utilization of all the sites in the region in terms of the amount of floor space that would be built in each zone. The amount of floor space allocated to each zone is the amount that results from the access provided by the network, the total floor space in the region, the desirability of the sites, and the constraints or impedances enforced on the sites.

The information on travel by mode supplies the number of trips using each of the transportation networks serving the region. This includes the use of each mode of travel and the trips originating from each site. Thus, the basic output of the model consists of the location and density of development in a region and the volumes using each of the transportation networks serving the region. These outputs are in equilibrium as a result of the mutual impact of transportation facilities and the location of floor space.

Capabilities

From the description of model inputs and outputs it can be seen that the ALD Model offers the potential for exploring the impact that factors such as (1) increase in population size, (2) changes in accessibility, and (3) combinations of transportation modes have on land development. A very real potential capability offered by this model is in the impact analysis of sketch plans (i.e., the impact of several alternative urban patterns upon transportation plans could be tested or the reverse).

The ALD Model calculates the total density of development which will be supported by transportation. All other urban development models require this as an input.

Calibration

The calibration process for the ALD Model is illustrated in Figure 16. There are two calibration parameters for the Travel Function. These are "a" and "b" which are calibration constants which determine the distribution of the sensitivity of trips to time and cost, respectively. References 12 and 14 describe the behavior of the travel function with repsect to changes in these two calibration parameters. Specifically, the effect of changes in "a" and "b" are discussed with respect to changes in the calculated average trip length and trip length plus modal split distributions. As a result of this analysis a range of possible values of "a" and "b" was identified ("a" is likely to lie between 0.05 and 0.20, while the value of "b" falls between 0.01 and 0.07.) More precisely for Chicago in 1956 a=0.1 and b=0.033 resulted from a detailed travel function calibration (25) and (28). Although the final values of the "a" and "b" will depend upon the characteristics of the particular study area these values can be used as a rough estimate to start the calibration.

In addition to the two travel function parameters the value of the ratio Rf/Ra plays a role in calibrating the ALD Model. Rf refers to floor area and Ra refers to land area. The value of the Rf/Ra ratio depends upon the relative attractiveness of floor area or development to land area in the particular study area. For instance, if this ratio equals one then this indicates that one square foot of land and one square foot of floor area are equally attractive. Since it is reasonable to assume that developed land (space in a building) should be relatively more attractive than vacant land this ratio should reflect the relative weighting between these. Based on past applications the model developers feel that this ratio ranges from 10 to 20. Further discussion of this ratio is contained in reference 10. It should be noted that the ALD Model can theoretically be calibrated with cross-sectional data from one point in time; time series data is not required.

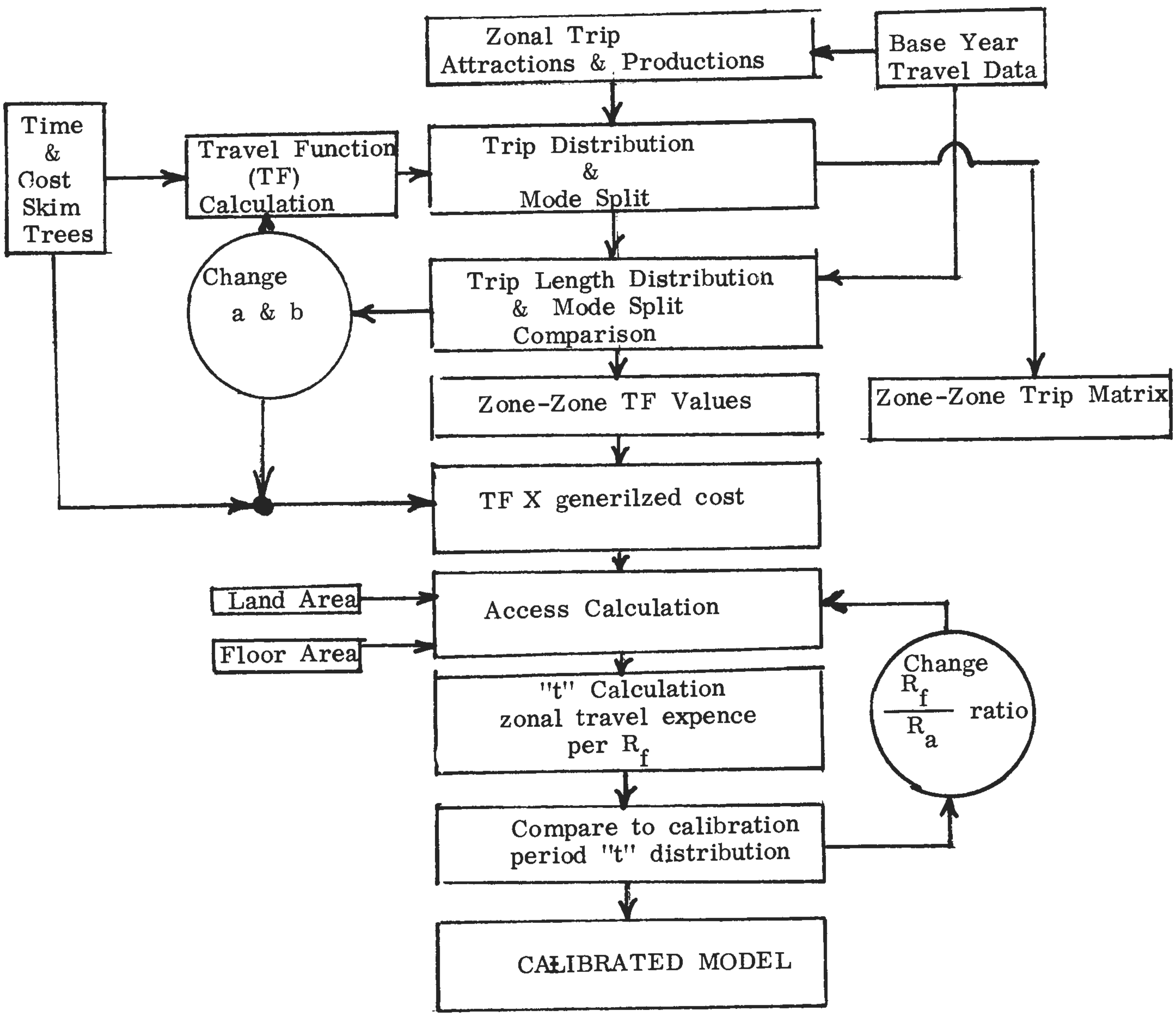
Computer Software

The ALD Model has been developed for operation on the IBM 360, CDC 3800, and the B-5500 computers. The IBM 360 Versions B and E are available from the FHWA or C, H, and Associates, Inc. The CDC and Burrough's Versions are available from C, H, and Associates, Inc.

Evaluation

The ALD Model is based on a comprehensive and unified theory where all of the elements are related to each other through sound deductive reasoning.

ALD Calibration Method



Thus, as with all good scientific models, the relationships are logically determined and not mere fits of empirical data.

The ALD Model focuses exclusively on the impact that transportation access has on development. In this respect the model may be classed as modest, addressing a particular policy problem. On the otherhand, the model may be considered ambitious, from the travel demand viewpoint, as it attempts to account simultaneously for generation, mode split and distribution (integrating transportation and land development).

The ALD calculates the total density of development which will be supported by transportation. All other urban development models require this as an input. Also, the ALD Model can theoretically be calibrated with cross-sectional data from one point in time; time series data is not required.

In essence the ALD Model, while operational, is still in an evolutionary and developmental stage with the CATS work being a very desriable step in the development of an ALD Version that will be of most use to Urban Transportation Planning Studies. Based upon the applications to date this model cannot be easily or quickly picked up by a planning staff and used inhouse without the aid of a consultant.

Most of the application have used floor area as the measure of development that is ultimately located by the model. Since the model does not offer the capability for easily handling various stratifications of floor area (i.e., development) it is questionable as to its use in providing small area forecasts in a form required by standard trip generation analysis, however, the model does provide an access sensitive estimate of trip generation.

In the course of development of an urban development model the name might vary until a commonly accepted and recognized name is adopted. The name "Access and Land Development Model" (ALD Model) has now been commonly accepted for the model that was formerly referred to as the "Model of Land Use and Transportation" (MLUT) in its earlier developmental stages by the Federal Highway Administration (FHWA). Three reports on the model have been published by FHWA using the MLUT name. They are:

1. Transportation and Land Development, A Third Generation Model - A Review and Summary, 1970.
2. Transportation and Land Development, A Third Generation Model - Theory and Prototype, MLUT Version A, 1969.
3. Transportation and Land Development, A Third Generation Model - Elaboration of the Model, MLUT Versions B and E, 1970.

