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* * * * IN THIS ISSUE * * * *

* * SIMULATION MODELS IN URBAN AND REGIONAL PLANNING * * * *

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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TABLE OF CONTENTS

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FOREWORD

by J. R. Doughty, Transportation Study Director

In reading the following Technical Record article, you will find that the Commission has departed from the format which has been followed in the preceding issues. In the earlier issues, the various articles contained a description of studies that were in process or completed. Here, an effort is made to bring to the readers an introduction to the concept and application of various economic and land use models, as envisioned by members of the staff, to be used in a land use-transportation study.

The timing of the model development is such that the 1990 forecasts of employment and population will have been completed for the Region by the end of December 1964. The development of the land use models will allow the completion of test runs on a pilot area for the city of Waukesha and its environs by early 1965. Upon completion of these current plans, a technical report will be prepared for each of the models submitting detailed information on the concepts, data requirements, and results of the completed runs.

The following report does not include descriptions of the Commission's "conventional" demographic inventories, analyses, and forecasts that are concurrently underway and which will be used as the base for the 1990 plans. It also does not include the Commission's methodology of preparing the "conventional" alternate regional land use plans from which supporting transportation facilities will be developed. These additional studies and methods of plan preparation, which are the responsibility of the Land Use Division and will be completed during 1965, will be the subject of future Technical Record articles.

It has been the intention of the staff to use this dual approach of providing separate population and employment forecasts as well as a different quantitative measurement for the alternate land use plans to provide a better understanding of the Region and its many related interactions.

SIMULATION MODELS IN URBAN AND REGIONAL PLANNING[1]

by Kenneth J. Schlager, Chief Systems Engineer

INTRODUCTION

Although computer simulation models[2] have played a major role in the design of complex engineering systems during the past decade their introduction to the field of urban planning is a comparatively recent event. A systems engineer involved in the design of a chemical processing plant control system would consider the formulation and application of a computer simulation model an integral part of the design procedure. In such engineering applications, computer simulation models have demonstrated their usefulness as vehicles for experimental computer tests of new systems prior to their actual realization in the form of equipment. This opportunity to pretest a large number of systems with a simulation model has resulted in better systems at reduced costs.

In contrast to this situation, computer simulation models in the field of urban planning are in the embryonic stages, and there is still some question concerning both their purpose and their eventual usefulness. Urban simulation models are really a subset of a larger class of socio-economic simulation models which have yet to demonstrate their effectiveness and are still not accepted as proven working tools in their many fields of application.

Significant advances have been made in recent years, however, in the application of computer simulation models to management systems in industry. These latter advances are particularly significant for urban planning not only as a result of their importance to industry as part of the economic base of the community, but also because of the common role played by the behavior of human beings in both types of models. Engineering simulation models, for the most part, have represented physical phenomena, but management simulation models have been concerned with man-machine systems in which the behavioral role of people was often the governing factor. For this reason, urban planning may benefit from the sometime successful but often frustrating experiences of industry in the systems simulation field.

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[1] Presented at the Second Annual Conference on Urban Planning and Information Systems and Programs at the University of Pittsburgh, September 24, 25, and 26, 1964.

[2] Although the writer really prefers the term system simulation model since the computer is only an aid to model solution and not an integral part of the model itself, he uses the designation in common usage.

In this presentation, an effort will be made to interpret some recent experience with computer simulation models in the regional planning program of the Southeastern Wisconsin Regional Planning Commission (SEWRPC). Because the experience of this writer indicates that the development and application of computer simulation models can best be understood in terms of the regional planning process as a whole, such models will be explained in the context of comprehensive planning as follows:

1. The function of two typical simulation models as part of a regional land use-transportation planning process will be delineated.

2. The contrasting roles of forecasting models, design models and plan implementation control models in planning will be clarified since much of the semantic confusion relating to the role of models in urban planning derives from a lack of such clarification.

3. The complementary aspects of mathematical optimization models and their function relative to simulation models will be described.

4. Finally, the two computer simulation models, one relating to a regional economy, and the other to regional land development will be explained in sufficient detail to provide an understanding of the potential and problems of such models.

The last topic relates to two simulation models being developed at SEWRPC and will form the major portion of this article.

