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An analytical tool to assist municipal planners in evaluating alternative planning strategies is proposed. Schlager's Land Use Plan Design Model provides the linear formulation of the problem, Goal Programming is used to create alternatives, and Brown and Kirby's Measures of Urban Performance serve to evaluate the alternatives. Resource Planning and Management networks are used throughout to represent the models and alternatives.

A prototype community of 40,000 is used as an example. Based on the 1975 land use statistics, goals, and priorities, a 1980 land use plan is formulated. The Urban Performance Model distributes the population on a socio-economic coordinate system so that the new land use plan can be compared with the present allocation. The computational results show that the residents of the community may gain slightly in Metropolitan Opportunity at the expense of Neighborhood Quality if the present set of goals and their priorities are followed. It is proposed that the integrated methodology be used by small community planners, as well as those working for large

municipalities, to create optimal alternatives under the given set of goals and priorities, and to measure the effects of changing goals and priorities upon urban attributes.

MULTI-OBJECTIVE PLANNING AND DESIGN FOR LAND USE AND URBAN PERFORMANCE

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MULTI-OBJECTIVE PLANNING AND DESIGN FOR LAND USE AND URBAN PERFORMANCE

CHAPTER I

INTRODUCTION

What is planning? Webster (1968) defines planning as: "The establishment of goals, policies and procedures for a social or economic unit." Planning accomplishes in the physical sense what legislation does in the moral realm. None of us could enjoy freedom and liberty if laws did not protect us from their abuses. Similarly then, nobody can enjoy our urban areas, our country side, and our landscape if we do not protect ourselves against their abuse (Gruen, 1959). Planning should be continuous. Every year it should produce a plan for the next few years, and every few years a plan for the next two or three decades should be formalized so that the next steps and distant goals are known at all times (Alonso, 1963).

A community planning process commonly includes the following steps (Salvato, 1968 and Steger and Lakshmanan, 1968):

1. Future regional needs and challenges are anticipated through a statement of community goals and objectives. Goals are the final purpose or aim; the ends to which a design tends. Objectives are the attainable ends; reality.
2. Preparation of base maps, data collection and analysis, problem identification, and alternative strategies addressed to these issues are generated.

3. The crucial impacts or outcomes of each of the alternative planning strageties are estimated and are evaluated with the desired future goals and objectives of the community.
4. A general plan and report are formulated to show how the components of the area studied in Steps 2 and 3 are to be coordinated to achieve the community goals and objectives of Step 1.
5. A capital improvement program is prepared with a priority listing of projects to achieve the established objectives along with a financing program to implement the general plan for comprehensive community development, at a minimum public and private cost.
6. Involvement of the public, including community organizations, during the planning process makes possible better appreciation of the community goals and objectives, and the problems to be overcome.
7. Periodic reevaluation of the community goals and objectives and revision of the general plan are necessary to prevent obsolescence of the comprehensive community plan as well as of the community.

Planner

A planner is one who supervises, participates in, or advocates social or economic planning. He is involved in a very complex task (Duhl, 1967): He must decide what in the community must be changed. He is presented with problems of the present, born of the past, and with the request that the future be different and bring different results. The planner is an agent of change. What is essential to his definition as a planner is that he be concerned with instituting change in an orderly fashion, so that tomorrow something will be different from what it is today. He must persuade a majority that his decision is valid on empirical, moral, and legal grounds. He must find ways to involve large segments of the affected population in implementing the action he is advocating.

Planning is an activity not reserved for one or another profession. The problems or our communities are too complex. For the planning process to be effective, planning teams must be multidisciplinary. Among the professionals included are economists, engineers, traffic experts, politicians, lawyers, sociologists, architects and landscape architects, and professionally trained planners.

In summary, planning can best be defined in one brief sentence (Henriksen and Vest, 1974): "Planning is having the answer before the question is asked."

Planning Models

It is the intent of this thesis to present an analytical tool to be used by a municipal planner. This tool is intended to aid the planner in the process of evaluating the impacts and outcomes of alternative planning strategies with respect to the goals and objectives of the community. This is Step 3 of the community planning process outlined earlier. It is proposed that this analytical tool be in the form of a mathematical model; also that this mathematical model be of such a form that it is readily available to municipal planners of both large and small communities alike.

A review of existing mathematical models that perform urban and land use planning was made. A summary of the literature search and a classification system used to compare various models is reported in the next chapter. None of the models reviewed met the requirement of being readily applicable to small communities.

The models found in existing literature can be called large-scale urban models. Typically, these models have data requirements that are enormous, and development and operating costs that are staggering. For example, San Francisco's housing market model needed 15,000 items of data for a single run and costs $5.54 million. The study by the Southeast Wisconsin Regional Planning Commission was billed at $1.99 million (Brown, 1972).

These characteristics of large-scale urban models puts them out of reach of a community of 50,000 people. Even if a completely developed model was made available, a small community could not support the cost of gathering and analyzing data to calibrate and run the model. The mere cost of data collection for some large metropolitan areas has run as high as $1 million (Brown, 1972).

There are some educational benefits associated with the development of urban models (Hemmens, 1968). One is better knowledge of the nature of models and the role of models in planning. Another is better knowledge about urban areas and about the interaction of components of urban areas. A third benefit is better understanding of planning through clarification of planning concepts and analysis of planning assumptions in the process of model development. Some planners feel that the relationship between knowledge gained about policy and urban structure and the size and complexity of a model is best expressed by the diagram in Figure 1-1 (Lee, 1972). It is for this reason that the proposed model will be kept as small and simple as possible.

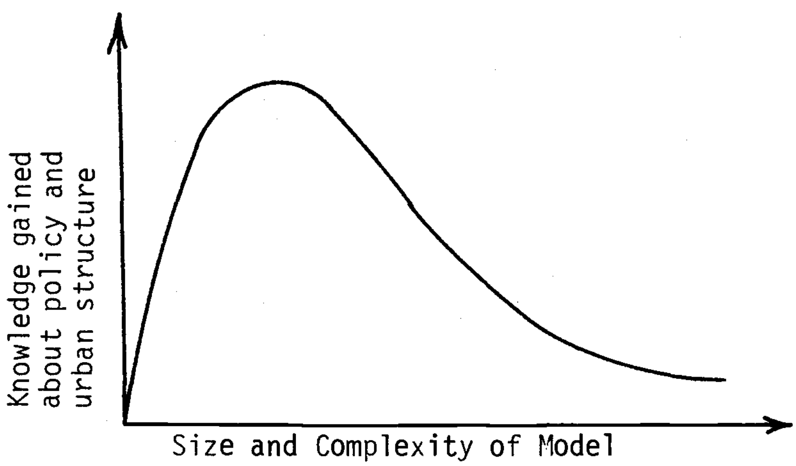


Figure 1-1
Relationship of
Model Size to Knowledge Gained

Planning Techniques

Techniques employed by various models and available methodologies will be combined to make a compact but effective tool to be used by the urban planner. The land use plan design model developed by Schlager (1965) will provide a means of allocating scarce urban land between conflicting and competing land use activities at a minimum combination of public and private costs. The mathematical tool to be implemented is linear programming, which is readily available as a packaged computer routine.

Linear Programming is generally restricted to the optimization of a single objective. The urban planner, on the other hand, has to deal with multiple conflicting objectives. The technique of goal programming (Lee, 1972) is a special extension of linear programming which is capable of handling multiple objectives.

The proposed model still does not provide a means for evaluating alternative urban policies and programs. Brown and Kirby (1971) divided urban attributes into two groups: metropolitan attractions and local or neighborhood characteristics. These attributes can be computed for the zones of an urban area. The result is a very special socioeconomic view of the city based on demographic characteristics, the distribution of land use activity, and the transportation system. This provides the urban planner with the capability of evaluating alternative urban policies and programs.

Resource Planning and Management System (Inoue and Riggs, 1972) is a general systems tool that will be used to combine these techniques and methodologies into one homogeneous urban and land use model. Through the use of Resource Planning and Management System networks (called RPM networks) the planner will better understand the working of the model. By understanding the model, the planner gains an insight into the interaction of activities of the urban process.

CHAPTER II

STATE OF THE ART

An extensive search of available literature was made of existing urban planning models. While it is not the intent of this thesis to report on all the existing models, this chapter discusses fifteen models that were found to be distinctive and representative of the current urban planning models.

A brief summary of each model is included. It is intended that these summaries be brief and not describe each model in great detail. The source documents listed in the bibliography should be referenced for further details of the models.

General Observations

During the literature search, it was found that documentation was often inadequate. Descriptions were vague and sometimes did not exist in a published form. Two reasons for this condition are apparent. First, most of these models have been in a continuous process of development since their inception. Second, most of the models have been developed by consulting groups. Whether consultants fail to document their wares (1) for fear of exposure of necessary operational compromises in their theories, (2) to protect their product from exploitation by others, or (3) because of time pressure, is unknown. Probably all three reasons are applicable.

Classifications of Model

In addition to the summaries, each model is identified by its basic characteristics (Kilbridge, et al, 1969). Table 2-1 presents all fifteen models in a conceptual framework that will allow comparisons of existing models. The adopted classification system is based upon the four basic characteristics of urban planning models: subject, function, theory, and method.

Subject Classification

The subject matter of a urban planning model falls into one of the four general classes: land use, transportation, population, or economic activity. Projection and allocation of land use is the typical purpose of an urban planning model. The simplest of this type are concerned solely with residential land. More general land use models process more diverse input data and allocate land to a variety of uses, residential, industrial, commercial, and public.

Transportation and land use allocation are usually interdependent, the common pattern being a circular causality. A typical transportation model allocates land zones to various uses for some future period, then determines traffic volumes between these zones. Given the traffic volumes, changes in the transportation system are projected. These changes then alter the land use pattern completing the initial round.

Table 2-1

Classification of Urban Planning Models

				Subject																				Function			Theory								Method									
Model Name	Author(s)	City	Approximate Date	Land Use	a) Residential	b) Industrial	c) Commercial	d) Public	e) Roads & Streets	f) Open Space	Population	Transportation	a) Interzonal	b) other	Economic Activity	a) Employment	1. Retail	2. Manufacturing	3. Service	b) Trade	1. Retail	2. Other	c) Personal Income	Projection	Allocation	Derivation	Behavioral	a) Economic	b) Preference	Growth Forces	a) Gravity	b) Trend	c) Growth Index	d) Input-Output	Econometric & Stochastic	a) Regression	b) Input-Output	c) Markov Process	Mathematical Programming	a) Linear Prog.	b) Other Analytic Forms	Simulation	a) Autonomous	b) With Intervention
City 1 (Game)	House	Hypothetical	1968		x	x	x				x					x	x	x					x	x				x						x										x
Community Land Use Game (CLUG) (Game)	Feldt	Syracuse	1963		x	x	x				x		x	x		x	x						x	x				x						x										x
The Emperic Model	Brand, Barber, Jacobs	Boston	1966								x						x	x	x				x	x		x					x		x			x								
Land Use Plan Design Model	SEWRPC	Southeast Wisconsin	1973		x	x	x	x	x	x	x													x	x			x													x		x	
M.E.T.R.O. (Game)	Meier & Duke	Hypothetical (Lansing)	1964								x													x	x			x						x										x
Model of Metropolis	Lowry	Pittsburgh	1964		x	x	x				x						x	x							x	x					x										x			x
NBER Urban Simulation Model	National Bureau of Economic Research	Detroit & Pittsburgh	1972		x	x	x				x		x			x	x	x					x	x	x	x		x			x		x							x				x
Oregon State Simulation Model	Willamette Simulation Unit	State of Oregon	1974		x	x	x			x	x		x			x		x	x			x		x										x			x						x	
Pittsburgh Urban Renewal Simulation	Steger	Pittsburgh	1964		x	x	x				x						x	x				x	x		x	x			x		x		x	x			x						x	
Planning & Land Use System (PLUS)	Skidmore, Owings & Merrill		1969		x	x	x	x	x	x	x															x		x	x								x						x	
San Francisco C.R.P. Model	A.D. Little, Inc.	San Francisco	1965		x						x													x	x	x		x	x									x					x	
TOPAZ	Brotchie, Toakley, Sharpe	Melbourne & Blacksburg, VI.	1973		x	x	x	x	x				x											x	x						x										x		x	
UNC Model	Chapin		1965		x						x													x	x				x							x							x	
Urban Dynamics	Forrester				x	x	x				x					x							x	x										x							x		x	
Urban Performance Model	Arad	Tel-Aviv	1971		x	x	x			x	x		x	x		x							x	x	x				x		x			x									x	

Another common subject is the allocation of present and future population. This is usually closely allied with the land use allocation. Concurrent projections of the population and land use are often used to check statistical reliability and consistency of the models.

The fourth subject of urban planning models is the intensity of economic activity, which is measured by employment, trade, and/or income levels. Economic activity is either provided as an external input, calculated by submodels, or generated by the primary model itself.