The latest report on this model published by FHWA is titled "A Test Application of The Access and Land Development Model in Suffolk County, New York," 1974.

LAND USE ALLOCATION MODEL

Background and Description

The Land Use Allocation Model (LUAM) is a computerized urban planning tool which was developed as part of the continuing comprehensive transportation planning study for the Mahoning and Trumbull Counties area in Ohio (now the Eastgate Development and Transportation Agency--EDATA).

The development of LUAM has as its basic objective the provision of a planning tool to speed the land use evaluation process. "The model has been designed to combine the analysis of existing land use characteristics, population and economic projections, physiographic conditions, present and potential public utility service, transportation system characteristics which affect land usage, public policies which affect master planning and urban renewal, development control activities, and established social and community factors" (1). Using a variety of data, LUAM predicts and identifies the amounts of industrial, commercial, public and semi-public, and residential use in future years.

A basic input to LUAM are population and economic projections for the forecast year (1990 for the EDATA application) which the model combines and interprets as requirements for the construction of homes, factories, shopping centers, offices, schools and other major land uses.

Theory and Operation

In LUAM, the allocation of land for specific uses (11 major categories) is determined on the basis of indices called desirabilities and suitabilities. These are factors synthesized from a number of specifically defined parameters each characterizing subdivisions of the planning area. In the sense that LUAM utilizes explicit mathematical relationships between these parameters, LUAM is an analytic model. The analytical relationships which define these indices are fixed in the model, however, the user has control over their interaction. This control is exercised by changing various weighting coefficients which control the contribution of each input factor.

LUAM is a macromodel. The land it allocates is identified only by the eleven land use categories, the amounts of land to be allocated, and the specific sub-area[1] in which the allocation is to be made. It does not specify where the various land uses are to be located within each subarea.

LUAM may be executed in either a static or dynamic mode. The model is presently designed to operate in a static mode, that is, the desirability and suitability indices remain constant for the given iteration step, which in this instance is 23 years (1967-1990). At the cost of increased running time, LUAM can be easily changed to operate in a dynamic mode, by

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1 The EDATA Planning Area is subdivided into 669 traffic zones and areas outside the cordon line.

recomputing the desirability and suitability indices after each of two or more given iteration steps.

LUAM is also deterministic. All relationships are defined with specific analytical expressions. Evaluation of probabilistic studies can be done by creating a family of population and economic projections corresponding to several probabilistic futures. The deterministic solutions of LUAM for each input would then define the probabilistic solution for the area.

Finally, LUAM is a sequential model. Land is first allocated for manufacturing uses. The homes for the new manufacturing employees are subsequently allocated. Next, land is assigned for population dependent services - schools, government, shopping centers, etc. and finally residential land is allocated for new employees of the population dependent services.

The chart in Figure 17 illustrates the flow of the overall LUAM program as conducted by the EDATA.

The initial tasks are involved with the manipulation of input data to provide land area summaries, develop the input data base, and formulate output tables.

The process, after data manipulation, could be described in the following steps:

1. Output the base year summaries for later comparison with the projection year output.
2. Formulate the employment tables by employment categories, and formulate certain employment ratios which are used in a later evaluation of the employment parameters.
3. Reorganize output from the population projection model.
4. Reorganize output from the economic prediction submodel.
5. Distribute employment by assigning people to available employment according to each of the eleven major employment categories.
6. Associate types of housing with households to whom such housing is desirable. Additional residential land is then allocated according to the needs of new housing to be constructed.
7. Determine the need to allocate land for population-dependent services such as trade, services, transportation, communication and utilities as well as cultural, entertainment and recreational activities. Subsequently, land is allocated according to the housing needs of the additional population that will be employed in the above mentioned services.
8. Formulate the projection year output for user evaluation. This information can also be used as basic input data for any future time increment projection.
9. Ready the population and economic prediction model output data for any future projections.

LUAM

PROGRAM FLOW CHART

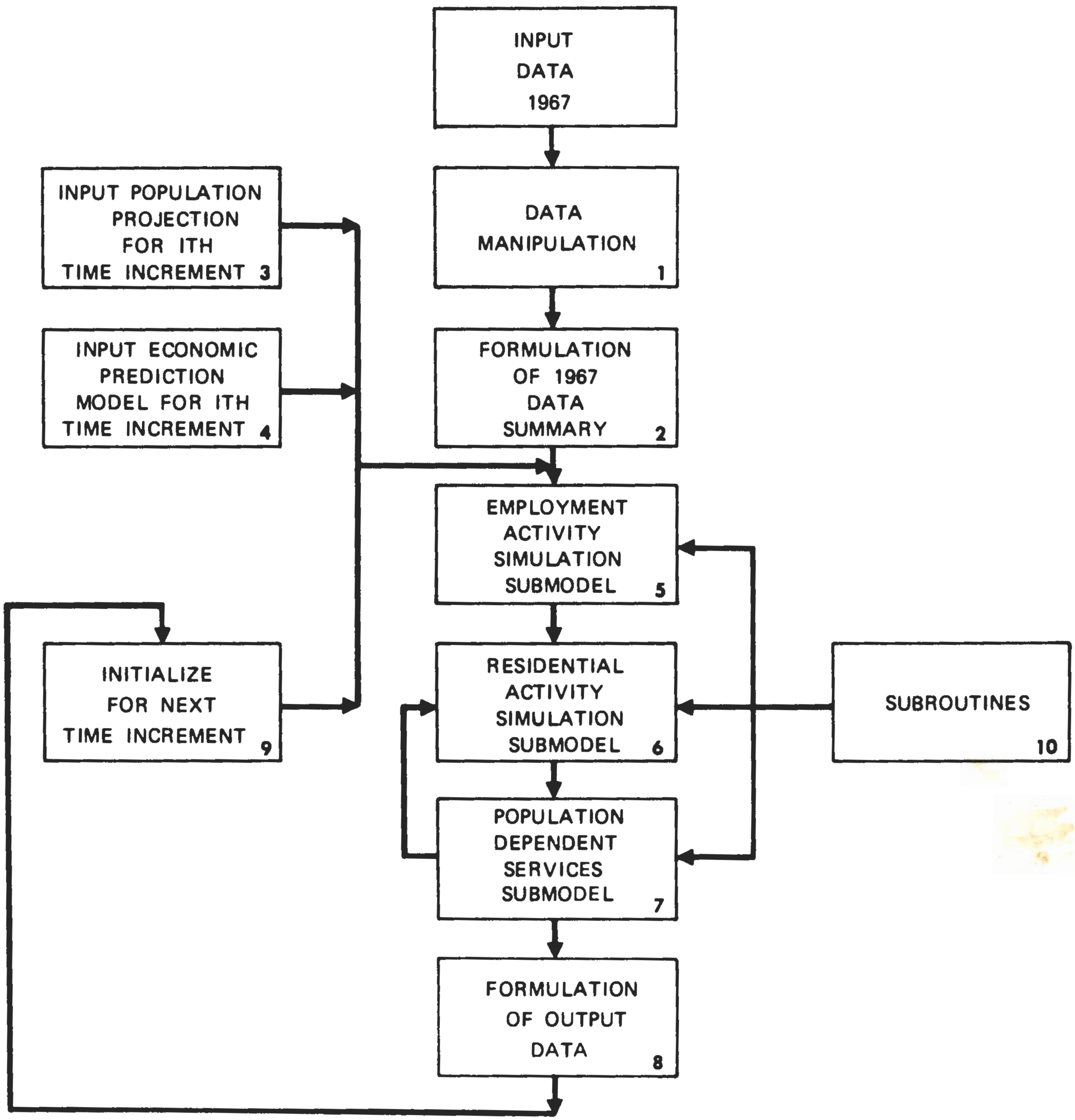

FIGURE 17

(Extracted From Reference 3)

In brief terms, the land allocation process in LUAM proceeds in these steps:

1. From the input new basic employment data (by 11 categories of manufacturing) the number of employees is converted to an amount of land consumed for new manufacturing by means of a land-per-employee factor.
2. Manufacturing land is allocated to analysis zones according to suitability indices.
3. Land is allocated for residential use by the families of the new manufacturing employees. The major influence in this process is the "relative desirability" indices which are computed for each zone. Zones are ranked in a high-to-low desirability sequence and the allocations follow that sequence. Allocations also follow an income heirarchy - highest income families are allocated first and the lowest income families last. A "housing preference matrix" is also used to define the exact number of families to be housed in each type of housing.
4. Land is allocated for population dependent services (e.g., schools, government, wholesale and retail trade, etc.) and the remaining residential uses. Land consumption for the service uses is derived from the adjusted employment projections. Land is first allocated to zones without constraints by use of the suitability indices. The excess allocations are then redistributed according to service category. The categories with the lowest suitability in each zone retain or gain the lowest allocations.