Definition of Terms

Prior to the introduction of these primary topics some definition of terms is in order. Although any complete exposition on the general subject of mathematical models is certainly beyond the scope of this article, some brief presentation of terminology is advisable to avoid unnccessary confusion.

A model is a representation of reality. Structural models of buildings, airplanes and automobiles are familiar to all of us, and the dimensional representations of such models are intuitively obvious.

Mathematical models represent reality symbolically. Variables in a mathematical relationship represent physical variables in the real world. A mathematical relationship allows for the determination of a set of variables given the values of another set of variables. In some mathematical models, usually designated as mathematical optimization models, it is possible to determine a best set of variable values to achieve some objective such as lowest cost.

Many mathematical models of complex systems, however, may be formulated but cannot be solved with present day techniques. Even these models, however, can be used to experimentally determine the effects of certain changes in some variables on the values of others. This experimental use of mathematical models is called simulation. One of the variables in most simulation models is time, so that a simulation model tends to "act like" the real life system over a period of time. In dynamic simulation the model generates a synthetic time history of the variables during the test period.

Until now, the computer has not been mentioned in the basic definition of a simulation model. In theory, it would be possible to manually calculate the dynamic outputs of a simulation model. In practice, however, the calculations involved in even a short period simulation of a complex system would be so lengthy that they would outweigh the practical benefits of the whole concept. With modern electronic digital computers it is possible to reduce the computation time of a simulation model to a degree that makes such models both practical and economically feasible.

SIMULATION IN REGIONAL LAND USE-TRANSPORTATION PLANNING

A system block diagram illustrating the functional relationship of mathematical models in a planning process is shown in Figure 1. Although this diagram specifically represents the planning sequence related to the formulation of a regional land use-transportation plan, it is typical of other planning sequences.

Population and Employment Forecasting

The first function in the planning sequence is that of population and employment forecasting. Because population and employment are the primary determinants of land use requirements, they must be forecast as a preliminary to the determination of future land use requirements.

These future land use requirements must be satisfied in the plan design, and therefore provide one of the primary inputs to the second function in the planning sequence: plan design. In the current land use-transportation study of the SEWRPC, new methods of socio-economic forecasting are being investigated in an attempt to provide more accurate and comprehensive employment and population forecasts. These new methods, which center around the "regional economic simulation model," will be discussed in detail later in this report. It is sufficient to state here that population and employment forecasts must be provided as the output of the first step of the planning sequence.

Population and employment forecasts are then translated into specific land use requirements through the use of design standards which specify the land needs and restrictions of various activities. Although this conversion may be thought of as a separate function, it has been combined with the plan design function here because the same design standards used to determine aggregate land use requirements also influence the detailed plan design.