Functional Classification

Urban planning models perform three basic functions: projection, allocation, and derivation. Projection is the estimation of the future state of the entities or activities which constitute the subject of the model. Allocation is the distribution of the subject of the model among subclasses of use or demand at a point in time. Derivation is the process by which a model transforms its subject or derives another subject from it. The transformation equations, which convert one subject to another, contain the model's theory of relationship between these subjects. This functional statement of causal relationships is the heart of most models.

Theoretical Classification

The underlying theory of an urban planning model is that set of relationships, stated or implied, which is assumed to prevail between the subject of the model and the larger environment. The model either derives directly from a hypothesis as a symbolic statement of it or it abstracts urban phenomena to symbolic form and relates these structurally, thus creating a hypothesis. In terms of the types of the theory, urban planning models can generally be sorted into two classes: micro-analytic behavior or choice models, and macro-analytic growth forces or index models.

Economic models based on concepts of rational choice, market behavior, and equilibrium comprise one class of behavioral models. These models simulate residential location based on the economic theory that individual households will tend to maximize their local advantage. Another class of behavioral models is organized around multifactor decision-making process. Called general preference models, these systems use the concept of choice as determined by such factors as household budgets, household activity patterns, and taste norms.

Models based on macro-analytic growth-forces assume statistical stability, rationality, and regularity in describing mass behavior. The dynamics of human behavior and urban growth are based on assumptions about social forces rather than individual decisions. The gravity model (Carrothers, 1956) is the purest example of this class. It assumes that the force of social attraction (F) between two population centers is taken to be directly proportional to the product of their populations ($p_1 p_2$) and inversely proportional to some power of the distance (D^m) between them:

$$F = f\left(\frac{P_1P_2}{D^m}\right) \quad . \qquad (1\text{-}1)$$

Another class of growth-force models are the trend models. These types of models analyze historical data to determine past trends of behavior and growth. A regression analysis is usually conducted to form the set of equations that describe the observed behavior.

Growth index models constitute yet another class of growth-force models. These are systems of equations using both implicit and explicit assumptions. Some are derived using intuition alone because of the lack of theory or the absence of data; others are calibrated using theory and data to deduce behavior.

Often a city planner needs to know how demand changes in some industries will affect the level of production and employment in his plan area. Input-output analysis provides a method of answering this question. The classic input-output model assumes that purchases made by each industry are proportional to its output, and that no basic change takes place in this relationship.

Methodological Classification

The operational method of a model is the technique employed to project, allocate, or convert the input data of the model's subject. Three classes of analytic technique are sufficient to describe the operational method of most urban planning models: econometric forms, mathematical programming, and simulation.

Econometric techniques have been developed by statistical economists engaged in derivation and test of economic theory. These include such well-known techniques as regression, input-output, and Markov processes. Econometric models are rigid mathematical forms found useful in economic theory but inhibited in use in urban models designed for testing public policy or programs.

Mathematical programming models are of three forms: linear, quadratic, or dynamic. The use of such models presupposes the existence of criteria of optimization, requiring a consensus difficult to achieve in a urban planning. Dynamic and quadratic programming have the potential for handling both discrete and nonlinear objective functions which linear programming cannot do.

Simulation refers to the way in which a model is used rather than to the structure of the model itself. While analytic models contain precise mathematical statements which can be solved by standard mathematical operations, simulation models usually involve nonmathematical statements about relationships between elements which have no numerical solution.

Although simulation models can be designed to operate autonomously from the beginning to end of their cycle, many are structured for human intervention. There are two reasons for the existence of interrupted simulation models: some urban relationships are too complex and not sufficiently understood for total reduction to mathematical form, and many models branch out into a vast number of alternatives, and thus overrun the capacity of even large computers.

To avoid this, the program is stopped for user's decision input at branch points. The user makes the necessary decision and sets the computer on that course.

Other analytic forms is a catch-all category for mathematical expressions that do not fit the econometric or mathematical programming classification. They are mostly open systems of exponential, logarithmic, or linear equations, without objective functions, used to represent urban relationships.

Presentation of some of the models in Table 1 may at first seem to contain contradictions in classification. This is because the larger models are general systems containing submodels of different types. The apparent contradictions arise from including both general and particular models under one title.

CITY I

The Washington Center for Metropolitan Studies has designed and built an urban simulation game called REGION, which was an outgrowth of CLUG (Community Land Use Game), upon which they made further revisions resulting in the present game CITY I (Haack and Peterson, 1971).

CITY I incorporates economic and political processes and several aspects of the social process. The economic system, however, is the most detailed. Teams try to maximize their private holdings on the one hand, and keep their governmental departments in good shape on the other. The teams derive economic power from the ownership of businesses and political power from the votes of residences owned.

A single day's play can point up the relationships between public and private decisions although the full complexities of urban-suburban development show up only after many rounds. A computer is used to eliminate tedious accounting, simulate a market economy, and evaluate the human differences that exist in the real world.

Its creators see CITY I as a teaching tool and planning aid for insuring that urban development is orderly and coordinated. Participants agree that the game is meaningful and that they have benefited from playing it.

COMMUNITY LAND USE GAME

CLUG (Community Land Use Game) was initially begun as a class project in an urban ecology course at Cornell University (Feldt, 1966a). The game provides its players with an opportunity to experience some of the more basic economic forces effecting land use decisions in the community.

The object of the game is to make money. The players start out with a specific amount of money with which to buy and develop land. Development only makes a profit when it is located fairly efficiently and when it is integrated into the economy of the game community that is being built. Players can reduce losses to themselves and the community by minimizing the distances between land uses that interact frequently, prudently managing a capital improvement program, and by juggling renovation and construction costs on existing buildings. Many rules of the real world are built into the game and restrict the players in their attempts to make money. Some criticism has been made about CLUG's focus on the economic factor of a community and its failure to include the social and political factors.

Mathematical sophistication is not required for play. Although CLUG is intended to be played manually, a computer program is available for use in research or extended play.

THE EMPIRIC MODEL

The EMPIRIC Model (Hill, 1965) was devised for the Boston Regional Planning Project which is engaged in formulating a comprehensive development plan for the Greater Boston Region. The model is designed to reallocate population and employment among the region's territorial subdivisions as the regional totals change over time and as local changes occur in the quality of public services and transportation networks.

The model distinguishes two classes of poulation and three classes of employment. The model is formulated as a set of simultaneous linear equations for each district, one equation for each population or employment variable. The dependent variable is the change, during the forecasting interval, in the district's share of the regional total for that activity. These changes-in-shares are added into the shares held by each district at the beginning of the forecasting interval, and the revised shares determine the distribution of independently forecast totals for each activity group.

Land use accounting plays a very minor role in this model. Since the dependent variable of each equation is a change-in-share of an unspecified regional total, the land-use implications of this model's forecast of activity distributions do not prevent over development of a district.

The model has been calibrated and tested successfully against past data. The accuracy of the EMPRIC Model compares favorably with the accuracy obtainable from other forecasting models.

A LAND USE PLAN DESIGN MODEL

The Land Use Plan Design Model (Southeastern Wisconsin Regional Planning Commission, 1973) is a mathematical model which is intended to aid the planner in creating an ideal land use plan for an area at some target year. An ideal plan that will minimize the total private and public costs as well as satisfy the community development objectives and design standards.

In using the Land Use Plan Design Model, the planning area is divided into a number of discrete land areas called cells. The land use demand is expressed in terms of a series of discrete land use elements called modules, such as residential neighborhoods, schools, commercial centers, and so on. Using a random search procedure, the modules are assigned to cells subject to the design constraints associated with the land use plan under consideration. These constraints form an essential part of the plan design process, for they control the feasibility of a plan. The total cost of a particular plan design is divided into two categories: site development cost, which includes the construction and maintenance costs of the module elements, and linkage cost, which consists of construction, maintenance, and operation costs of facilities such as transportation routes, water and sewer lines, and connections for other public utilities between a pair of module units.

The random search technique assumes that there is an optimal zone of module-cell combinations which contains a number of best alternative plans. Rather than generating all feasible combinations, which would be impracticable and expensive, only a given number of plans are made. The number of plans to be generated is determined by the plan accuracy and the probability of success designed by the planner.

The Land Use Plan Design Model has displayed only limited success in "real world" application. Although the model appears to be conceptually valid, Southwestern Wisconson Regional Planning Commission recognize several deficiencies in the present model which require further work. As further refinements are made, the Southwestern Wisconsin Retional Planning Commission feels that the model can be an important tool in the operational planning process.

METRO

METRO (Meier and Duke, 1966) is a gaming simulation developed as part of a long range effort to improve the quality of education in the urban planning field and to advance urban research and research methodology. METRO is an acronym which stands for Michigan Effectuation, Training, and Research Operation. The primary aim of the game is to reduce the gap between "plan-makers" and "decision-makers" by letting decision-makers see the implications of "alternative decision chains". Also, METRO was designed to illustrate the kinds of information available for decision-making, and the techniques available for evaluating and implementing decisions.

The major groups of participants in the game are politicians, educators, planners, and land developers. They are each assigned to each political jurisdiction. Each player is cross-pressured, with his professional role often in conflict with the needs of his area. Furthermore, public demand always exceeds available funds, requiring a continual balancing of costs and benefits. Game play is a constant exercise in making bargains and forming coalitions.

METRO incorporates a family of mathematical models to simulate voter responses, economic and demographic growth, and redistribution of population. The model has been calibrated with data from Lansing, Michigan which it simulates. Computer programs provide a variety of data base manipulations, visual displays, and record keeping activities that adds realism to the game. The computer programs also adds considerably to the continuity and flow of the game by maintaining a time compression of real world years to a few game hours.

A MODEL OF METROPOLIS

The Model of Metropolis (Lowery, 1964) is designed to generate estimates of the distribution of retail employment, residential population, and land use for a bounded region. Input to the model are geographic distributions of basic employment (industrial, commercial, and administrative establishments), the amounts of space occupied by basic establishments, and constraints imposed on land by physical and legal circumstances. Given these inputs, the model applies certain allocation rules, which are empirically devised, to generate the number of households and retain employees assigned to each square mile of the metropolis. Properly adapted, this model should be useful for the projection of future patterns of land development and for the testing of public policies in the fields of transportation planning, land-use controls, taxation, and urban renewal.

A region of 420 square miles centering on the city of Pittsburgh has been fitted into the model. Although a shortage of data eliminated the possibility of rigorous tests of validity for the model as a whole, the model reflected trends already visible in the Pittsburgh area and in other large urban areas of the United States. A second-generation effort of revision, elaboration, and improvement of data within the general structure of the present model has been conducted as part of the Pittsburgh Urban Renewal Simulation Model.

Two major revisions were made in formulating the Pittsburgh Urban Renewal Simulation Model (Steger, 1965): first, the model now determines the relocation of most basic activities on the basis of conditions within the model and thus within the city; and second, the model does no longer distribute all activity in one attempt, but takes as its starting point existing conditions and incrementally handles the location and relocation of new and moving households and businesses.

NBER Urban Simulation Model

The NBER (National Bureau of Economic Research) Urban Simulation Model (Ingram, 1972) was designed to simulate major changes on urban spatial structure that occur over periods ranging from ten to fifty years. The principal theoretical interest was to understand the effects of the level and spatial distribution of employment, of changes in transportation technology, of increases in income, and of the growth in employment and population. Principal policy concern was with the indirect and relatively long-term impacts that various public policies would have on urban spatial structure, on investments in residential and nonresidential capital, and on changes in the characteristics of neighborhoods.

What makes this model different from previous simulation models is that it is deeply rooted in economic theory; the utility-maximizing households and the profit-maximizing firms that pervade microeconomics are the basic building blocks of the model. Previous models have represented household location decisions and changes in urban spatial structure by elaborate statistical descriptions, usually with little or no theoretical justification. In contrast, the NBER model directly simulates most of the important market behaviors which influence urban spatial structure.

The preliminary NBER model was calibrated for the city of Detroit and was called the Detroit Prototype. A number of serious deficiencies in the model were exposed. As more complete data became available, the model was shifted to a Pittsburgh data base and was called Pittsburgh I. Early test results from the Pittsburgh I have convinced the authors of the model that they can achieve a satisfactory calibration of the NBER Urban Simulation Model for Pittsburgh, and eventually for other cities as well.

OREGON STATE SIMULATION MODEL

The Oregon State Simulation Model (OSSIM) (Willamette Simulation Unit, 1974) is part of a research project underway at Oregon State University entitled "Man's Activities as Related to Environmental Quality." The primary objectives of this project are: 1) to assist the people of Oregon as they make choices relative to environmental quality and economic growth; 2) to enhance the capacity of Oregon

State University to deal with problems of environmental quality; and 3) to provide experience to students in working with multiple disciplines and systems analysis.