The allocation of land for "population dependent services" is repeated for six zoning classifications. Of the eight zoning classifications considered by the model, three are residential and are combined into one category for allocation purposes. The residential allocation is then subdivided in proportion to the areas of the three residential classifications.

Inputs and Outputs

LUAM has rather extensive input data requirements as shown in Figure 18. These data have been subdivided into three general types:

1. The "data base" (28 items), which is composed of factual information describing existing conditions that are not subjected to the planner's control.
2. The "population and economic projections" (5 items) contain data from independent models, which data may be modified by the user, but exogenous to the model.
3. The "control variables" (31 items) include all the quantities the planner can directly manipulate to affect the results of the model--e.g., zoning classifications, accessibility, desirability and suitability indices, utility availability, etc.

Important members of the control variables are the suitability indices which are used in the allocation of land for nonresidential uses. A

Figure 18

LAND USE ALLOCATION MODEL INPUTS

DATA BASE

1. Land area allotted to highways in each traffic zone
2. Total area of each traffic zone
3. Travel time between each zone and the nearest employment center
4. Number of families in each type of housing in each traffic zone
5. Existence of Manufacturing Employment Center in each zone (yes/no)
6. The number of cars driven to work from or in each traffic zone
7. The number of off-street parking spaces for all employed working in the zone
8. Amount of existing vacant manufacturing floor space in each zone
9. Total land area of each zone
10. Total occupied land area in each zone
11. Number of people employed in each of the 10 non-residential categories in each traffic zone
12. Number of people and families in each income group
13. Amount of land occupied by the residences for each income group
14. Number of dwellings in each income group
15. Number of cars owned by each income group
16. Average number of cars/dwelling unit
17. Number of students - elementary, junior high, senior high
18. Identification of base year associated with the data base information
19. Definition of the traffic zones in each zonal group
20. Area-wide averages for % of land occupied by each service category
21. Area-wide total vacant floor space for manufacturing
22. Actual manufacturing unemployment
23. Employment Participation rate for each income category
24. Percent of manufacturing employees in each of the 4 income classes
25. Average number of autos owned in each income category (per family)
26. Average number of families in each income category
27. Number of families living in each of the 5 types of housing
28. Percentage of each income category living in sparsely populated areas.

ECONOMIC AND POPULATION PROJECTIONS

1. Number of employees in each population dependent service category
2. Projected employment changes in each of the eleven service group categories
3. Shortage or excess of employees
4. Projected employees and unemployed from Population Model
5. Manufacturing employees from Economic Model

CONTROL VARIABLES

1. Weighing factors and coefficients for computing suitabilities and desirabilities
2. Minimum land requirements to support each land use category ("Must" Code Matrix)
3. Scale of values for land attributes in Suitability Index
4. The maximum percentage of the land in each of the eleven land use categories that may be assigned to each of the eight zoning classifications

Figure 18 (cont.)

The following information is specified for each zone:

5. Aesthetic rating
6. Amount of land zoned for each type of housing
7. Suitability of ground for construction
8. Availability of public water and sewer
9. Zoning classification of the zone
10. Residential holding capacity
11. Distance to nearest population center
12. Accessibility to transportation systems - highway, rail, bus, air, rapid rail
13. Population density
14. Income profile
15. Degree of need for each of 11 land use categories
16. Iteration step increments to be used for the Model analyses
17. Land per employee in each service group category
18. For each of the 11 land use categories, the land requirement for parking and highways
19. Percentage of governmental service land used for elementary, junior high and senior high schools
20. Pupils per acre for elementary, junior and senior high schools
21. Percent of the population dependent service employees in each of four income categories
22. Land and floor area required per manufacturing employee
23. Average number of autos driven to work and average number of parking places per employee
24. Option (yes/1)(no/0) should available jobs be filled with existing unemployed in the study area
25. People per acre ratios which define manufacturing and employment centers
26. Population densities for densely, moderately and sparsely populated areas
27. Housing preference matrix. The elements of which identify the percentages of each income category which prefer each of 5 housing types.
28. Average travel time between home and work for each income category
29. Population density preferred by each income group for its housing
30. Maximum allowable fraction of land to be occupied by highways and roads
31. Household unit factor - average number of persons per household.

suitability index is derived for each of the ten nonresidential uses from various parameters and weighting factors. The system has the form of a pyramid of parameters. On the lowest level are the most objective parameters which describe conditions in fine detail. Numerical values are assigned at this level, and the suitability index is completed from a weighted average of the major components which are scaled 0 to 10.

The output of LUAM is printed in tabular form for each traffic zone. The output is as follows:

(1) Total land use (in tenths of acres) for the 11 major land use categories.
(2) Vacant land by major zoning calssification.
(3) Maximum holding capacity of vacant residential land.
(4) The presence of public water supply.
(5) The presence of sewers.
(6) Employment by major non-residential land use categories.
(7) Proposed number of dwelling units.
(8) Estimated automobile ownership.
(9) Average number of automobiles per dwelling.
(10) Land suitability for development based on ground water characteristics, bedrock, slope and soil condition.
(11) Estimated population.
(12) Estimated number of families.
(13) School enrollment (elementary, junior high, and senior high), (1).

LUAM operates on two levels of aggregation--the zonal group (e.g., 20 traffic zones) and the traffic zone. Allocation by the submodels is first on a zonal group basis, and then on a traffic zone basis.

Capabilities

The LUAM can be used for allocating land use, population and employment for some future point in time. It can also be used to evaluate land development patterns and the effects of certain development-related conditions or policies.

LUAM can respond to policies that are reflected in items such as: zoning classifications; accessibility to transportation; availability of public water and sewerage; land use constraints; and school standards. The policy factors reflect their influence through the normal desirability and suitability indices which may also be modified by weighting factors.

Calibration

The calibration process for LUAM consists essentially of determining weighting coefficients. In order to calculate these coefficients, it is necessary to gather a substantial amount of data; enough to develop a socio-economic profile that properly characterizes the area. If the model is to be properly calibrated, it is necessary that data from three or four time frames (e.g., 1960, 1965, 1970, 1975) be available.

The LUAM developers indicate that the values for the weighting coefficients may be determined by a sensitivity study, or values may be a-priori, based on real world experiences. The EDATA developed weighting coefficients using data from a single base year. The weighting coefficients were developed based upon local evaluation of the characteristics influencing the value of the coefficients. The coefficients can be refined as more information becomes available.

Computer Software

The software package for LUAM is operational on the Burroughs B5500 computer and the IBM 360 computer. Reference 2 provides documentation on the Burroughs version. The computer program for both versions including documentation is available from the Eastgate Development and Transportation Agency, 1616 Covington Street, Youngstown, Ohio 44510.

Evaluation

The LUAM appears to be a sound and logical model for providing transportation planning inputs. LUAM operates in a sequential manner in its allocation of land, similar to that used in a Lowry-type model.

Since LUAM has been, to date, used exclusively in the EDATA area, it has not been subjected to those universal adaptations which normally occur when a model is applied to different study applications. The specific structure of the LUAM data inputs may be found to be a constraint on the transferability of the model to another study area. However, the EDATA feels that that the availability and reliability of some of the data necessary for LUAM input should not be a constraint to transferability. The new study area would be in the same position as EDATA when their model application was undertaken. Certain data would be readily available and other data would have to be collected. All of the data should be available from some source. Therefore, the reliability of the model should not differ significantly. Application of the model could not be immediate, as there are a great amount of data necessary for input.

Similarly, in its present form, LUAM is tailored to the EDATA application and is limited in the number and kind of immediately available options which it offers. However, if one is prepared to make changes to the body of the programs, there are many more options that are feasible.

The EDATA application of LUAM identified two major deficiencies in the model. One of these is the inability of LUAM to subtract. If new growth is being allocated to all zones the model performs well. However, if some zones experience a loss of growth the model cannot account for this, and the amount of existing zonal activity remains unchanged. The other concerns the strict requirement that all LUAM allocation areas must be zoned. In the EDATA study area there were several rural townships that had not developed zoning plans and values had to be assumed by the study in order to undertake the LUAM application. Since it is not likely that some of these townships will develop zoning plans by the next LUAM application in 1977 the EDATA study plans to modify LUAM to relax this strict requirement. In addition, LUAM will be modified to incorporate a subtraction capability in the model.

The EDATA intends to validate LUAM as part of their major review process. Following the validation process, the EDATA will use LUAM to forecast data to the year 2000.