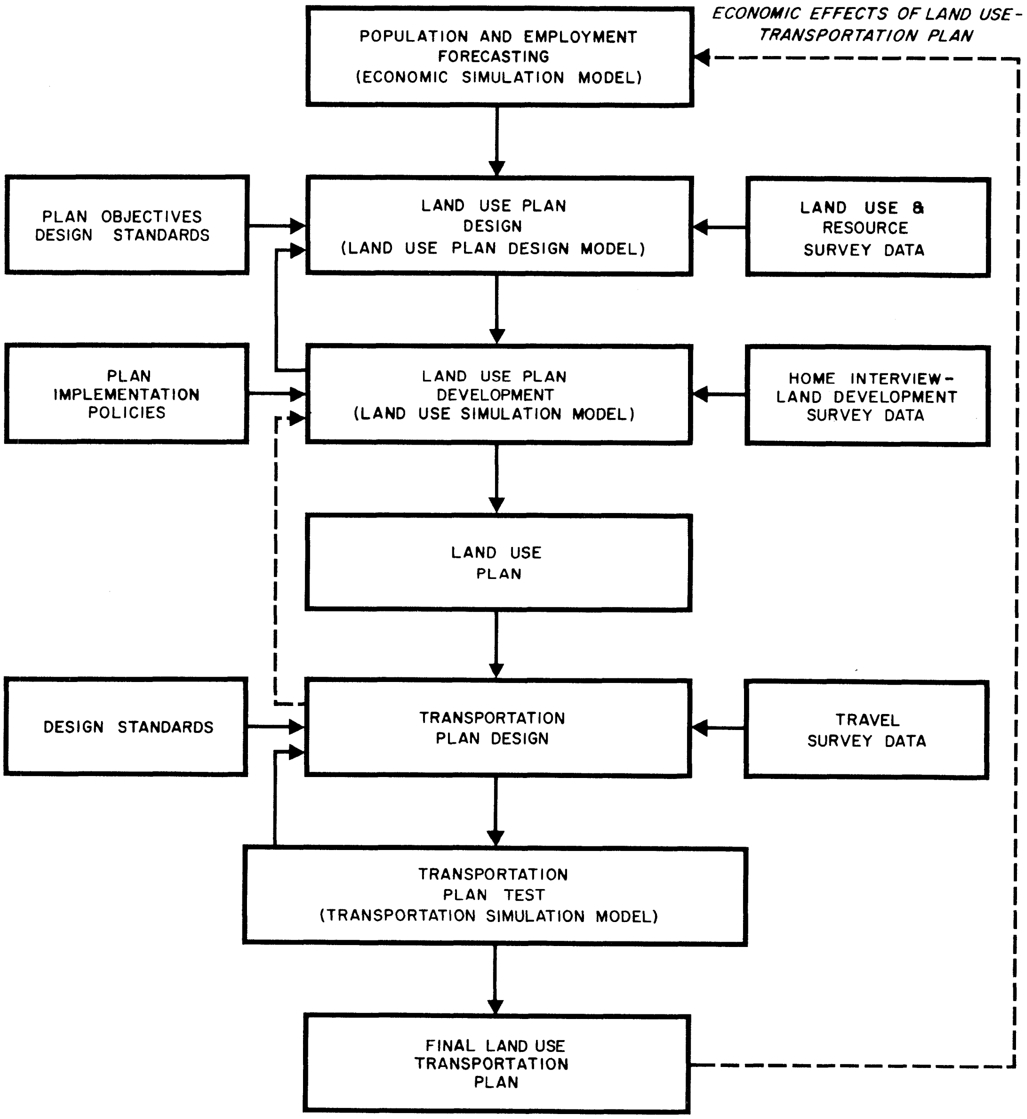
Plan Design, Heart of Process

Plan design lies at the heart of the planning process. Obvious as it may seem, it is necessary to continually emphasize that the end point of the planning process is a plan. All of the most sophisticated data collection, processing, and analysis are of little value if it does not result in better plans or in their efficient execution.

The land use plan design function consists essentially of the allocation of a scarce resource--land--between competing and often conflicting land use activities. This allocation must be accomplished so as to satisfy the aggregate needs for each land use and comply with all of the design standards derived from the plan objectives at a reasonable cost.

Figure 1

LAND USE-TRANSPORTATION STUDY
PLANNING SYSTEM DIAGRAM



The "land use plan design model" assists the land use planner in the design of a land use plan. Given a set of land use demands, design standards, land characteristics (natural and man-made) and land development costs, the model will synthesize a land use plan that satisfies the land use demands and complies with the design standards at a minimal combination of public and private costs. It is important to emphasize that the plan is the minimal cost plan complying with the design standards. It will be a pure minimal cost plan only if no design standards are specified. The rationale implies that there is no need to have a more expensive plan provided all of the design standards are satisfied.

Model, A Planning Tool

It is important to emphasize the use of a model, particularly a design model, as a planning tool and not as a replacement for the planner.[3] The concept of automatic design is misleading in that it emphasizes the less important aspect of the effect of a design model on planning. Typically, the advent of automation in industry has had the final effect of increasing the value of the output and reducing the costs of the inputs. In land use plan design, and probably in design in general, the need for improved quality is so apparent and so unlimited in its horizons that most of the effect of computerized design models will be an improved quality of the output (the plan) rather than a reduction in the costs of the inputs, namely human intellectual effort. The benefit-cost ratio will rise but from increased benefits rather than decreased costs.

This is not to say that the land use plan design model is "just another tool" with only a marginal effect on real plans. Properly used, the model should greatly extend the scope of the planner and significantly discipline the design process without destroying its creative aspects.