The symbolic language of "System Dynamics," developed by Jay W. Forrester, (1968) was used to formulate the model. This provided a common framework for discussions and increased the likelihood that model components built by different participants would be compatible with one another. A maximum time horizon for the model is fifty years (1970-2020).

The state is divided into three geographic regions: the Willamette Valley, the Coastal Range, and Eastern Oregon. Hence, the OSSIM consists of three interdependent "parallel" models which are structurally identical but qualitatively different.

Each model is composed of seven components: Demographic, Economic, Land Use, Transportation, Energy, Pollution, and Government Revenue. These components are dynamically connected to one another to form the model. The internal structure of each component reflects the modeler's conceptual views of the State of Oregon. While the methodology employed is general and could be used to model other regions, the specific structure and dynamic behavior of the components of a new application could differ considerably from those of the Oregon State Simulational Model.

In a separate but related effort, a simulation model of the quality of life is being developed by Robert Mason and Alex Seidler. Ultimately, this Quality of Life Model will be integrated with the

OSSIM. The fundamental concept employed is that the quality of life is inversely proportional to the discrepancy between the perceived achievements and the perceived desires in the important domains of life. The closer are the perceived achievements to the perceived desires, the higher the quality of life is expected to be. The QOL model has been divided into ten domains of life: income security, family planning, transportation, health care, public safety, neighborhoods, environmental quality, recreation, energy availability, and the political system.

PLUS

The Planning and Land Use System (PLUS) was developed to analyze urban development alternatives and to assist in the process of physical planning and development (Sutphin, et al, 1971). PLUS provides the engineer, architect, and planner with the immediate capability of testing alternative building and land-use mixes.

Three logically distinct concepts are used in the formulation of PLUS: the development objectives, the characteristics of the land uses available to meet those objectives, and the set of design standards which apply to the proposed development. A development objective is a measure of the project size, expressed in square feet, dollars, residents, or employees. Each land use is defined by a set of characteristics comprising economic, spatial, population, and utilities data. Design standards are expressed as minimum and maximum amounts of specified land uses or as ratios between land uses. The planning problem is then to find those combinations of land uses which satisfy the development objectives, subject to the given set of planning standards.

Rather than provide the designer with a single solution maximizing or minimizing a single objective function, PLUS provides a range of solutions which cover and effectively sample the solution space. A one-line summary is printed for each solution showing how the land to be developed is apportioned among the various categories of use, project costs, annual income, and rate-of-return on the investment. PLUS provides additional information for the solution offering the maximum return on investment: a land use summary, a site planning and population summary, a cost summary, a financial summary, a utilities summary, and a summary of additional requirements.

PLUS has been used with excellent results on several projects. Because of its ease of use and its adaptability to many variations, the authors feel that PLUS will provide the planner with a useful, standardized, analytic tool to assist in new developments whether it be of a small subdivision or of a complete new town.

THE SAN FRANCISCO MODEL

The San Francisco Model (Robinson, 1965) was developed for the City and County of San Francisco, to assist them in the preparation of a Community Renewal Program. The model, as initially designed, will deal primarily with the residential sector. It is intended to be used as a tool for analyzing the impacts of various public programs (zoning projects, public housing, rent subsidies, mortgage guarantees, etc.) on the housing stock of the city and its utilization.

The operation of the model is based upon a matching of existing stocks of space in the city with the potential users of the space. Changes in the amount or quality of space occur when the users of space create a demand for space which results in a space pressure. The advent of space pressure causes rents to rise. Actual changes in the space stock will be generated to a degree sufficient to relieve this pressure if the change is financially feasible. If a profitable development exists, an appropriate number of new housing units is added to the inventory. When all the effects of making such a change have been made, the process beings again. In this way a new configuration of space-usage is repeatedly generated, approximating the actual functioning of the city's space market and the physical development of the city.

Public action programs and policies may be introduced into the simulation as they effect the operation of the market. The resultant effect on the allocation of space-usage may be evaluated in terms of city goals and objectives. In this way a time-phased program of public actions may be selected to achieve the objectives of renewal.

TOPAZ

The basic idea behind TOPAZ (technique for the optimum placement of activities in zones) was to use readily available mathematical allocation schemes to organize land use development in an urban area with the objective of minimizing public service and travel costs (Dickey, et al, 1973). Basic data requirements necessary for TOPAZ are per acre capital development costs and benefits, travel costs, estimates of areas available for development in each zone, and estimates of the areas of each land use required by the horizon year.

A gravity model is used to make estimates of zone-to-zone movements based on existing and future amounts of each land use on each zone. This makes the determination of the optimal allocation of activities a very difficult matter. However, TOPAZ involves an iterative solution procedure in which a feasible solution is assumed initially. As a result, the objective function becomes linear throughout and this linear version is the standard transportation problem which can be solved rapidly with available algorithms. The solutions from such an iterative solution are not necessarily global optima, but they are claimed to be sufficiently close.

TOPAZ was developed initially for use in Melbourne, Austrialia. This technique was employed in Blacksburg, Virginia, both to test a proposed land use scheme and to use this scheme as a basis for finding better arrangement patterns. Even though the results could be of significance to Blacksburg's development policy, it was found that

TOPAZ focused almost entirely on physical planning and not enough on economic, social, and political planning.

THE UNC MODEL

A model of residential growth was developed at the Center for Urban and Retional Studies located at the University of North Carolina (Chapin, 1965). The objective of this model is to predict the incidence of conversion of rural or vacant land to residential use as the population of the study area increases.

The metropolitan area is divided into a system of cells. Those cells that are already developed or are scheduled for nonresidential use are removed from the inventory. The cells remaining are available for conversion to residential use at densities which are determined from zoning laws.

The UNC program assigns to each cell an attractiveness rating which is a linear combination of initial assessed value, accessibility to work areas, availability of public sewage, accessibility to nearest major street, and accessibility to nearest elementary school. The probability of an undeveloped cell being converted to residential use is proportional to its attractiveness rating. Discrete units of development are assigned to cells by random sampling (without replacement) from the resulting probability distribution. The sampling process continues until enough cells have been developed to accommodate the given increment of urban population.

A new inventory of available cells is made and the attractiveness rating is re-evaluated for each cell. The sampling process is done again for the next increment of time. This cycle continues until the end of the forecast period. Preliminary tests of this model have been promising and improvements and refinements are continually being made.

URBAN DYNAMICS

Urban Dynamics (Forrester, 1969) examines the life cycle of an urban area using the methods of industrial dynamics that have been developed at Massachusetts Institute of Technology. The model consists of a selection of factors that are believed pertinent to questions about urban growth, aging, and revival.

The growth model starts with a nearly empty land area and generates the life cycle of development leading to full land occupancy and equilibrium. This equilibrium model is then used to explore how various changes in policy would cause the condition of the urban area to be altered over time. Various common urban-management programs have been examined. It was found that many past and present urban programs may have actually worsened the condition they intended to improve. Alternative programs, addressed to the underlying causes of urban decay rather than to symptoms, suggest different approaches.

This model has been developed as a method of analysis. Urban policies can be evaluated once the dynamic model or a modification of it has been accepted as adequate.

URBAN PERFORMANCE MODEL

The Urban Performance Model (UPM) (Arad, 1972) is a predictive and distributive urban growth model and a tool for organizing and processing large amounts of metropolitan area data in a manner which predicts the effects of changes in the distribution of land uses, facilities, and services on fulfillment of the needs of urban populations. One of the main purposes of the UPM is to assist urban decision makers in the allocation of urban resources by providing quantitative estimates of the consequences of policies and projects on overall urban performance.

The UPM concept recognizes that urban programs affect land uses, and that the spatial arrangements of the various land-use activities determine the level of performance of an urban area with respect to its residents and other users of urban space. A change in even a single policy, program, or project is likely to alter urban land uses or change the effectiveness of several other programs.

The Urban Performance Model has two underlying assumptions which are fundamental to its development and directly used in urban performance measurement. The UPM assumes that all urban residents seek: 1) To increase real freedom of choice (Opportunity) in significant aspects of life. 2) To increase the Quality of their immediate surroundings. These two measures of Opportunity and Quality are the bases of the Urban Performance Model.

It is difficult to imagine any single program or project which will result in an equal distribution of benefits and costs. Today, the new-felt power of various social and economic groups is such that decision makers must be concerned with expected changes in the distribution of benefits and costs. The UPM provides this information through analysis of the changes on Opportunity and Quality of Life for the geographic areas as well as social and economic groups.

CHAPTER III

PROPOSED METHODOLOGY

The purpose of this thesis was defined in Chapter I as the presentation of an integrated analytical tool to assist the municipal planner in evaluating alternative planning strategies. This chapter will present both the model and the methodology. The two components of the proposed model have previously been developed independently as the Land Use Plan Design Model by Kenneth J. Schlager (1965) for the Southeastern Wisconsin Regional Planning Commission, and the Evaluation of Urban Performance by Albert Brown and Ronald F. Kirby (1971) for PRC Systems Sciences Company. The methodologies of Resource Planning and Management System (Inoue and Riggs, 1972) and Goal Programming (Lee, 1972) will be combined and used to formulate, solve, and present linear Land Use Plan Design Model.

Optimization Methods

Resource Planning and Management System (RPMS)

The general systems approach of Resource Planning and Management Systems (RPMS) was developed by Dr. Michael S. Inoue and Dr. James L. Riggs at Oregon State University in 1972. One of the major attributes of RPMS is the ability to describe a Linear Programming (LP) problem visually by a RPM diagram. The RPM diagram easily portrays any resource conversion system that can be described in terms of linear equations and inequalities. The formulation of the RPM diagram to a standard linear programming model has been described in a previous thesis (Mercer, 1975).

Goal Programming

Goal programming was introduced by A. Charnes and W. W. Cooper in 1961 (Lee, 1972) as a modification of linear programming. Standard linear programming models are limited to a single objective function. The goal programming approach allows the solution of multiple, conflicting objectives. Instead of maximizing or minimizing the objective function directly as in linear programming, goal programming minimizes the deviations from the goals within the given set of constraints (Lee, 1972).

The general form of a linear programming model may be expressed as:

$$\text{Min} \quad Z_x = \sum_{j=1}^{n} c_j x_j \tag{3-1}$$

$$\text{s. t.} \quad \sum_{j=1}^{n} a_{ij} x_j \geq b_1 \qquad 1 \leq i \leq m \tag{3-2}$$

$$x_j \geq 0 \qquad 1 \leq j \leq n \tag{3-3}$$

The conversion of resources by a process in a RPM network is shown as a flow through the model. This flow may be either positive or negative. Taking the general linear programming model, shown in equations 3-1 and 3-2, and dividing each constant and coefficient into its positive and negative component, the linear programming model can be expressed in terms of RPM (Mercer, 1975):

$$\text{Min} \quad Z_x = \sum_{j=1}^{n} c_j^+ x_j - \sum_{j=1}^{n} c_j^- x_j \tag{3-4}$$

(See Figure 3-1)

$$\text{s.t.} \quad \sum_{j=1}^{n} a_{ij}^+ x_j + b_i^- \geq \sum_{j=1}^{n} a_{ij}^- x_j + b_i^+$$

$$1 \leq i \leq m \tag{3-5}$$

(See Figure 3-2)

$$x_j, c_j^+, c_j^-, a_{ij}^+, a_{ij}^-, b_i^+, b_i^- \geq 0$$

$$1 \leq i \leq m; \quad 1 \leq j \leq n \tag{3-6}$$

$$c_j^+ \; c_j^-, \; a_{ij}^+ \; a_{ij}^-, \; b_i^+$$

$$1 \leq i \leq m; \quad 1 \leq j \leq n \tag{3-7}$$

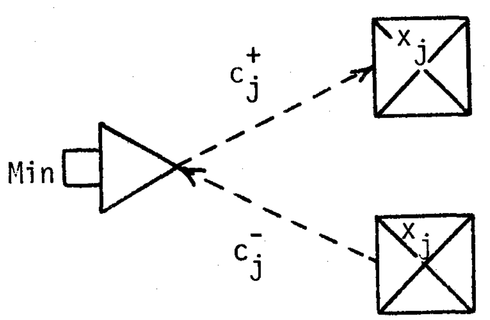


Figure 3-1
Objective Function

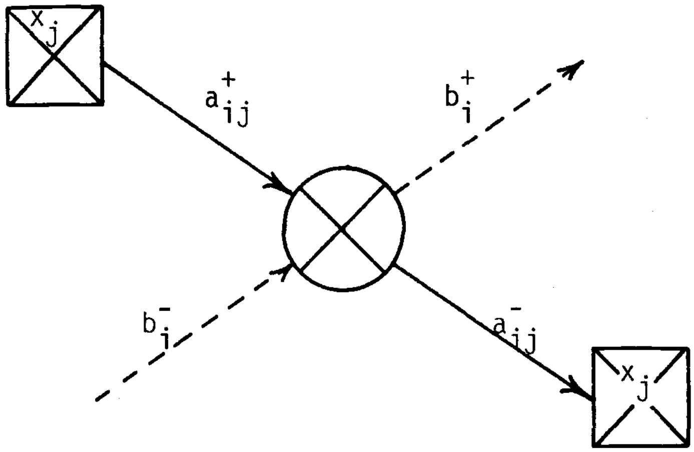


Figure 3-2
Constraint

In goal programming each objective is expressed in terms of the deviation from that objective. This deviation may be either negative or positive and is called underachievement (d^-_i) or overachievement (d^+_i). A hierarchy of importance must be made among the objectives so that higher-order goals are satisfied first. For goals with the same priority level a weighting coefficient (w_i) must be added. For example, if the under- and overachievement of an objective have the same priority but underachievement has twice the regret of overachievement, a weighting coefficient of two is applied to d^-_i, and the goal is written as: min $P_i - 1d^+_i + 2d^-_i$.