LAND USE PLAN DESIGN MODEL

Background

In 1965 the concept of a Land Use Plan Design Model was conceived at the Southeastern Wisconsin Regional Planning Commission (SEWRPC). Up to this time most mathematical urban development models were designed to forecast (allocate) future growth as opposed to designing the pattern of this growth (1, 2). The Land Use Plan Design Model is a normative model which attempts to provide an "ideal" land use plan for an area on the basis of the given land use requirements.

In late 1966 SEWRPC undertook a study, sponsored by the U.S. Department of Housing and Urban Development, to develop a mathematical model which could be used to design minimum cost land use plans taking under consideration the users development objectives. This contract was undertaken in three phases during the period from October, 1966 through April, 1973. Phase one consisted of the development of initial model concepts and computer programs (3). Phase two consisted of refinements and testing of the model (4). The last phase consisted of further refinements including the final development and testing of the Model (5).

Additional testing work on the land use plan design model was conducted by the Department of Civil Engineering, Marquette University, Milwaukee, Wisconsin (6, 7) through a research grant from the National Science Foundation.

Model Description

A complete description of the land use plan design model is contained in the several reports listed in the reference. Basically the Model is a computerized mathematical model which can be utilized in the design of a land use pattern for any particular area. The Model seeks to develop minimum cost (Public and Private) designs that will satisfy market demands while complying with established development objectives. In addition the Model searches for the optimal design that satisfies development objectives while minimizing development costs from among all of the land use patterns that are generated (5). The user must perform several preliminary steps prior to the use of the Model. Some of these are as follows: "The total available land is divided into a number of smaller subareas, called cells, which are then classified according to their size and their location in the plan area. The design demand is determined by the land area required by each of the discrete land use activities, such as residential neighborhoods, schools, industrial areas, or parks. The term module is used to designate these land use activities or elements, and a set of these modules can be used to define the entire land use configuration of an area".[1]

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[1] (Reference 7, page 8)

The basic operation of the model, in its present form, consists of using a random search procedure to place the various modules into certain cells within the area(7). Two earlier versions of the model utilized the techniques of linear programming and linear graph theory respectively in the optimization part of the model.

Input Requirements

A complete, detailed description of the input data for a model run is contained in Reference 5. As is true for most urban development models, the preparation of input data for the Model or interpretation of its output takes a great deal of the user's time. Basically there are four categories of data required; Module data, Land data, Constraint data and Cost data. The general format of these data, for use in the Model are as follows:

Module-Module Constraint Matrix - this matrix contains the maximum or minimum distance allowed between one module and the next closest module. For instance, a residential module might have as a spatial accessibility standard that it be within five miles of a high school module. A plan not meeting the constraints is classified as infeasible by the Model (5).

Module-Cell Site Cost Matrix - this matrix contains the cost of locating any given module in any given cell, based on the costs of the components of the module, and the particular site conditions in each cell (5).

Module-Module Linkage Cost Matrix - All modules have specific linkage requirements (ie, transportation, water, sewer facilities, etc.) as designated by their specific design standards. For each type of linkage, construction and operating costs are developed. Construction costs are those associated with building the linkage per unit distance of construction. Operating costs refer to the cost of using the linkage, and are discounted to present value. This matrix contains the cost associated with the linkage requirements for each module to the closest second module (5).

Plan Accuracy and Success Probability Requirements - The use of a random search procedure in locating modules in cells requires the user to indicate what the desired plan accuracy is. For instance, does he want a plan which is within the lowest 5 percent of all possible costs? Next the user must specify what assurance is desired of obtaining a plan within the previously specified cost range. For instance, does he want a 90 percent chance of obtaining a feasible cost plan. These two values must be input in order to determine the number of experimental plans the Model will make (5).

Modules - The user must specify the number of each type of module and the land area each requires (5).

Cells - The user must specify a number designation, the land area, and geographic coordinates of all cells in the plan area (5).

The Module - Cell Constraint Matrix - This binary matrix designates which module may be located in which cell. For instance, a noisy, air polluting, heavy industrial type module might be classified as unacceptable in a residential cell.

Module - Cell Limit Vector - This vector limits the number of a particular type of module that can be located in any individual cell.

It should be noted that information from a detailed soil survey is required to provide a large amount of the data input. For instance, the soil data is the primary input in the determination of site costs. There are several computer programs available for converting the raw data (from surveys, etc.) into the form that is required by the model.

Model Outputs

The Model produces three categories of outputs. They are as follows:

1. Module - Cell Placement Matrix
2. Plan Costs
3. Constraint Schedule Analysis

The Module-Cell Placement Matrix indicates which modules are located in which cells. It can be viewed as a land use plan design in tabular form. In another version of the model this information is given in graphic form through an online plotter (7). The plan costs information gives the site and linkage costs of each plan, along with a total cost for each plan. The Constraint Schedule Analysis results in a set of reports which detail the effects of the inter-cell constraints on the feasibility of a plan. All violations of the module-to-module distance constraints are listed, including their location, the actual distance between them and the specified distance constraint for the particular set of modules (5).

Capabilities

The model offers the potential for developing land use designs that minimize public and private development costs and at the same time satisfy the given community objectives. SEWRPC has indicated that several levels of application of the model are theoretically possible, ranging from site level plan design through national level plan design (5).

It is interesting to note that SEWRPC has a separate land use simulation model that provides a forecasted land use pattern based upon current development trends. By using both models, SEWRPC has the potential for presenting decision makers with an indication of what is likely to happen along with an indication of what is most desirable.

Calibration

While the forecasting (allocating) type urban development models require calibration, the Land Use Design Model does not. The nearest thing to calibration of the design Model might consist of comparing the land use plan design from the model against a land use plan designed by a land use planner. SEWRPC made a similar comparison for a portion of the southeastern Wisconcin region and found that they did not match exactly. However, they concluded that the Model produced a reasonably satisfactory solution and that the Model is conceptually valid.

Computer Software

The Land Use Plan Design Model is operational on an IBM 360/22 or larger computer. At the present the computer programs are available only from SEWRPC. However, if several requests for the model arise then SEWRPC will provide a copy of the program to FHWA, Urban Planning Division for distribution. At the present, assistance in the operation of this Model is available only from SEWRPC.

Evaluation

The Land Use Plan Design Model, while operational, still requires system modifications and improvements before it will be ready for wide application in land use planning. The system deficiencies and required improvements are discussed in detail in Chapter VIII of reference 5 and Chapters 7 and 8 of reference 7.

In addition, due to the implicit treatment of travel time or accessibility it does not appear that this model could be used to easily illustrate the effect of alternative transportation plans on the future development pattern. Transportation facilities and their related accessibility is mainly represented by the cost of various linkage connections between the modules.

Moreover, the linkage costs of the transportation facilities (ie, arterial, freeways, etc.) are only one component of the total linkage cost which are required input to the model. Other components of the total linkage cost include the construction, maintenance, and operating costs of water and sewer lines as well as connections for other public utilities between a pair of modules. The type and size of modules to be linked as well as the cell soil condition also influence the total linkage cost.* Therefore, based upon all of the factors which influence linkage costs it is clear that the effects of accessibility on the location of modules cannot be clearly seen.

*It is noted that, although there are several components of the total linkage cost, SEWRPC found approximately 80% of the total cost was due to the transportation linkages.

THE NBER URBAN SIMULATION MODEL

A BRIEF OVERVIEW

The National Bureau of Economic Research (NBER) Urban Simulation Model, which was developed over the last few years with a grant from the Department of Housing and Urban Development, is now available in its initial version, which is basically a prototype. The model is to function essentially as a policy impact model for evaluating the consequences of public policies regarding urban transportation, land use, and urban form. A particular objective of the model is to represent interrelationships between transportation investments and land use. Although the model can conceivably be used for a variety of purposes, its most basic function is that of residential allocation. With the transportation network and industrial locations as inputs, the model uses a series of housing market submodels to allocate housing and households to various zones. Much of the basic theory behind the model can be traced to the work of John Kain and John Meyer in the 1960's.

Although the model makes use of information from various cities, the bulk of the data used was from Detroit for the period 1960-1964. The intent of the model's authors was to use the data to construct some basic relationships in the model which would represent a "generic urban area" and would be valid for a general application of the model. When the model is applied to a specific area, it will be necessary to combine the specific and unique area characteristics with the general behavioral relations which were previously established. Simply speaking, this means that city-specific coefficients are a required input.

The authors have made a special note of their attempt to make use of general "behavioral relations" rather than mechanistic algorithms as are used in some other models. Therefore, residential location and urban development in the NBER model are treated as a "market phenomena" in accordance with the "behavioral relations" approach.

ASSUMPTIONS, RESTRAINTS, AND REQUIREMENTS

Important to the operation of the model is two of the basic assumptions used. These are: 1) a household chooses a housing type and location to maximize real income; and 2) a household knows it's work place location when a choice of residence is made. The first assumption is the basis for much of the model's operation and can account for some of the strengths and weaknesses of the model.

There are also certain "negative assumptions" in the model--items which are not accounted for or are assumed to have a negligible influence. These include: the omission of neighborhood or zonal "quality" (schools, environment, social climate, crime, etc.) as a significant influence in the choice of residence; the effects of racial discrimination; the influence of personal preferences or values; and the employment of persons other than household heads.

The fact that the model depends heavily on a pure or simplified market phenomena and quantifiable income measures can result in certain inadequacies and distortions of reality. For instance, the maintenance or deterioration of housing is dependent simply on the "relative profitability" of such action or inaction on the past of the owner.

As stated previously, the model uses industrial location data as an input. This requires exogenously developed forecasts of industry location patterns for each simulation period. Therefore, the model user must either possess a submodel or process to forecast zonal employment by type or have this forecast data available from another source.

THE SUBMODELS

One of the major features of the NBER model is its systematic approach to the simulation of a number of activities of the housing market. Filtering, ageing, demolition, structural modification, and construction of housing are some of the factors considered. The authors offer the following as items which the model takes into account:

1. The decision to move.
2. Changes in work trip patterns.
3. Housing construction and renovation.
4. The influence of the type and location of housing.

Listed below, in the order of their execution, are the six submodels used in the model. A brief description of each submodel's function follows:

SUBMODEL	FUNCTION
Filtering	Change quality classification over entire housing stock according to quality premiums derived from expected prices and exogenous maintenance costs.
Employment Location	Revise level and composition of employment at each work place and by each of nine industry types. Translate employment changes by industry to changes in employee characteristics.
Movers	Generate households who move out of housing units, and modify them to produce households who are demanders of housing this period. Generate potential vacancies in housing stock created by moving households.

Demand Allocation	Combine transportation costs from work zones to residence zones with housing prices expected this period to form an array of gross housing prices. Form expected gross housing prices by work place for each housing type. Allocate households to housing types with demand equations and expected gross prices.
Supply	Calculate profitability of construction and transformation activities from expected prices and exogenous building costs. Perform stock transformation according to profit levels and several constraints.
Assignment	Match moving households to available units of type chosen by households in the Demand Allocation Submodel. Each house type or submarket is solved separately. Shadow prices are used to generate prices for next time period. Work trip patterns are updated.

DIMENSIONAL FACTORS

In order to calibrate the model the city of Detroit, during the period 1960-1964, was chosen for the initial model simulations. While other cities may differ in certain aspects in a NBER model application, the Detroit case provides a typical example of the dimensions of the model. Some of these dimensional factors are listed below:

Dimensional Factors - Detroit Example

1. Zones	19 work zones , 44 residential zones
2. Employed Households	72 classes by size and income and by education and age of household head
3. Housing Types	27 types by structure, number of rooms, quality, and lot size
4. Transportation System	represented as an interzonal matrix consisting of trip costs, travel times, and number of trips. Travel time costs = 0.4 (hourly wage) per hour. Two modes were used. The use of large area zones precluded impact measurement for other than rather large system changes.
5. Time Iterations	one year or more (10-50 year simulation period)

SUMMARY COMMENTS

The initial impression of the NBER model indicates that it is essentially a well constructed model with a more detailed consideration of the housing market than is normally found. However, there appears to be a need for a significant number of expansions or modifications before the model becomes suitable for widespread application.

While the operation of the submodels is basically sound, there may be an unbalanced emphasis on the functioning and influence of the market place. Certain locational influences such as the quality of the neighborhood environment and other social influences are not adequately accounted for as yet. These are some of the problems which arise when decisions are based on maximizing real income.

Fortunately, the authors of the model have recognized many of these limitations and have given thought as to how the model could be modified or expanded to improve its operation. They have also recognized the desirability of including within the model an industry location forecast submodel which would relieve the present burden of providing employment data for each iteration. This would be an important addition to a model which uses work place location as a dominant factor in its operations.

Looking to the future of the model, it appears that much could be gained (by increasing the experience with the model and the confidence in it) if the model could be applied to another city other than Detroit. In this second city application, which would hopefully entail a "calibration" period of ten years or more, the validity of some of the basic relationships could be tested and the transferability problems of the model could be defined.

INTEGRATED TRANSPORTATION AND LAND USE MODELS PACKAGE

Background

The Integrated Models Package resulted from an FHWA sponsored research study at the University of Pennsylvania (1). The purpose of this research study was to investigate the phenomena of heavy usage and the subsequent congestion which often follows the construction of new urban and suburban highways, and to develop recommendations or guidelines for preventing this phenomena from occurring. Due to the complexity of the research problem the Integrated Models Package was developed to assist in the analysis of feedback between land use and transportation decisions.

Model Description

The Integrated Transportation and Land Use Models Package is a set of models that have been linked so that the transportation and land use interface is explicit. The basic components of the package consist of two versions of the Projective Land Use Model (PLUM) and a transportation network models package. A general flow scheme of the model package is presented in figure 19.

A verbal description of the process is as follows:

1. First, comes the various base year inputs as to the existing spatial distributions of activity, along with data on the characteristics of the unloaded base year transportation network.

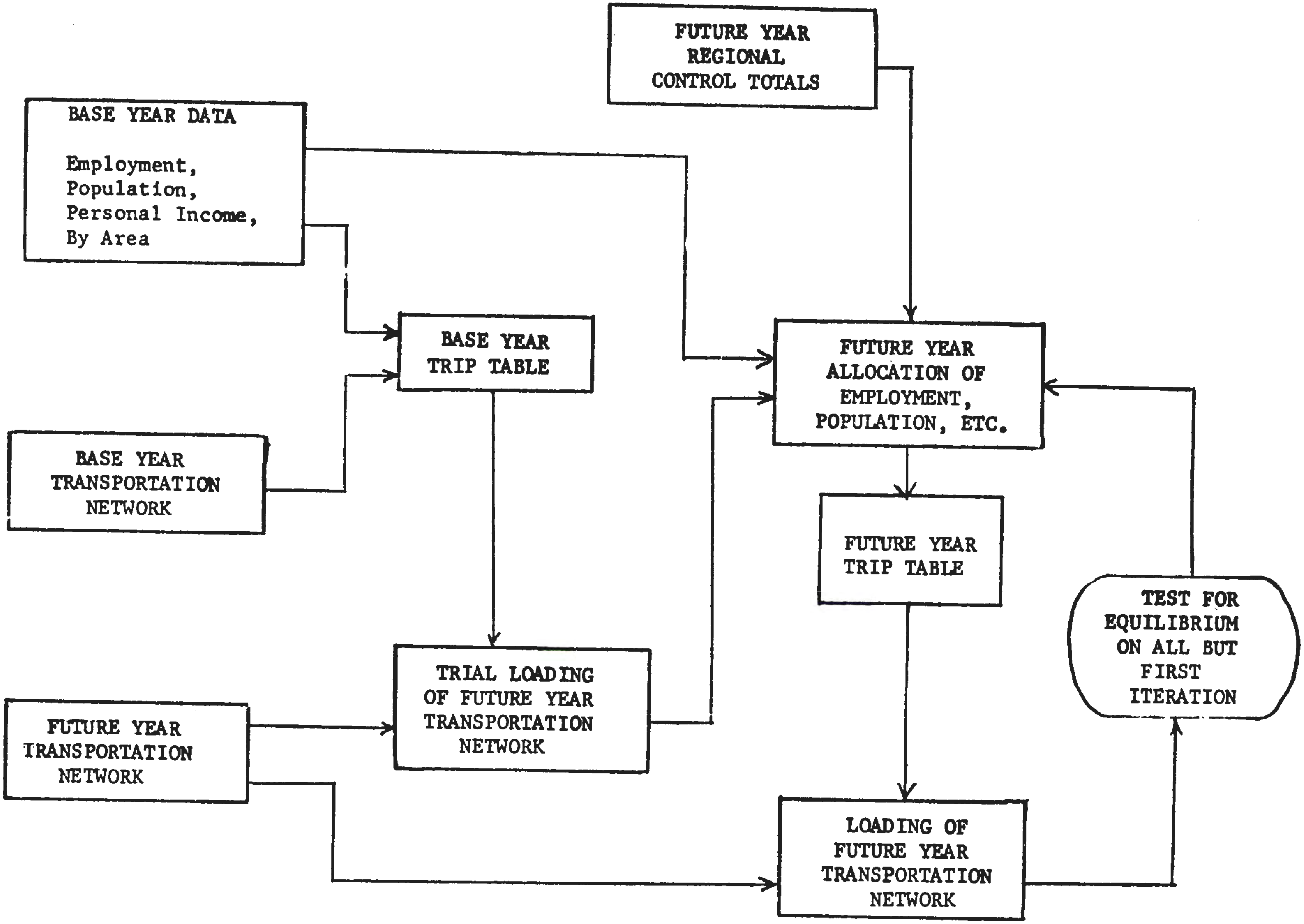
2. These data are used to generate a preliminary, and probably inflated, estimate of trips taking place in the metropolitan area.