The general form of a goal programming model may be expressed as follows:

$$\text{Min} \quad P_k = \sum_{i=1}^{m} (w^+_i\, d^+_i + w^-_i\, d^-_i) \tag{3-8}$$

$$\text{s.t.} \sum_{j=1}^{n} a_{ij}\, x_j - d_i^+ + d_i^- = b_i$$

$$1 \le i \le m \tag{3-9}$$

$$x_j,\ d_i^+,\ d_i^- \ge 0$$

$$1 \le i \le m; \quad 1 \le j \le n \tag{3-10}$$

$$d_i^+\, d_i^- = 0 \quad 1 \le i \le m \tag{3-11}$$

Expanding equations 3-8 and 3-9 into their positive and negative components, the general goal programming model can be expressed in terms of RPM. In a RPM network the deviational variables for each objective are minimized separately and in order of importance. The optimal value of the kth goal (P_k^*) is then placed in the network as a constraint for evaluating lower-order goals. The value of P_k^* when a goal is met is zero.

The general linear programming model, upon the achievement of the last goal can be expressed in terms of RPM as:

$$\text{Min } Z_x = \sum_{j=1}^{n} c_j^+\, x_j - \sum_{j=1}^{n} c_j^-\, x_j \tag{3-12}$$

(See Figure 3-3)

$$\text{s.t.} \sum_{j=1}^{n} a_{ij}^+\, x_j + d_i^- + b_i^- = \sum_{j=1}^{n} a_{ij}^-\, x_j + d_i^+ + b_i^+$$

$$1 \le i \le m \tag{3-13}$$

$$P_k^* \geq \sum_{i=1}^{m} w_i^+ \, d_i^+ + \sum_{i=1}^{m} w_i^- \, d_i^- \qquad (3\text{-}14)$$

(See Figure 3-4)

$$x_j, d_i^+, d_i^-, c_j^+, c_j^-, a_{ij}^+, a_{ij}^-, b_i^+, b_i^- \geq 0$$

$$1 \leq j \leq n; \quad 1 \leq i \leq m \qquad (3\text{-}15)$$

$$d_i^+ \, d_i^-, \; c_j^+ \, c_j^-, \; a_{ij}^+ \, a_{ij}^-, \; b_i^+ \, b_i^- \; = \; 0$$

$$1 \leq j \leq n; \quad 1 \leq i \leq m \qquad (3\text{-}16)$$

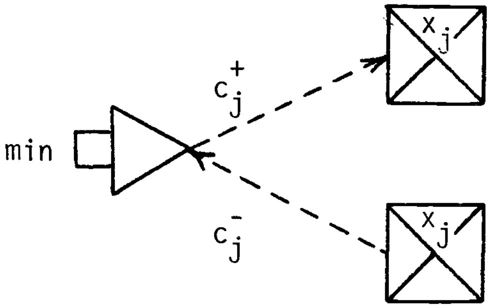


Figure 3-3
Objective Function

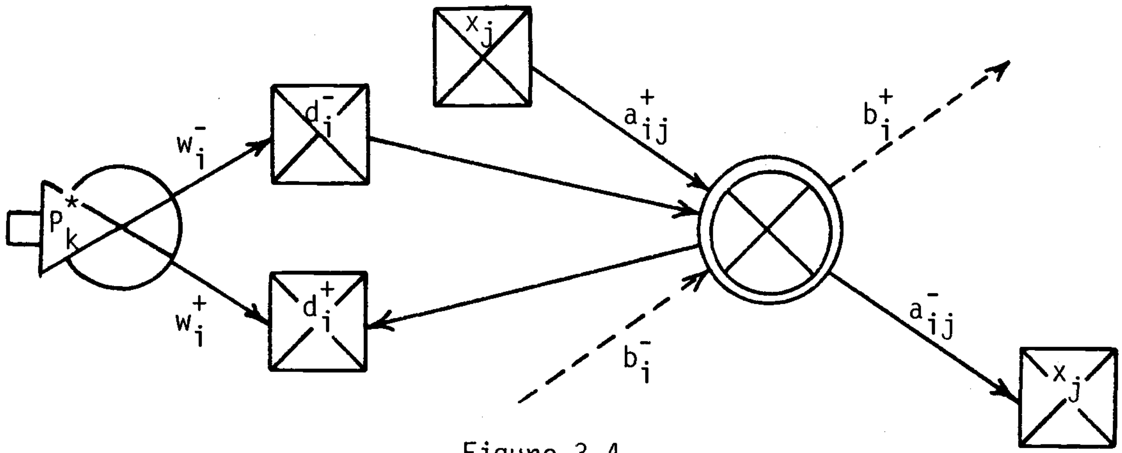


Figure 3-4
Goal Programming Constraint

Land Use Plan Design Model

There are two approaches to modeling land usage. The first approach conceives the urban complex as a phenomenon to be explained scientifically and as a changing configuration that can be predicted. The second approach conceives the urban complex as a subject for design. The design approach to planning has usually been an alternative. Alexander (1964) defined the design process as an effort to achieve fitness between two entities: the form in question and its context. The form is the solution to the problem and the context defines the problem.

Design Approach

Using Alexander's definition of the design process, Schlager (1965) proposed that the objective of the design methodology be to achieve as good as possible a match between the form and context of the land use plan. The achievement of this match is difficult because the multitude of design variables interact in a complex way. Difficulties in the design process derive primarily from the inability of the human designer to manipulate simultaneously a large number of interacting design relationships. Mathematics provides a powerful tool for the manipulation of these relationships for the more effective solution of design problems.

The first requirement of the land use plan design is to generate alternative solutions in terms of the basic measure of land use, the land itself. Three sets of variables will be used: (1) the type of land use (quality variables), (2) the density of land use (quantity variables), and (3) the geographic location (location variables). These variables will be used to characterize the process of dividing the land with a grid system. For each location the types and densities of land uses will express a measure of the activities in that area. The amount of detail provided will depend on the coarseness of the grid.

The grid nature of the coordinate system does not limit the result to rectangular plans. The most complex and irregular plan may be expressed with the designated variables if an appropriate grid size is selected.

The second condition affecting the relationship between alternative forms and design requirements is the existence of standards that restrict the possible land use plans. For a design model, these standards may be divided into two primary classes: (1) Standards that restrict the minimum or maximum numerical value of a land use or a relationship between land uses within a grid zone. Examples of these standards are the requirement of simultaneous development of both open space and residential land in the same grid zone (relationship standard) or the exclusion of flood plain areas from development in a given grid zone (maximum value standard).
(2) Standards that restrict a relationship between land uses between grid zones. An example would be the provision of a regional shopping center within a certain travel time of every residential area.

The design requirements can be expressed symbolically as algebraic equations (or more often inequalities) using the three classes of variables noted earlier. This is possible because land use planning is concerned with a single measurable resource, land.

Given both the design requirements and the design alternatives, Schlager's statement (Schlager, 1965) of the land use plan design problem can be summarized as follows:

> Honor any land use restrictions and satisfy the prediction of land use needs for urban activity by forming a land use plan design which operates at a minimum combination of public and private costs.

The basis for minimal costs is not to provide a cheap plan but to avoid unnecessary expenditures of precious resources as long as the design standards and land demands are compiled within the plan design.

Linear Programming Application

The application of linear programming to the land use plan design is well suited since the objective of linear programming is the optimization (maximization or minimization) of some objective, such as cost, within the restrictions of certain constraints such as design standards. The formulation of the land use plan design model is a linear programming problem is straight forward. The objective function relates to the cost of developing land for a given land use:

$$C_T = \sum_i \sum_u C_{iu} X_{iu} \tag{3-17}$$

where C_T = total cost of the land use plan

x_{iu} = quality and quantity of land use u located in zone i

c_{iu} = cost of developing land use u in zone i

The equality and inequality constraints are as follows:

1. The total demand requirement (E_u) for each land use category (u) must be met:

$$\sum_i \sum_u X_{iu} = E_u \tag{3-18}$$

2. Development within a grid zone must be limited:

$$\sum_i \sum_u d_u \; X_{iu} \leq F_i \tag{3-19}$$

where F_i = the size of grid zone i

d_u = coefficients that account for land service requirements, such as streets, for land use u.

3. Inter- and intrazonal land use restrictions must be satisfied:

$$x_{iu} \leq Gx_{iu'} \qquad \text{or} \qquad x_{iu} \leq Gx_{ju'} \tag{3-20}$$

where G = ratio of land use u in zone i allowed relative to land use u' in either the same zone i or different zone j.

For each primary land use category, there is one equality constraint. Since some land uses such as residential are usually subdivided further according to densities, the number of demand equations increases. The second and third categories of constraints reflect the design standards and may take a wide variety of forms. For a region subdivided into about 30 zones, the size of a typical linear program for a land use plan design is about 60 constraints and 400 variables.

The design focus of the land use model allows the planner to suggest what should be done, as opposed to merely explaining what is being done. The optimum design also permits the development of evaluation criteria for existing ongoing urban processes. The burden of explaining precisely what is happening is a complex interaction is replaced by the rewarding talk of comparing the outcomes of the interaction in the present system to those of an optimally designed structure.

Goal Programming Application

The steps in relating goal programming to the Land Use Plan Design Model are:

1. Define the area to be studied. Define the grid pattern to be used and delineate each zone.

2. Graphically portray the existing land resources on a RPM diagram.
3. Decide upon the goals and their priorities and portray them on the RPM diagram.
4. Determine P_k^* and represent them as constraints on the RPM diagram.
5. Evaluate the final land use plan in terms of the goals. At this time the planner may restate his goals and determine a new land use plan.

Chapter IV illustrates these steps numerically.

Urban Performance Evaluation

Urban planners and decision makers have the need for improved methodology and tools for evaluating alternative urban policies and programs. The complex and interactive nature of the urban system rarely permits the use of just a single evaluation criterion for decision making. Often the improvement for one group of residents of an urban service (such as travel mobility) carries with it significant negative impacts (such as neighborhood disruption and increased pollution) for other groups of residents.

Urban planning procedures often utilize computer programs to check and organize urban data, forecast travel volumes, and analyze transportation networks. The recognized limitations of these programs is that they provide little or no information to the decision maker on the social impacts of alternative urban programs (Harris, 1968).

A useful evaluation methodology would permit a comparison of alternative urban policies instead of local evaluation of direct urban service adjustments (Brown & Kirby, 1971). The methodology will be developed in three steps:

1. The major attributes desired by the residents of an urban area will be identified and quantified in marcoscopic terms;
2. Using these desirable urban attributes, the overall performance of the urban area is described in terms of the availability of these attributes to different groups of its residents;
3. Alternative planning policies and programs can now be evaluated in terms of changes that effect the availability of the urban attributes.

The position of this methodology is to determine what the urban dwellers want, then find out how well those desires are being met as a measure of urban performance. An alternate would be to find out what the people should have according to a value structure other than their own. An idealized urban system could be designed according to some acceptable criteria, then the existing urban system compared to it to evaluate a measure of urban performance.

Urban attributes are composed of two factors, metropolitan attractions, and local or neighborhood characteristics (Butter, et al, 1969). Metropolitan attributes include such things as employment, shopping, and recreation. This attribute must be in terms of quantity, quality, and accessibility, and will be defined as metropolitan opportunity. Neighborhood attributes include the quality of local streets, housing, schools, shopping, and fire, police, and other local services. These items are essentially independent of the surrounding urban structure and will be termed neighborhood quality. The development of quantitative measures for each of these urban attributes is discussed in the following sections.