3. This preliminary estimate of metropolitan trips is loaded onto the future (forecast year) network so that its travel characteristics (i.e., time and cost) reflect the traffic volumes which would be on the network if there were no change in the distribution of activities from the base year.

4. The network characteristics, along with the base year data and the forecast year control totals are used to generate a spatial distribution of activities for the forecast year.

5. A new estimate of metropolitan trips is then produced from this spatial distribution.

6. The new estimate of trips are, in turn, loaded on the forecast year transportation network.



GENERAL SCHEME OF INTEGRATED MODEL PACKAGE

Figure 19

7. The modified characteristics of the transportation network is then used to reallocate the projection year spatial distribution of activities.

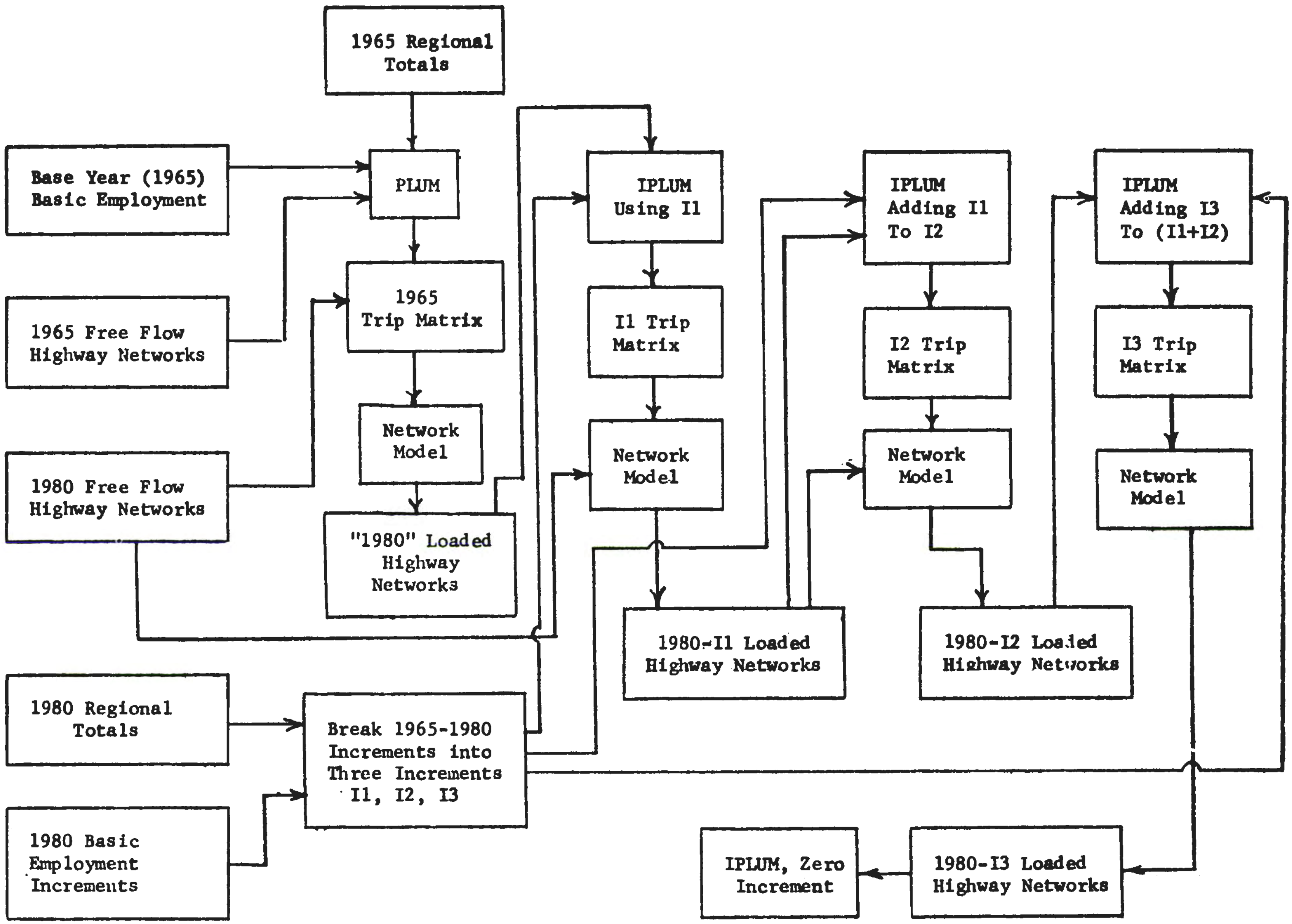
8. The reallocated distribution of activities is then compared to the first estimate.

   a. If there are no significant differences an equilibrium has been reached and the model run is ended.

   b. If there are significant differences, new trips are generated and loaded on the networks and further iterations are made.

It should be noted that in this generalized description the forecast is made from a base year in one step. Successive iterations of the Model Package are simply attemtping to find an equilibrium solution. The following more detailed flow scheme shown in figure 20, presents an approach to finding an equilibrium more gradually in a way analogous to making the forecast from a base year to a forecast year in several steps rather than in one grand leap. A verbal description of the process is as follows:

1. Assume that the base year is 1965 and the projection year is 1980.
2. The base year (1965) trips are loaded on the 1980 network and zone-to-zone impedances are calculated.
3. With these impedances, one-third of the regional control totals, and one-third of the 1965-1980 basic employment increments as inputs, IPLUM is run, and new trip matrices generated.
4. The 1965 trips are subtracted from the new trip matrices and the remaining new trips are loaded on the already partly loaded 1980 network. New zone-to-zone impedances are calculated.
5. With these impedances, two-thirds of the regional control totals, and an additional one-third of the basic employment increments as inputs, IPLUM is run, and new trip matrices are generated.
6. The trip matrices from Step 4 are subtracted from these new trip matrices and the remaining new trips are loaded on the partially loaded 1980 network. New zone-to-zone impedances are calculated.
7. With these impedances, the full regional control totals and the final one-third of the basic employment increments as inputs, IPLUM is run and new trip matrices are generated.
8. The trip matrices from Step 6 are subtracted from these new trip matrices and the remaining new trips are loaded on the partially loaded 1980 network. New zone-to-zone impedances are calculated.
9. With these impedances, the full regional control totals, and zero basic employment increments, IPLUM is run and should then produce an equilibrium solution.



DETAILED SCHEMATIC OF INTEGRATED MODEL PACKAGE

Figure 20

A detailed description of the individual programs that comprise the Integrated Models Package is contained in Reference 1. Briefly, the models which comprise the Package are:

A. PLUM and IPLUM - Land Use Models
B. TGEN - Trip Generation Models
C. NET3 - Network Model
D. INTER - Transportation and Land Use Interface
E. Analysis and Summary Programs
AVGT VOLCAP WGTR

PLUM and IPLUM develop relationships between "basic" employment and "service" employment, and between employment and residence location for a base year. Given an exogenous forecast of future basic employment by small analysis area, these models are used to project future local serving employment and future residential location. PLUM is applied, without a forecast, to simulate the base period for calibration, and to produce data used later for trip generation. IPLUM is an incremental version of PLUM, and is used to project the increments of employment and residence location that occur between the base and future periods. The outputs of PLUM and IPLUM are the following three allocations:

1. Work to residence
2. Work to shop
3. Residence to shop

The trip generation model serves as the interface from the land use models to the network models. There are two trip generation models referred to as TGEN2 and TGEN3. TGEN2 is used when the model Package is used to make a forecast from a base year in one step as implied in figure 19. TGEN3 is used when the Package is applied utilizing the flow scheme of figure 20. These models utilize the three allocations from the IPLUM Model to generate an auto trip matrix.

The Network Model (NET3) finds the minimum path through the network from each zone to all other zones. It also loads traffic onto those minimum path routes, and adjusts the link impedances via a volume delay function. Program INTER adds terminal impedances, to a inter-zonal time matrix, computes intra-zonal times, and inserts them into the diagonal elements of the matrix. The following programs can generally be classified as analysis and summary programs. They are program AVGT which is used to compute the average of two trip matrices; program VOLCAP which computes the weighted average volume to capacity ratio (a measure of congestion) for the network load nodes, which correspond to the analysis zone of IPLUM; and, program WGTR which computes the weighted mean trip length for each analysis sub-area of the IPLUM model.

Input Requirements

The general input data required by the Integrated Models Package are as follows:

1. Base year Regional Control totals
2. Base year Basic Employment for each analysis zone
3. Base year Highway Networks
4. Forecast year Regional Control Totals
5. Forecast year Basic Employment (increments of change) for each analysis zone
6. Forecast year Highway Networks

Specific Land Use and Employment data items required are:

1. Number of dwelling units (occupied)
2. Population
3. Employed Residents
4. Non-working population
5. Basic employment
6. Commercial Employment
7. Area (Acreage)
8. Unusable land (acreage)
9. Basic land (acreage)
10. Commercial land (acreage)
11. Residential land (gross)
12. Vacant land (acreage available for residential)
13. Streets and Highways land (acreage)
14. Vacant Industrial land (acreage)
15. Mean income (Household)
16. Standard deviation income (log normal form)
17. Group quarters population

Specific network data required are:

1. Skim tree network (nodes and links)
2. Times and Ranks Files (produced from skim tree). This is a matrix of interzonal travel times with their associated ranks. The times and ranks matrices have been aggregated into one matrix to simplify input specifications.

Model Outputs

The general output from the Integrated Models Package consists of a forecast of activities by small analysis areas along with the associated loading on the transportation network (skim trees). The small area forecast is considered in equilibrium with the transportation network in the sense that the resulting development in each zone is in equilibrium with the accessibility of each analysis zone.

Specific outputs include:

1. Dwelling units
2. Population
3. Employed residents
4. Non working population
5. Basic employment
6. Population serving employment
7. Ratio of incremental residential land to available land
8. Total land (acreage)
9. Basic land (acreage)
10. Projected population serving land (acreage)
11. Projected residential land (acreage)
12. Projected vacant land (acreage)
13. Streets and Highways land (acreage)
14. Vacant industrial land (acreage)
15. Group quarters population
16. Network loading

Capabilities

Use of the Integrated Models Package allows the analysis of land use patterns and transportation flows including the impact that factors such as (1) changes in accessibility, and (2) increase in population size have on land development.

Calibration

The calibration process for the Integrated Models Package is not as well defined as is the case for certain other urban development models. Efforts to develop a more clearly defined calibration procedure are currently underway at the University of Pennsylvania. At the present each model is essentially calibrated on an individual basis. This assures that the output of one model is satisfactory for use in other models. A description of the process for calibrating PLUM is contained in the section on PLUM included in this chapter.

Computer Software

The Integrated Models Package is operational on an IBM 360 or 370 computer with 256 bytes of main core, plus seven tape drives or one disk drive. The majority of all coding is in FORTRAN IV, compiled under both the G and H compilers. The remainder is coded in IBM 360/370 assembler language subroutines that have FORTRAN substitutes. The computer programs are available from FHWA or the University of Pennsylvania.

Evaluation

The Integrated Models Package has been tested utilizing data for the San Francisco metropolitan area. This test indicated that the models in the package are internally consistent and that the Package can be used to test the impact of land and transportation related public and private policies. The California Department of Transportation presently has the Integrated Models Package operational on their computer system. The Models Package can be considered as being in both the operational and developmental stages. While revisions are being made by the model developer at the University of Pennsylvania it is their intent that at least the latest operational version will be complete and ready to use. Several revisions envisioned to the models in the Package include:

1. Providing a more explicit and direct feedback between the exogenous location of basic employment and the endogenous location of population and service employment.
2. Modifying the network models to include uhe capability to handle highly detailed network specifications such as turn penalities, etc.
3. Modifying the Package to include non-peak hour shopping trips and other non-work trips. At present peak-hour work and peak hour shopping trips are only being utilized.
4. Modifying the Model to include transit trips.

APPENDIX A

Zonal Allocation Procedure (ZAP)

zonal allocation procedure

JACK C. BARRETT

INTRODUCTION

The EMPIRIC Model, which is COG's activity allocation model, was calibrated at the district level and all runs to date have been allocations of future year values to Planning Analysis Districts. There is a need, however, to develop forecast year values by zone, an area smaller than a district. One example of this need arises when zonal level trip tables are required for detailed transportation planning. These can be developed two ways:

1. Zone level values of households and employment can be developed by estimating distributions to zones within a district, and the trip generation equations can then be applied to the resulting zonal land use values. These generated trips can then be distributed using the FHWA gravity model program (GM). This process requires a fair amount of computer time and the availability to zone level transportation networks. This is the standard traffic forecasting approach.

2. District level work-trip tables generated by macro models can be "split" into zonal level tables using the FHWA program TRPVRT. This process only requires zonal level land use percentages of households and employment within each district.

The second of these two methods is sometimes preferred because of art savings and the ZAP system is being employed to calculate the zone level percentages required by the program.

Another need for areal summaries to lower levels than districts arises in some applications utilizing computer graphics for display purposes. This is a technique which is being used extensively in COG as an output medium for selected EMPIRIC displays. The districts in rings beyond the urbanized area are very large and relatively sparsely populated. It is felt that some zone level displays result in better representations of the forecast values in these large districts, primarily because it is possible to display the actual development in the small areas where it occurs. This prevents a relatively small amount of development from dominating the map of a very large area and results in a more accurate representation of the actual development patterns. The ZAP system was developed to satisfy these two principal data needs and has been utilized for these purposes for about nine months.

ZONAL ALLOCATION THEORY

The basic theory used in the algorithm for zonal distribution is that locally adopted Master Plans will control future *intra-district* development. In specific terms this means that the changes which occur in district level values for a variable, such as "Multi-Family Households," between the EMPIRIC base year and the forecast year will be distributed within the district to zones based upon the zonal percentages of land with a Master Plan Land Use suitable for that activity.

The critical parameters are these:

1. Base year district value of forecast variable.
2. Forecast year district value of forecast variable.
3. Base year zonal values of forecast variable.
4. Zonal Master Plan Land Use acreages.

To continue the example of "Multi-Family Households," Table 1 shows a simplified example of how the theory is applied in a specific case.

Table 1

Zone	Base Year Values	Forecast Year District Value	Multi-Family Household Acres	LU %
101A	40		160	20
101B	70		400	50
101C	20		240	30
101*	130	170	800	100

The district level change from base year to forecast year is +40 Multi-Family Households, and they will be distributed by the ZAP system in accordance with the percentage of land in each zone devoted to Multi-Family Housing according to adopted Master Plans. Table 2 shows the distribution and the resultant New Zonal Values.

The newly calculated forecast year zonal values will of course be used in the succeeding forecast as the base year values. For example, if the base year in the table above is 1968 and the forecast year is 1976, the "New Zonal Values" calculated in Table 2 will be

SOURCE: Metropolitan Washington Council of Governments, Transportation Planning Board, Technical Notes, No. 5, Spring 1973, pp. 14-16.

used as "Base Year Zonal Values" when applying the ZAP system to the 1976-1984 time period.

Table 2

Zone	Base Year Values	Distributed Forecast Year Change	New Zonal Values
101A	40	+ 8	48
101B	70	+20	90
101C	20	+12	32
101*	130	+40	170

District level changes is of course not always positive. There will usually be in any forecast some district values which decrease between the base year and the forecast year. In the example just cited in Table 2, the system would have performed in exactly the same fashion if the district level change had been –40 instead of +40. Table 2 would then have looked like this:

Table 3

Zone	Base Year Values	Distributed Forecast Year Change	New Zonal Values
101A	40	– 8	32
101B	70	–20	50
101C	20	–12	8
101*	130	–40	90

Complications arise however when a Zonal Base Year Value is not large enough to support the calculated amount of negative change without going to a minus value. For example, suppose in Table 3 that Zone 101B had had a Base Year Value of 18 instead of 70. The calculated New Zonal Value would have been –2, an obviously unacceptable result. On this condition the system would set the New Zonal Value to zero and distribute –2 among the remaining positive values. This distribution is based on a recalculation of the zonal percentages of Multi-Family Land Use with Zone 101B excluded. Table 3 would then look like this:

Table 4

Zone	Base Year Values	Distributed Forecast Year Change	New Zonal Values
101A	40	– 9	31
101B	18	–18	0
101C	20	–13	7
101*	78	–40	38

In the event that this re-distribution results in another New Zonal Value becoming negative, the process is repeated until no negative values remain in the New Zonal Value fields.