Metropolitan Opportunity

As an urban area increases in size, more jobs, more educational facilities, more recreational facilities, and more housing is made available to the residents of that urban area. While the mere existence of these various attractions spread throughout the urban area is necessary to provide opportunity for its residents, it is not sufficient. Metropolitan opportunity must have two basic components. First, the metropolitan attractions must be available to the residents. Available in the sense that certain minimal requirements such as skills, funds, or suitable background must be satisfied before it is possible for residents to take advantage of many urban attractions. Any given attraction will be viewed differently by the different social, economic or other groups in the metropolitan region. For example, blue collar workers may not find much attraction in a white collor office complex whether it is near or far. High income families are not attracted to areas of low cost housing.

The second component of metropolitan opportunity is the ease, in terms of distance, time and cost, in getting from the residents home to the location of the metropolitan attraction. The resistance to this accessibility, or urban impedance, will depend on the distribution of metropolitan attractions and on the means of transportation available to the various groups of residents. Just as with metropolitan attraction, the different economic or social groups in the city use different mixes of the transportation modes, and allocate different amounts of their resources for moving from their homes to the various attractions. For example, movement between the locations along a freeway is possible at low cost and time for residents who have automobiles. However, if the public transportation system is poor, the cost and time for movement between the same two locations by bus may be many times greater for residents who do not or cannot use automobiles.

Quantification of Metropolitan Attractions. Let the urban area be divided into a number of geographical neighborhoods or zones, designated $i = 1,2,3,\ldots$. These zones may be census tracts, school districts, voting precincts or any other division depending upon the interests of the planner. The residents of the urban area can also be divided into groups according to income, race, years of education, or other criteria and designated as p_1, p_2, p_3 .... Let the different types of metropolitan attractions be labeled $t_1, t_2, t_3, \ldots$ In our computer model, $t = 1$ when the urban attraction is work. Then

A_{ip} = measure of metropolitan attractions appropriate to resident group p in zone i.

Q_{tip} = quantity of metropolitan attractions of type t in zone i appropriate to resident group p.

For example, Q_{1ip} may be measured in number of jobs. Another Q_{tip} measured in square feet of shopping space, may be used to represent the attraction for shopping.

The overall attraction (A_{ip}) is a dependent variable of the quantity of attractions, Q_{tip}:

$$A_{ip} = f(Q_{1ip}, Q_{2ip}, \ldots). \tag{3-21}$$

Not all attractions are of equal importance to urban residents, so a weighting term, B_{tp}, will be used to account for the importance of an urban attraction t to resident group p. The total time spent by members of resident group p per week in taking advantage of attractions of type t might be used for B_{tp}. More readily available values are the total number of trips or the total time spent travelling to attractions t by resident group p. A more useful unit of measure would be the importance to resident group p of a unit of attraction t in the urban area: $\frac{B_{tp}}{Q_{t \cdot p}}$ where a period in place of a subscript denotes summation over that subscript: thus, $Q_{t \cdot p} = \sum_i Q_{tip}$.

Assuming the functional relationship between A_{ip} and Q_{tip} to be a linear summation, the total attraction to resident group p in a particular zone i can be given as

$$A_{ip} = \sum_t \frac{B_{tp}\, Q_{tip}}{Q_{t \cdot p}} \tag{3-22}$$

where the units of attraction are those of B_{tp}. A more common unit of attraction would be that of employment attraction. The units can be changed by dividing the above expression by the importance of one unit of employment attraction (t=1) for resident group p,

$$\frac{B_{1p}}{Q_{1\cdot p}} \quad . \tag{3-23}$$

Total attraction to resident group p can now be defined in units of job-equivalents and can be expressed as

$$A_{ip} = \sum_{t} \frac{B_{tp}\, Q_{tip}\, Q_{1\cdot p}}{B_{1p}\, Q_{t\cdot p}} \tag{3-24}$$

or

$$A_{ip} = Q_{1ip} + \sum_{t\neq 1} \frac{B_{tp}\, Q_{tip}\, Q_{1\cdot p}}{B_{1p}\, Q_{t\cdot p}} \tag{3-25}$$

In order to evaluate metropolitan attractiveness, A_{ip}, data must be available to determine Q_{tip} and B_{tp} values. It is assumed that values of B_{tp}, therefore the ratios $\frac{B_{tp}}{B_{1p}}$ for $t\neq 1$, can be obtained from primary data sources such as home surveys and home interviews. Evaulation of Q_{tip} is based on other data usually available for most United States cities. Typical information required includes:

J_p = total jobs appropriate to resident group p in the urban area.

U_{iu} = units of activity of land use classification u in zone i,

F_{tup} = fraction of attractions t appropriate to resident group p occuring in land use u in the urban area.

For each attraction t and resident group p, $F_{t\cdot p} = 1$. It may be that in many real applications all nonwork attractions, $t \neq 1$, such as shopping, recreation, and education can be regarded as equally appropriate to all resident groups p. In this case the subscript p can be dropped for $t \neq 1$. It is assumed that area wide values of F_{1up} and F_{tu} are valid on a zone by zone basis.

Given the above data items, A_{ip} can be computed from its components as follows:

$$Q_{1\cdot p} = J_p \tag{3-26}$$

$$Q_{1ip} = J_p \sum \frac{F_{1up} U_{iu}}{U_{\cdot u}} \tag{3-27}$$

$$\frac{Q_{tip}}{Q_{t\cdot p}} = \sum_u \frac{F_{tu}\, U_{iu}}{U_{\cdot u}} \quad \text{for } t \neq 1. \tag{3-28}$$

<u>Quantification of Urban Impedance</u>. The second component in determining metropolitan opportunity is urban impedance. Such a measure is intended to reflect both the transportation services available and the manner in which the residents take advantage of them.

Urban impedance will be designated:

d_{ijp} = a measure of urban travel impedance encountered by residents of group p in travelling from zone i to zone j.

The calculation of d_{ijp} is made from the following definition:

$$\frac{1}{d_{ijp}} = \sum_{v} \frac{P_{pv}}{d_{ijpv}} \tag{3-28}$$

where P_{pv} = a factor representing the preference of resident group p for mode v

d_{ijpv} = a measure of the urban travel impedance encountered by residents of group p in travelling from zone i to zone j by mode v.

A formulation of d_{ijpv} which reflects the trade-off between travel time and travel cost by each mode v for each resident group p is as follows:

$$d_{ijpv} = t_{ijv}^{\ \tau p} \ c_{ijv}^{\ \gamma p} \tag{3-30}$$

where t_{ijv} = travel time from zone i to zone j by mode v

c_{ijv} = cost to the traveller for travel between zones i and j by mode v

τ_p, γ_p = elasticities of travel time and cost characteristic of resident group p.

P_{pv} can be measured by the average number of trips made by residents of group p per week by mode v. For example, a resident group with low car ownership may make few trips by automobile and several by public transit. This tripmaking behavior will be captured in the P_{pv} values, and the d_{ijpv} values for the different modes will be weighted accordingly. The elasticities are generally measured as the percent change in the mode of travel from a one percent change in travel time or cost of travelling for each resident group (Lane, et al, 1973).

Quantification of Metropolitan Opportunity. The two components of metropolitan opportunity, attractiveness and urban impedance, have been defined so that quantification is feasible. These two values are combined to give a composite measure of metropolitan opportunity.

Let T_{ip} = a measure of the total metropolitan opportunity for resident group p in zone i. Then T_{ip} is defined as follows:

$$T_{ip} = \sum_{j} \frac{A_{jp}}{d_{ijp}} \qquad (3\text{-}31)$$

The term T_{ip} has been defined so that it reflects all the attractions appropriate to resident group p in the urban area adjusted for the travel difficulties encountered by the resident group living in zone i and travelling to the attractions in each zone j.

Given the definitions of A_{jp} and d_{ijp} discussed earlier and the expression above, T_{ip} is identified as a function of the following factors:

1. the quantity and location of all the metropolitan attractions appropriate to resident group p in the urban area;
2. the transportation service available on all the transportation modes, and the preference of resident group p for the various modes.

Changes in any of these aspects of the urban environment will be reflected in the T_{ip} values. These variations in T_{ip} will serve as a measure of the effects of such changes in the urban environment.

Because larger resident groups p usually have large number of jobs, $Q_{1 \cdot p}$, available to them in the urban area, A_{ip} values will be larger due solely to the size of the resident group. In order to compare metropolitan opportunity values for different resident groups, the attractions per unit of resident group p would be more meaningful.

Let R_{ip} = number of residents of group in in zone i,

$\frac{A_{ip}}{R_{\cdot p}}$ = the attractions in zone i per resident of group p,

M_{ip} = a measure of metropolitan opportunity per resident group p. Then M_{ip} is defined as follows:

$$M_{ip} = \sum_{j} \frac{A_{jp}}{R_{\cdot p}\, d_{ijp}} \qquad (3\text{-}32)$$

$$= \frac{T_{ip}}{R_{\cdot p}} \;. \qquad (3\text{-}33)$$

These M_{ip} values can be compared for different values of p to illustrate any difference in the metropolitan opportunity per resident available for different resident groups.

One more term needs to be defined. The metropolitan opportunity actually enjoyed by urban residents in the zone is average metropolitan opportunity, M_i, and is given by the following expression:

$$M_i = \sum_{p} \frac{R_{ip}}{R_{i\cdot}} M_{ip} \;. \qquad (3\text{-}34)$$

The opportunity values, M_i, in an urban area can be changed either by changing the T_{ip} values as described earlier, or by changing the number or mix of residents in the zones of the area. For example, the income of some residents in a zone could be increased to the extent that they become members of a resident group with a higher M_{ip} value. The value of M_i for the zone would then be increased even though no other changes in the transportation service or location of metropolitan attractions had occured.

Neighborhood Quality

The second major aspect of urban attributes is neighborhood quality. The definition of attractiveness did not include any attributes of the immediate neighborhood such as local street appearance, quality of nearby schools, effectiveness of police, fire, and sanitary services, and many similar items which are neighborhood in nature and describe the quality of that neighborhood.

The first assumption regarding the measurement of Neighborhood Quality, N_i, is that some quantifiable surrogate(s), q_i, can be computed, which characterizes the neighborhood in the sense just discussed. Depending upon the data available to the planner, q_i might combine in some way several observed and measured local attributes such as rooms per person, average family income, and years of education of all family members over age 16. For example, Kain and Quigley (1970) developed a multiple regression model that measured the average market value of the residential quality of a block in St. Louis. This model is summarized in Table 3-1. They cautioned that it would be a mistake to conclude that the composite quality model developed for St. Louis is directly applicable to other cities. They added, however, that the method could easily be extended and that many of the substantive findings would obviously be pertinent to other cities.

Table 3-1

Composite Quality Model

Variable	Coefficient
Percentage of block land area -- commercial usage	$ -5.10
Percentage of block land area -- industrial usage	-3.50
Percentage of block land area -- vacant	-13.60
Percentage of block housing units -- dilapidated	-27.50
Percentage of block housing units -- overcrowded	-12.90
Average value of owned units (in thousands of dollars)	+0.20
Average contract rent of rental units	+3.00
Median age of housing stock	-6.20
Percentage of census tract land area -- commercial usage	+11.00
Percentage of census tract land area -- industrial usage	+2.10
Percentage of census tract land area -- vacant	+2.70
Percentage of tract housing units -- shared bath	-4.50
Percentage of tract housing units -- owner occupied	+1.80
Average achievement score -- public school servicing each block	+268.20
Number of major crimes in 1967	-1.60
Dependent variable: average monthly cost of residential quality	
Constant	$2040.80

The second assumption regarding Neighborhood Quality is that the q_i values should be weighted to account for the effect on a zone of the characteristics of surrounding zones. For example, consider two zones having equal values of q ($q_i = q_j$). Zone i is surrounded by zones of lower q's, while zone j is surrounded by zones of higher q's. Although the values of q_i and q_j are equal, the value of N_j should be higher than that of N_i. Also, the Neighborhood Quality of any zone should depend on the number of residents in its surrounding zones and the influence of these zones should decrease rapidly as distance increases.

Within these considerations a formulation of Neighborhood Quality is as follows:

$$N_i = \sum_j \frac{q_j \, R_{j\cdot} / d_{ij}^2}{\sum_j R_{j\cdot} / d_{ij}^2} \qquad (3\text{-}35)$$

where $R_{j\cdot}$ = total residents in zone j

d_{ij} = a measure of the proximity of zone j to zone i, for example, road distance.

MN Coordinate System for Urban Areas

The concepts and procedures discussed in previous sections show that values for Metropolitan Opportunity (M) and Neighborhood Quality/(N) can be calculated for the various zones of an urban area. Consider an MN coordinate system where the location of each zone is specified by its M and N values. This MN coordinate system can be thought of as describing a socio-economic space in contrast with locating zones in geographical space using a map of the city (Brown and Kirby, 1971).

To formalize the presentation of the MN matrix, it will be necessary to normalize the two scales between their extreme values.

For example, if the urban area is divided into 200 to 400 zones, values for M and N may have ten ranges.