It is possible for the EMPIRIC process to make district level allocations of some variable, such as Multi-Family Households, when in fact the adopted Master Plans for that district contain no land planned for that use. This is possible of course because the EMPIRIC alogrithm does not use Master Plan Land Use by zone as the basis for its distribution at all. In the event this condition arises, the ZAP system makes the intra-district zonal allocation based simply upon the relative size of the zones.

There is also built into the program a "dampening" effect to account for the fact that the changes in zonal level values which are indicated by adopted Master Plans do not occur all at once. The trend towards compliance with adopted Master Plans may occur gradually over many decades. This effect is included in the alogrithm by weighting the distribution process to take into account the base year zonal distribution of activity values. Mathematically the effect is achieved by giving equal weight in the calculations to the percentage of base year activity and the percentage of Master Plan Land Use in making the zonal allocations.

There are six basic EMPIRIC variables which are allocated to zone by the ZAP system:

1. Single Family Households
2. Multi-Family Households
3. Employment on Commercial Land
4. Employment on Industrial Land
5. Employment on Institutional Land
6. Employment on Other Land

Table 5 is a matrix which shows for each of the six

Table 5

MST LU Variable	SF LU	MF LU	Comm. LU	Ind. LU	Inst. LU	Farm LU
SF Res.	90	10				
MF Res.		100				
E/Comm.			100			
E/Ind.				100		
E/Inst.					100	
E/Other	45	45				10

Figure 1

ZONAL ALLOCATION PROGRAM – MASTER PLAN – ALT #: 6 RUN #: 2

	BASE YEAR (68) VALUES						FORECAST YEAR (92) VALUES						MASTER PLAN LAND USE CATEGORIES							
	HOUSEHOLDS			EMPLOYMENT			HOUSEHOLDS			EMPLOYMENT										
ZONE	SING FAM	MULTI FAM	COMM LU	INDUS LU	[illegible] LU	OTHER LU	SING FAM	MULTI FAM	COMM LU	INDUS LU	[illegible] LU	OTHER LU	[illegible]	[illegible]	[illegible]	COMM LU	IND LU	INST LU	PARKS	FARMS
101C	0	1057	569	127	544	77	0	972	731	152	854	108	52	0	49	0	0	3	0	0
101D	75	265	923	726	0	258	75	0	2396	804	0	330	62	53	0	6	0	0	3	0
101E	0	0	117	5	38	28	0	0	[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	10	0	0	10	0	0
101F	0	0	0	170	0	192	0	0	0	[illegible]	0	124	[illegible]	[illegible]	0	0	0	0	51	0
101G	41	0	400	167	[illegible]	42	41	0	[illegible]	[illegible]	[illegible]	40	13	[illegible]	0	0	0	0	13	0
101H	83	196	543	2	0	40	63	0	698	8	0	58	20	20	0	0	[illegible]	0	0	0
101	448	4351	3175	1250	612	741	319	3657	4994	1457	1603	969	368	93	148	6	0	26	95	0
102A	116	179	1024	537	108	90	0	0	1427	[illegible]	[illegible]	103	[illegible]	0	32	0	0	2	26	0
102B	56	777	1374	115	25	444	0	0	[illegible]	128	[illegible]	442	[illegible]	7	38	0	0	0	0	0
102C	93	1366	1052	44	260	200	0	266	1419	54	382	225	52	0	52	0	0	0	0	0
102D	406	3247	2003	128	228	366	0	1393	2631	150	335	410	81	0	81	0	0	0	0	0
102E	464	1414	361	2	40	146	0	284	617	12	59	167	56	0	56	0	0	0	0	0
102F	113	32	435	45	115	122	52	0	604	53	169	167	27	27	0	0	0	0	0	0
102	1248	7015	6249	871	776	1388	52	1931	8427	[illegible]	[illegible]	1514	[illegible]	[illegible]	249	0	0	2	26	0
103A	481	2190	1259	445	311	328	0	976	1284	366	415	301	197	0	91	5	0	11	0	0
103B	57	2734	1540	270	237	1083	0	1304	1567	222	246	1027	62	0	62	0	0	0	0	0
103C	927	1573	999	451	252	599	91	662	1017	360	261	356	131	0	124	0	0	0	7	0
103D	944	799	1303	261	515	324	97	59	1326	186	534	293	132	0	119	0	0	0	13	0
103E	639	1389	1801	877	1156	124	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	111	56	0	44	61	0	0	0	0
103	3048	8685	6902	2304	2471	2458	263	[illegible]	[illegible]	1098	[illegible]	[illegible]	[illegible]	0	420	15	0	11	20	0
104A	525	459	650	368	174	73	7	380	693	162	228	120	86	0	80	0	0	0	6	0
104B	525	212	326	204	118	176	91	159	472	101	156	253	61	0	61	0	0	0	0	0
104C	618	96	474	164	94	63	137	57	644	81	127	100	57	0	57	0	0	0	0	0
104D	368	168	320	376	413	35	3	119	464	376	487	61	61	0	49	0	12	0	0	0
104	2036	935	1770	1112	799	347	258	719	2473	740	998	534	265	0	247	0	12	0	6	0
105A	254	191	831	356	0	5	39	251	976	0	0	15	47	0	42	5	0	0	0	0
105B	169	382	263	340	397	47	26	460	284	0	2018	61	54	0	43	0	0	11	0	0
105C	254	127	5764	1154	786	142	39	178	6404	819	917	162	52	0	39	10	3	0	0	0
105D	86	202	3089	185	383	399	13	221	4034	0	445	429	54	[illegible]	0	46	0	[illegible]	[illegible]	0
105E	128	310	4331	0	298	214	128	339	3809	0	348	241	89	17	0	61	0	0	23	0
105F	0	0	2021	2074	7307	40	0	0	2194	1655	8521	44	89	[illegible]	0	0	71	3	18	0
105G	0	0	724	627	30	0	0	0	765	412	33	0	76	0	0	0	76	0	0	0
105H	113	0	364	407	0	60	18	0	394	194	0	64	35	0	0	0	35	0	0	0
105J	504	278	250	538	169	120	504	321	271	289	197	155	57	34	17	0	6	0	0	0
105	1508	1490	17637	5691	9370	1027	768	1770	20883	3367	12481	1171	547	51	141	102	191	11	51	0
106A	0	0	3495	2	349	201	0	118	3762	101	818	262	108	0	0	11	0	0	97	0
106B	177	392	3764	79	823	76	150	605	3955	208	1426	120	60	60	0	0	0	0	0	0
106C	262	409	767	48	68	45	224	613	806	134	221	74	45	45	0	0	0	0	0	0
106D	66	0	3948	132	60	97	40	68	4648	313	252	131	62	12	0	50	0	0	0	0
106	505	801	11974	261	1300	419	413	1404	13191	756	2718	587	275	117	[illegible]	61	0	0	97	0
107A	0	0	1002	38	82	108	21	494	1657	170	1883	298	79	0	0	0	0	0	79	0
107B	0	0	1706	2	131	36	20	431	2617	99	2048	136	75	0	0	0	0	0	75	0
107C	0	0	319	1	3	0	9	208	513	47	682	24	36	0	0	0	0	0	36	0

variables what percentages of the variable are allocated to different types of Master Plan Land Use. These percentages are subject to change without major program modifications. In fact it is shown by experience that some percentage of "Commercial Employment" for example will occur on "Single Family Residential" Land Use, then the table values could be changed to use that fact as a condition of allocation.

The acreage in each zone devoted to each Master Plan Land Use was arrived at by a process of manually superimposing zonal boundaries on the Master Plan maps and estimating the percentage of each use by zone. The zonal percentages were then multiplied by total zonal acreage to arrive at Master Plan acreage. It is of course critical to the quality of the allocation that these percentages be developed with care. Figure 1 is a sample print-out of a Zonal Allocation run which shows what the Base Year Values were and the year they represent, the Forecast Year Values, and the Adopted Master Plan Land Use upon which the Zonal Allocation was based.

In Figure 1 zones are identified by the fact that the fourth digit is alphabetic. In the case of District 102, which is the first full district in Figure 1, there are six zones numbered 102A-102F. The values shown for Zone 102 are district level values and represent the sum of the zonal values listed in each column. For example, in District 102, there were 1248 Single Family Households in 1968 but in 1992, this number had shrunk to 52, for a total loss in Single Family Households of 1196. These 1196 households are taken from the 1968 zonal values to produce the 1992 values which total to 52. The Master Plan acreages on which the allocation of change was partly based are shown on the right-hand side of the page.

The Zonal Allocation Procedure is not a static system, and as it is used more and more, it is expected that refined allocation methods will be developed. For the present it represents a rational method of making allocations which meet the current needs for zone level data forecasts.

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