The normalized matrix is constructed as follows. Let the ranges on the M and N scale be labeled m = 1, 2, ... m' and n = 1, 2, ... n' where m' and n' designates the last range. The location of the matrix cell containing zone i is specified by its m and n values, designated by m_i and n_i. If the M and N scales are to be divided into integer ranges of equal size then,

$$m_i = \begin{cases} \left[\dfrac{m'(M_i - \min M)}{\max M - \min M}\right] + 0.5 & \text{for all } M_i \neq \max M \\ m' & \text{for } M_i = \max M \end{cases} \tag{3-36}$$

and

$$n_i = \begin{cases} \left[\dfrac{n'(N_i - \min N)}{\max N - \min N}\right] + 0.5 & \text{for all } N_i \neq \max N \\ n' & \text{for } N_i = \max N. \end{cases} \tag{3-37}$$

An example of a mn matrix is shown in Figure 3-5. Each cell in the mn matrix represents the percent of population with similar values of M and N. The percent of the population may be comprised of residents from several different zones in the urban area, possibility widely separated geographically.

	24	21	13	34	7	100%
5				1%		1
4			3%	3%	7%	13
3		5%	4%	24%		33
2			6%	6%		12
n 1	25%	16%				41
m	1	2	3	4	5	

Figure 3-5.
mn Matrix Showing Percent of Population

There are two characteristics of the mn matrix that should be noted. First, there are some matrix cells that will not represent any zone in the urban area. The second characteristic is that at least one zone must have a value m = 1 and at least one zone must have a value m = 10. The same is true for n.

Planning decisions to be made today may provide different socio-economic conditions for residents in the future. Forecasts of the land changes and expected growth will provide the inputs for computation of M_i and N_i values to compare plans and future projects by looking at the changes in the mn matrices. In general, changes in the transportation system or in location of metropolitan attractions will affect metropolitan opportunity, while changes in housing and urban services will affect neighborhood quality.

A matrix summarizing the changes in mn matrices can thus be considered a final product of the proposed methodology.

CHAPTER IV

NUMERICAL EXAMPLE

A 40,000 population rural community with a moderate industrial growth has been selected as a prototype to illustrate the proposed methodology. Though much of the data are factual, and taken from the "greater" Corvallis, Oregon area, some are artificial and/or modified for illustrative reasons. Because of this, the example will represent a hypothetical community and is not intended to simulate any specific community.

The hypothetical city contains 5,000 acres within its corporate limits. Surrounding the city is an additional area of 33,000 acres with close physical, social, and economic ties to the city proper. It is this area that will absorb any new growth. The combined region will be referred to as the urban planning area. Figure 4-1 shows the urban planning area and its division into five zones.

Land Use Plan Design

The city is considered fully developed and future growth is expected only in zones 1 through 4 of Figure 4-1. Table 4-1 lists these zones and pertinent data for each zone. Figure 4-2 is an RPM diagram depicting the existing land resources.

The assigned task is to look at a five year projection for the area. Table 4-2 shows the expected demand for various land uses in the year 1980. Five top goals, their priorities, and pertinent design constraints are:

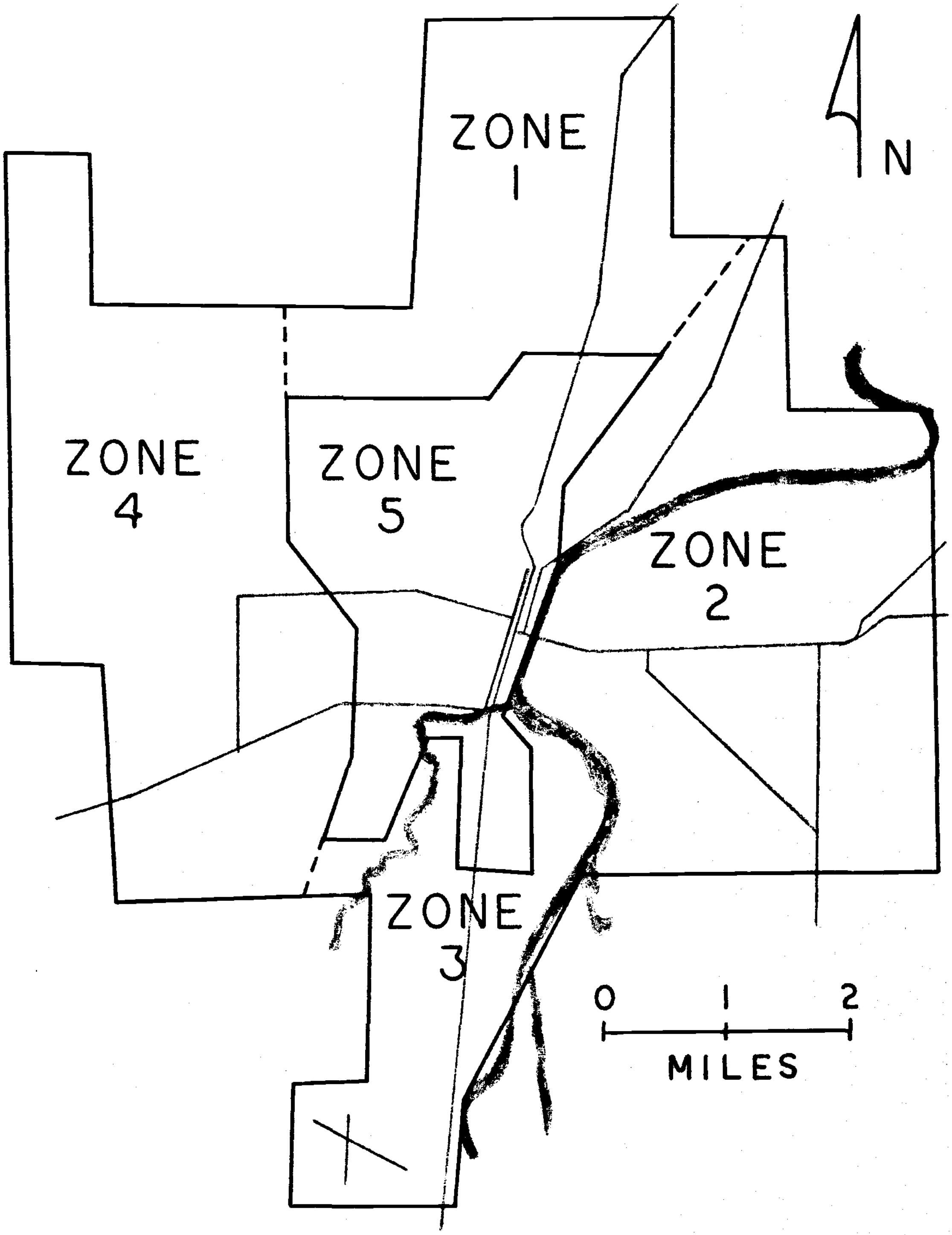


Figure 4-1.
Urban Planning Area

TABLE 4-1

Land Use in Urban Planning Area

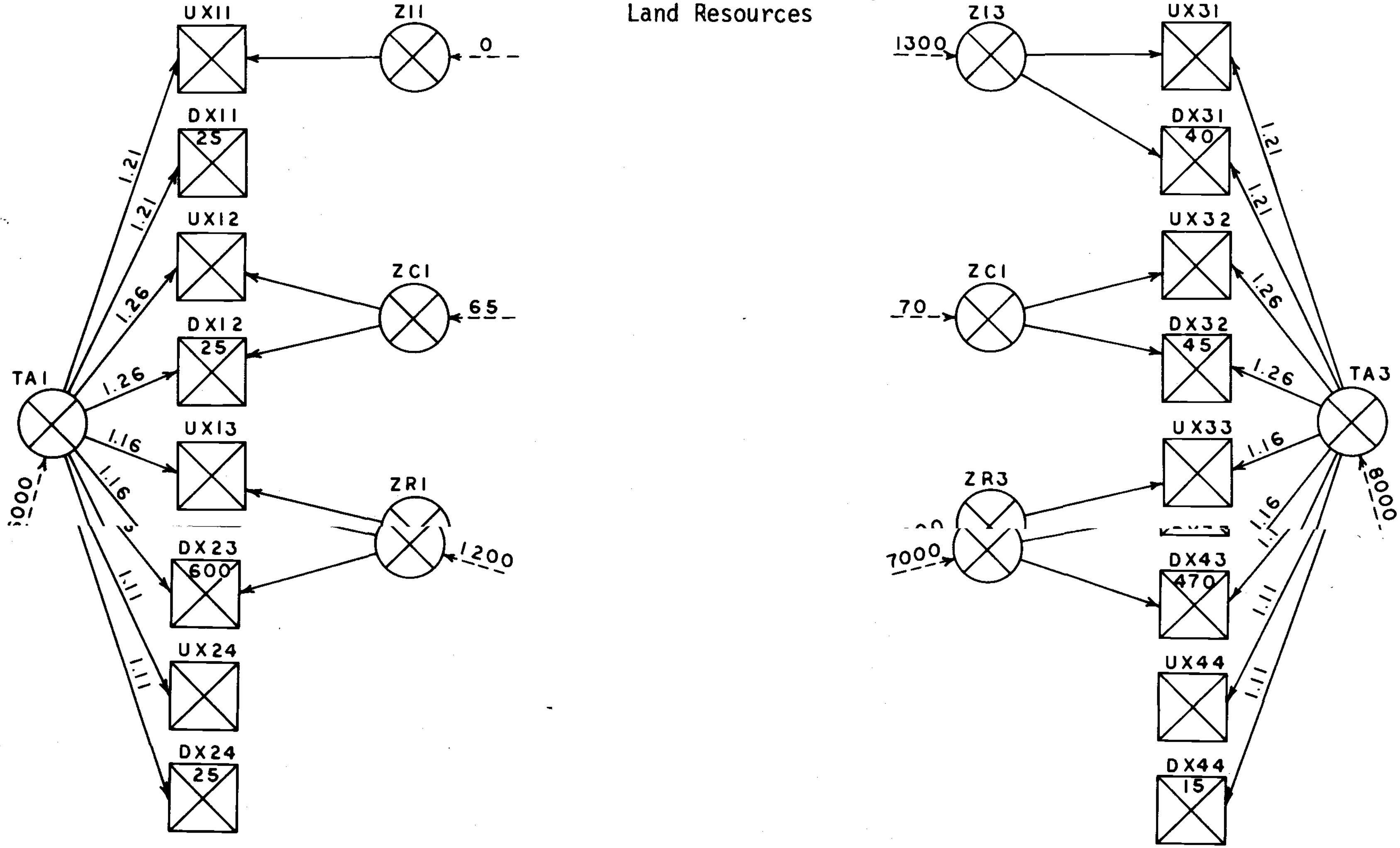
Zone i	Size Acres TA_i	Zoned: Industrial Acres ZI_i	Zoned: Commercial Acres ZC_i	Zoned: Residential Acres ZR_i	Zoned: Agriculture Acres	Cost Of Development $/Acre	Developed Land: Industrial Acres DX_{i1}	Developed Land: Commercial Acres DX_{i2}	Developed Land: Residential Acres DX_{i3}	Developed Land: Open Space DX_{i4}
1	6000	0	65	5935	0	3516.1	25	25	550	30
2	10000	0	240	1200	8560	2495.6	270	50	600	25
3	8000	1300	70	1800	4830	4865.6	40	45	300	150
4	9000	0	50	7950	1000	2785.9	25	20	470	15

Land Use

u	du
1 - Industrial	1.21
2 - Commercial	1.26
3 - Residential	1.16
4 - Open Space	1.11

Figure 4-2

RPM Diagram of Existing
Land Resources



Goal 1 (PG1) - meet the residential demand (RD), minimize both under- (URD) and over-achievement (ORD).

Goal 2 (PG2) - meet the design constraint of at least 0.15 acres of open space per acre of residential use, minimize underachievement ($OSTR_i$).

Goal 3 (PG3) - meet the design constraint of at least 0.05 acres of commercial development per acre of residential use, minimize underachievement ($UCTR_i$).

Goal 4 (PG4) - meet the industrial demand (ID), minimize underachievement (UID).

Goal 5 (PG5) - produce a land use plan at a minimum of public and private cost (TC), minimize overexpenditure (OTC).

Additional constraints are imposed to meet both commercial (CD) and open space demands (OSD). These goals and additional constraints are added to Figure 4-2 and show as the RPM Land Use diagram of Figure 4-3. The values of P_k^* are determined as the optimal function value when the kth goal is used as the objective function and are subsequently added as constraints to Figure 4-3.

Table 4-2

1980 Projected Land Uses

Land Use u	Acres
Industrial	30
Commercial	175
Residential	870
Open Space	260

The data file and output from the final run of the Linear Programming program *Rex (Scheurman, 1970), is shown in the Appendix B. The results from the final run are shown on the RPM diagram in Figure 4-4.

Goals one through four have objective function values of zero and are therefore considered to have been met completely. Even though goal five is not zero, the resulting objective function value represents the lowest cost under the given design criteria.

All land use demands are met exactly except the demand for open space. The additional 43.5 acres are allocated because of the design constraint requiring 0.15 acres of open space for every acre of residential use. Both of these constraints should be reviewed for possible changes. Table 4-3 summarizes the results of the land use plan.

Measure of Urban Performance

Before using the Urban Performance Model to evaluate the land use plan of 1980, an mn matrix representing the urban planning area

Figure 4-3

RPM Land Use Diagram

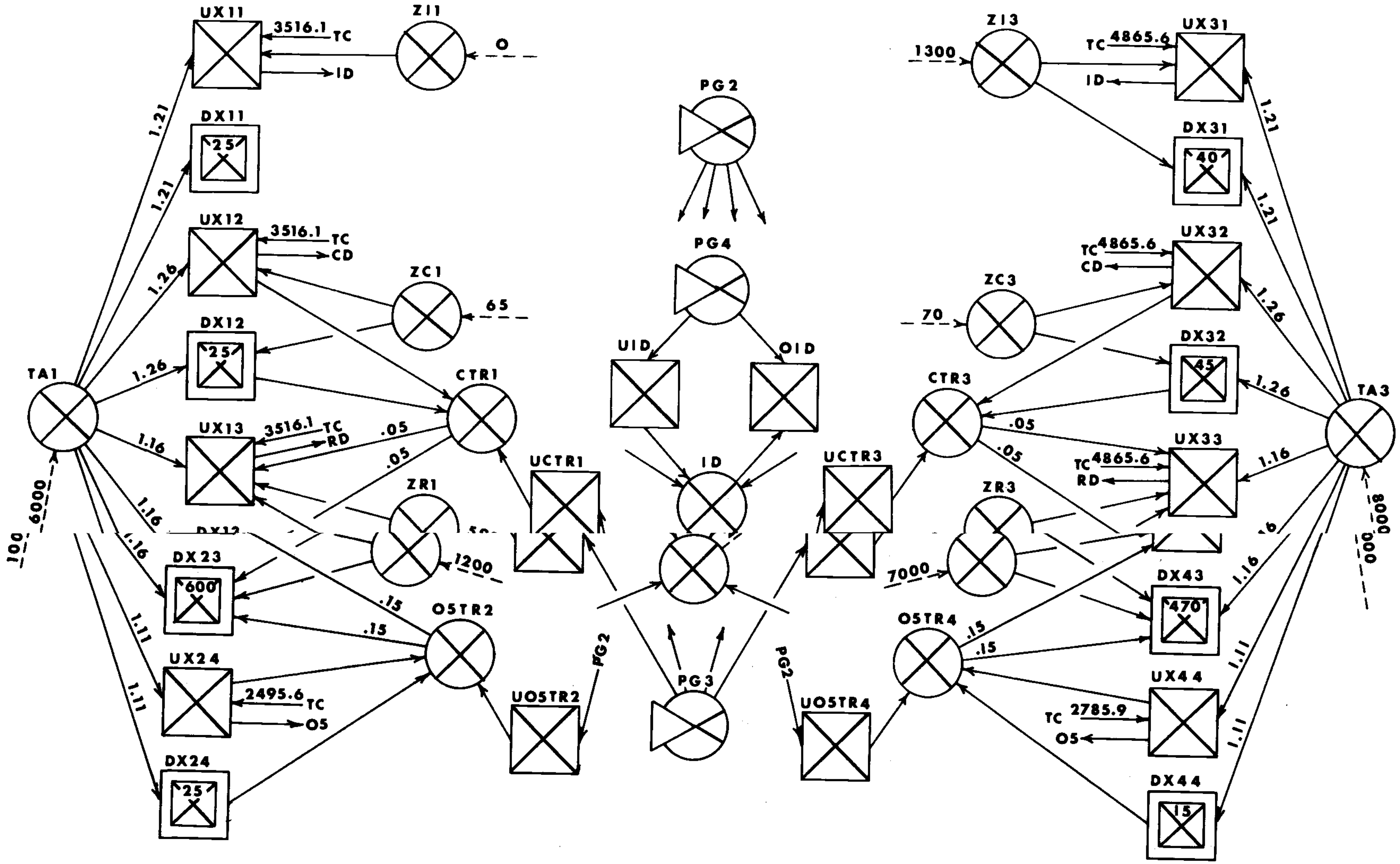


Figure 4-4

RPM Diagram of Land Use
Plan for 1980

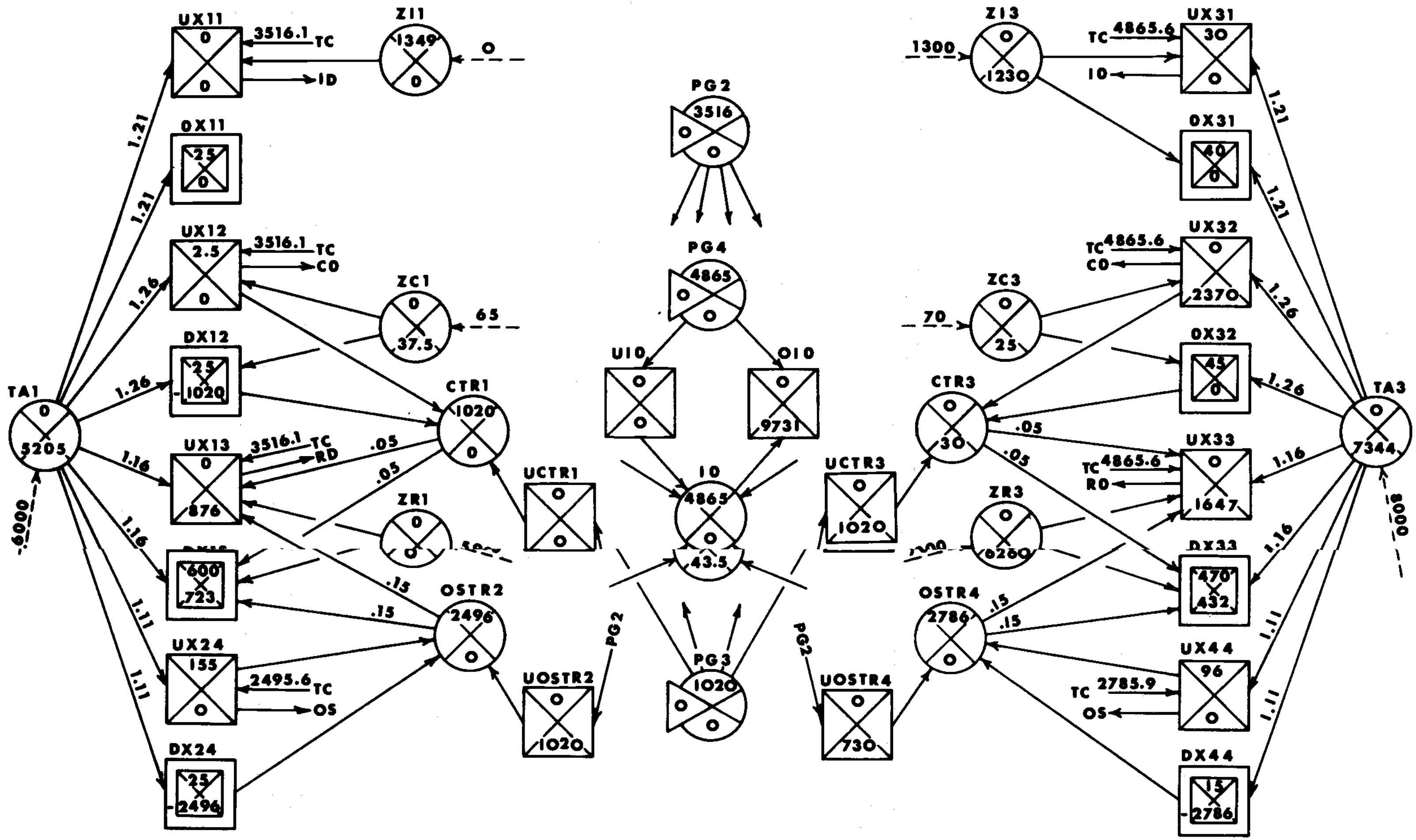


TABLE 4-3

Land Use Plan Summary For 1980

Zone i	Industrial (UX_{i1})			Commercial (UX_{i2})			Residential (UX_{i3})			Open Space (UX_{i4})			Land Remaining		
	Present	Allocation	Total	Present	Allocation	Total	Present	Allocation	Total	Present	Allocation	Total	Industrial	Commercial	Residential
1	25	0	25	25	2.5	27.5	550	0	550	30	52.5	82.5	0	37.5	5385
2	270	0	270	50	155.5	205.5	600	600	1200	25	155	180	0	34.5	0
3	40	30	70	45	0	45	300	0	300	150	0	150	1230	2.5	1500
4	25	0	25	20	17	37	470	270	740	15	96	111	0	13	6260

Goal	Shadow Price, $
3	1,020.5
1	3,218.3
2	3,516.0
4	4,865.0
Public and Private Cost	3,678,597.0

under present conditions must be determined. Table 4-4 through Table 4-6 lists the additional data necessary for computation of this mn matrix. A FORTRAN program was written to compute Metropolitan Opportunity and Neighborhood Quality values (Appendix A). Table 4 7 summarizes the output from this program and Figure 4-5 is the mn matrix for the urban planning area under present conditions.

Given the allocation of land proposed by the land use plan and the expected growth for 1980, a new mn matrix is computed and compared with the mn matrix for 1975. Table 4-8 lists the data for the year 1980, Table 4-9 shows the values of Metropolitan Opportunity and Neighborhood Quality, and Figure 4-6 is the mn matrix for the urban planning area for 1980. Figure 4-7 shows the percentage change in population on the socio-economic coordinate system proposed by the 1980 land use plan.

Interpretation of Results

The following discussion pertains to the RPM diagram (Figure 4-4) of the land use plan for 1980. The majority of residential development is in Zone 2 with the rest of the residential development occuring in Zone 4. The portion of Zone 2 north of the river contains most of the residentially zoned area of that zone. Zone 2 also received the majority of commercial development because of the low cost of land development. Zones 1 through 4 received some commercial development to meet the design constraints. All of the

TABLE 4-4

Distribution of Population

Zone i	Population Low Income R_{i1}	 Middle Income R_{i2}	 High Income R_{i3}	Residential Quality q_i
1	150	250	350	2.6
2	325	500	500	2.0
3	250	350	400	1.8
4	310	575	300	2.2
5	9500	13300	12900	3.1

Table 4-5

Resident Group Characteristics

Resident Group p	Metropolitan Attraction t	Fraction of Attractions (F_{tup}) Industrial u = 1	Commercial u = 2	Residential u = 3	Open Space u = 4	Jobs Jp	Attraction of Importance Shopping B_{2p}/B_{1p}	Recreation B_{3p}/B_{1p}
1 Low Income	1 Work	0.50	0.30	0.20	0	4400	0.15	0.10
	2 Shopping	0	0.85	0.15	0			
	3 Recreation	0	0.45	0.25	0.30			
2 Middle Income	1 Work	0.35	0.50	0.15	0	6300	0.20	0.15
	2 Shopping	0	0.85	0.15	0			
	3 Recreation	0	0.45	0.25	0.30			
3 High Income	1 Work	0.15	0.78	0.07	0	6000	0.20	0.20
	2 Shopping	0	0.85	0.15	0			
	3 Recreation	0	0.45	0.25	0.30			

TABLE 4-6

Transportation Data						
From Zone i	To Zone j	Distance miles d_{ij}	Automobile Travel time min. t_{ij1}	Automobile Travel cost c_{ij1}	Bus Travel time min. t_{ij2}	Bus Travel cost c_{ij2}
1	1	2.58	6.2	.31	8.6	.35
1	2	7.42	17.8	.89	24.7	.35
1	3	7.09	21.8	1.09	30.3	.35
1	4	7.58	18.2	.91	25.3	.35
1	5	5.45	13.1	.65	18.2	.35
2	2	2.12	6.1	.25	7.1	.35
2	3	6.36	15.3	.76	21.2	.35
2	4	5.76	13.8	.69	18.2	.35
2	5	3.03	7.3	.36	10.1	.35
3	3	1.97	4.7	.24	6.6	.35
3	4	6.97	16.7	.84	23.2	.35
3	5	4.09	9.8	.49	13.6	.35
4	4	1.52	3.6	.18	6.1	.35
4	5	2.73	6.6	.33	9.1	.35
5	5	1.21	2.9	.15	4.0	.35

Resident Group, p	Preference Factor For Automobile (P_{p1})	Preference Factor For Bus (P_{p2})	Elasticities Travel Time (Z_p)	Elasticities Travel Cost (r_p)
1 Low Income	1.8	2.2	-1.695	-0.75
2 Middle Income	2.0	1.5	-1.500	-0.90
3 High Income	2.4	0.6	-1.408	-1.05

TABLE 4-7

Metropolitan Opportunity and Neighborhood Quality

For Urban Planning Area 1975

Zone i	Metropolitan Opportunity (M_i)	Neighborhood Quality (N_i)
1	228.64	3.04
2	63.46	3.04
3	133.75	2.99
4	101.05	3.03
5	36.61	3.09

mn Matrix For 1975

	92	3	3	0	2	100
5	89%					89
4						0
3	3%				2%	5
2		3%				3
↑ n 1			3			3
m →	1	2	3	4	5	

FIGURE 4-5
mn Matrix For 1975

TABLE 4-8

Data For 1980

Zone	Population: Low Income	Population: Middle Income	Population: High Income	Developed Land: Industrial	Developed Land: Commercial	Developed Land: Residential	Developed Land: Open Space
1	150	250	350	25	27.5	550	825
2	725	900	900	270	205.5	1200	180
3	250	350	400	70	45	300	255
4	510	775	500	25	37	540	111
5	9500	13300	12900	325	300	2500	300
Jobs J_p	4600	6700	6400				

TABLE 4-9

Metropolitan Opportunity and Neighborhood Quality For Urban Planning Area 1980

Zone	Metropolitan Opportunity (M_i)	Neighborhood Quality (N_i)
1	209.59	2.94
2	75.91	2.81
3	132.82	2.92
4	118.01	2.83
5	34.26	3.05

n ↑	91	4	2	0	3	100%
5	85%					85
4						0
3					3%	3
2			2%			2
1	6%	4%				10
m →	1	2	3	4	5	

FIGURE 4-6

nm Matrix For 1980

n ↑					
5	-4%				
4					
3	-3%				+1%
2		-3%	+2%		
1	+6%	+4%	-3%		
m →	1	2	3	4	5

FIGURE 4-7

Difference Between The Two Matrices

(Figure 4-5 and 4-6)

industrial development was allocated to Zone 3 which reflects the communities objective of an industrial park in that zone.

Although the land use model is not a forecasting model, it is interesting to compare the results just given with the growth tendencies of Corvallis which resembles the prototype community. The majority of the residential growth is occuring in Zone 1 and the northern portion of Zone 2 with some growth in Zone 4. Zone 1 is a forested hilly area and has high esthetic values. This area is experiencing some problems with septic tank drain fields as reflected in the high development costs in our mathematical model. The construction of a hospital in the northern portion of Zone 5 and the possible development of a large industrial site in the northern portion of Zone 2 will create a large attraction for both residential and commercial development in these areas. Zone 3 and the southern portion of Zone 2 are experiencing low growth because of a high water table and frequent flooding.

The mn matrix of 1975 (Figure 4-5) reflects that a large proportion of population resides in areas of high Neighborhood Quality (n=5) and low Metropolitan Opportunity (m=1). This is a result of using only five zones to describe the urban planning area. The mn matrix of 1980 (Figure 4-6) still shows this same high concentration of population located at one point of the socio-economic scale. This matrix also shows a change in the distribution of the rest of the population on the socio-economic scale.

Figure 4-7 is the mn matrix which shows the difference between the two matrices of 1975 and 1980. The majority of positive changes occur in cells of low Metropolitan Opportunity and Neighborhood Quality. Further analysis can be made by comparing the rim distributions of each mn matrix for 1975 and 1980. Histograms are plotted for each urban attribute and shown in Figure 4-8. There is a slight increase in the distribution of population to areas of higher Metropolitan Opportunity and a pronounced increase of population shifts to areas of lower Neighborhood Quality.

It must be emphasized that the mn matrix represents a socio-economic coordinate system for the residents of the community. The population shifts on the matrix shown in Figure 4-7 do not necessarily imply that residents moved to different geographical locations. The shifts can also be caused by changes in the Metropolitan Opportunity and Neighborhood Quality values of their zones.

This apparent trade in Neighborhood Quality for increased Metropolitan Opportunity is one reflection of the goals and priorities set for the model. This result may or may not be acceptable to the community. If it is not acceptable, the planner can consider changing the goals and their priorities.

To make this example simple for presentation, only five large zones were utilized. In gaining this simplicity detailed information about the community was lost. A grid of 300 zones would have better described the urban planning area and provided a more detailed picture of the socio-economic distribution of residents of the

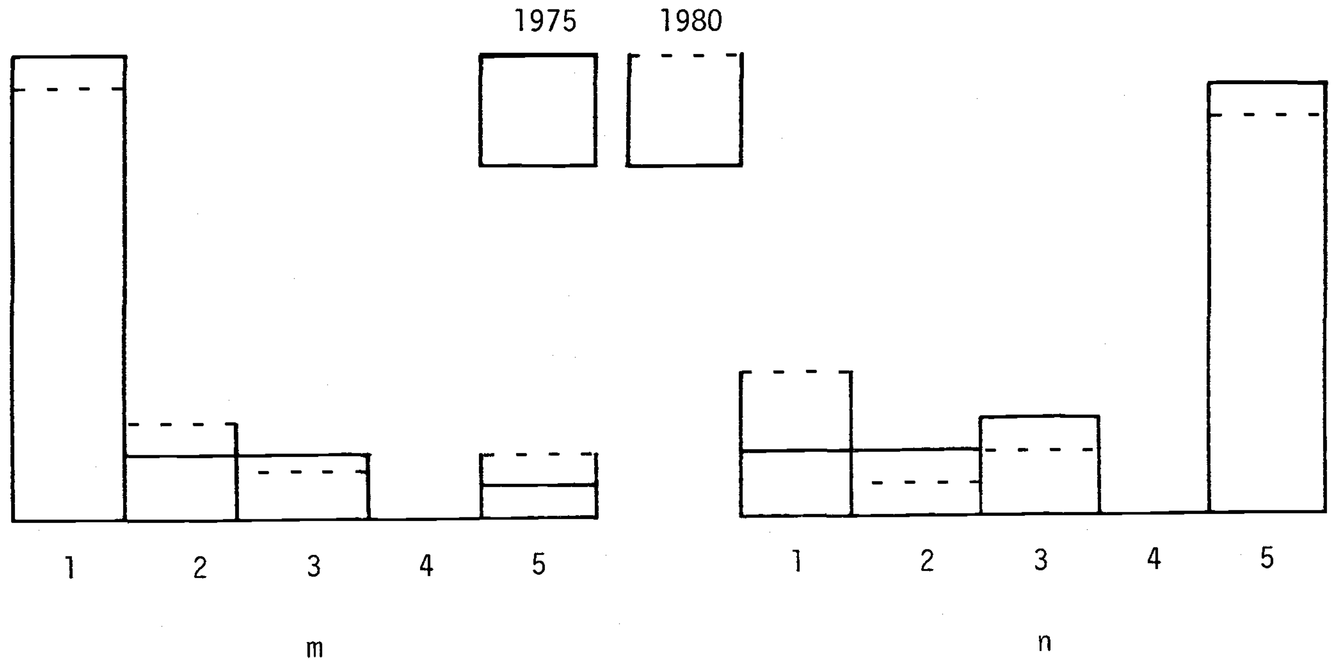


Figure 4-8

Histograms of m and n

community. The smaller zones would have provided for more detailed cost data and possible a different land use plan.

CHAPTER V

GENERAL DISCUSSION

In the previous chapters a model for allocating future land uses in the form of a land use plan design and a method for quantifying certain urban attributes as a measure of urban performance has been proposed. A numerical example using a prototype community was given along with a discussion of the results. As with all methodologies, certain limitations and disadvantages exist, and future research efforts are essential.

Limitations of Present Methodology

Because Resource Planning and Management System (RPMS) is a new methodology it is relatively unknown. RPMS has, however, been employed successfully in recent research (Mercer, 1975). In the present study, the use of a graphical display gave the planner a concise and useful presentation of the land use plan. Persons not familiar with the mathematical technique of linear programming found the graphical display much easier to understand.

Goal programming, as an extension of linear programming, is capable of handling multiple objective functions. A characteristic of goal programming is that the model can be sensitive to changes in the priorities of the goals. The example used, however, happened to be insensitive to priority changes because all goals were met.

Much of the data needed for the model is readily available in census reports and locally supervised surveys. The one item of data that may be difficult to obtain is land development costs. Cost data may be obtained from either engineering estimates or from statistical analysis of recent land development in the area. The later is always expensive and often impossible to obtain. The Southeastern Wisconsin Regional Planning Commission (1968) has developed a series of land cost tables for different land uses and types of soil. The advantage of using land development costs is that the cost of each goal is computed and the planner can evaluate his goals in terms of land development costs.

The use of linear programming for allocating land uses has certain inherent disadvantages. All variables must be continuous when many land uses are discrete, as for example, in a residential subdivision or an industrial park. The constraints and objective function must be linear. Southeastern Wisconsin Regional Planning Commission abandoned linear programming because of its inherent disadvantages and now utilize a random search technique to obtain an optimal land use plan (Southeastern Wisconsin Regional Planning Commission,1968; and Sinha, et al., 1973). Other mathematical techniques such as dynamic or nonlinear programming also have the potential for overcoming these disadvantages but the formulation and computation of such programs are subject to the curse of dimensionality. The simplicity of linear programming provides answers with readily available computer programs.

Quantitative methods were developed for describing the Metropolitan Opportunity and Neighborhood Quality enjoyed by different resident groups. It is not implied that these attributes are the only measures of urban performance. Depending upon the desires of the planner and the data available, other suitable units can be used for quantifying these urban attributes.

By observing the changes of the urban attributes over time the planner and decision-maker have a tool for evaluating alternative planning strategies. It must be cautioned that comparison of the socio-economic coordinate system between different communities may not be possible due to variances in the data base. The present methodology provides only for the comparison of population shifts on the socio-economic scale on a local level.

The quantification of q_i which was defined as a measure of Neighborhood Quality may be difficult. An example was given in Chapter III of a multiple regression model for the city of St. Louis (Kain and Quigley, 1970). This model incorporates many variables which are not applicable to a rural western community. The planner will have to find those variables that his community feels are important as a measure of its Neighborhood Quality.

Future Research

The distribution of population on a socio-economic scale nationally would provide national planners with an overall picture of the country different from that of a geographically map. A standardized data base would be necessary so that the urban attributes from all over the country would compatible. This socio-economic coordinate system could be used to distribute Federal Revenue Sharing Funds to those communities of low Metropolitan Opportunity and Neighborhood Quality measured on a national scale.

Perspective

Hopefully, this study will find acceptance within the planning profession. If nothing more than a better insight of the complex interactions of a community is realized, then the thesis's objective is accomplished.

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APPENDICES

APPENDIX A

INPUT DATA FILE

```
           5         3          4         3         2
150.       250.      350.
325.       500.      500.
250.       350.      400.
310.       575.      300.
9500.      13300.    12900.
           1         1 2.58
           1         2 7.42
           1         3 9.09
           1         4 7.58
           1         5 5.45
           2         2 2.12
           2         3 6.36
           2         4 5.76
           2         5 3.03
           3         3 1.97
           3         4 6.97
           3         5 4.09
           4         4 1.52
           4         5 2.73
           5         5 1.21
2.6          2.0       1.8        2.2       3.1
25.          25.       550.       30.
270.         50.       600.       25.
40.          45.       300.       200.
25.          20.       470.       15.
325.         300.      2500.      300.
4400.        6300.     6000.
.5           .3        .2         0.0
0.0          .35       .15        0.0
0.0          .45       .25        .3
.35          .5        .15        0.0
0.0          .35       .15        0.0
0.0          .45       .25        .3
.15          .78       .07        0.0
0.0          .35       .15        0.0
0.0          .45       .25        .3
.15          .1
.2           .15
.2           .2
1.8          2.2
2.           1.5
2.4          .5
           1         1 6.2      .31
           1         2 17.8     .89
           1         3 21.8     1.09
           1         4 18.2     .91
           1         5 13.1     .65
           2         2 6.1      .25
           2         3 15.3     .76
           2         4 13.8     .69
           2         5 7.3      .36
           3         3 4.7      .24
           3         4 16.7     .84
           3         5 9.8      .49
           4         4 3.6      .18
           4         5 6.6      .33
           5         5 2.9      .15
           1         1 8.6      .35
           1         2 24.7     .35
           1         3 30.3     .35
           1         4 25.3     .35
           1         5 18.2     .35
           2         2 7.1      .35
           2         3 21.2     .35
           2         4 19.2     .35
           2         5 10.1     .35
           3         3 6.6      .35
           3         4 23.2     .35
           3         5 13.6     .35
           4         4 6.1      .35
           4         5 9.1      .35
           5         5 4.0      .35
-1.695     -1.5       -1.408
-.75       -.9        -1.05
 5
```