In design application, the land use planner will typically require a significant number of design model runs with varying design standards and land use requirements before he is able to produce a satisfactory plan. The sensitivity of the plan to land use requirements forecast inaccuracies must be ascertained. Ideally, the plan will not be adversely affected by reasonable forecast errors. The effect of each major design standard on the pattern and cost of the plan must be examined before a final plan selection can be made.

Land Use Plan Implementation

The plan selected in the design stage of the planning process must be implemented in the real world under conditions often adverse to its realization. Private decisions of land developers, builders, and households often run contrary to the development of the land pattern prescribed in the plan. This problem of plan implementation is the function of the third stage of the planning process, illustrated in Figure 1--land use plan implementation.

If plan design is visualized as the development of the anatomy of the system, then plan development represents the physiology. Plan design emphasizes the structure of

[3] Sophisticated readers may consider this reassurance obvious, but this writer has found this fear of replacement by traditional planners as one of the primary obstacles to the application of models in urban planning.

the system. Plan development considers the dynamics of changing land patterns over time. Flow is the key concept in dynamics, and the second model, the "land use simulation model," simulates the flows related to emerging land development.

Land development in the land use simulation model is portrayed as a series of interacting flows like the physiology of the body or a complex chemical processing plant. A continual stream of decisions made by land developers, builders, and households results in a changing land pattern and a continuous movement of households and business firms to new geographical locations.

Land use development is simulated in the land use simulation model by detailed representation of the decision processes of households and business firms influential in land development. Public land use control policies and public works programs are exogenous inputs to the model. In practice, a number of experimental simulation runs must be performed with different land use control policies and public works programs until a set of policies and programs are determined that result in the implementation of the target land use plan. The feedback on the diagram between land use development and land use plan design accounts for the changes that will probably need to be made in the plan design to make it realizable. The output of the third stage of the process illustrated in Figure 1 is a land use plan capable of practical implementation.

Development of a Transportation Plan

The remaining stages of the planning sequence depicted in Figure 1 relate to the development of a transportation plan. The primary inputs to a transportation system are the trips generated as a function of land use. For this reason, the land use plan is shown in the diagram as an input to transportation plan design. It will be noted that no models are indicated in the transportation plan design function. None exist to the knowledge of this writer. Trip distribution and traffic assignment models may be used to test the plan intuitively designed by the transportation planner. As a result of a model simulation, the transportation plan network is revised until a satisfactory system is developed. A vast literature exists in the field of transportation planning and associated simulation models.

In the system diagram, certain feedback relationships are designated by dotted lines. These feedbacks relate to the effect of a later stage of the planning process on an earlier stage. The most obvious is the accessibility effect of the transportation network on land use development. This effect is explicitly formulated in the land use simulation model by an accessibility factor that influences the flow of relocating households to each geographic area.

The other two feedbacks, relating to the economic effects of the transportation plan, are more difficult to explicitly formulate. Decreased travel times may reduce the interregional costs of transporting goods, and adequate industrial sites may encourage new firms to locate in the Region, but these effects are difficult to measure and formulate.

Establish Purposes of Models

This rather extended exposition of the function of a particular set of mathematical models in the solution of a regional planning problem may seem obvious to some readers and of peripheral interest to others. Space has been allocated in order to clearly establish the purposes of the models being developed. Some critics of recent applications of mathematical models and computers in planning have questioned the relevance of these new concepts to the final goal of planning--better plans.

One often experiences an undertain uneasy feeling about models that seek to explain urban development as a phenomenon in social physics. First of all, it is not at all certain that such a mechanistic approach to urban change is potentially valid, but more important, perhaps, it is even less clear as to the purpose of such models if they are valid. A primary function of urban planning is plan design. The role of a mechanistic model in design is not clear, and its more obvious role in plan implementation policy determination, the usual stated purpose of such models, may not be effective unless the model is capable of reflecting the actual alternative policies in question. Further understanding of this problem requires a more explicit statement of the role of design in urban planning.

PLANNING, FORECASTING, AND DESIGN

Prior to any further discussion of the economic and land use simulation models, it is necessary to clarify the relationships between forecasting, planning, and design. One of the major points of confusion in the field of urban planning lies in the basic definition of its function. Concepts of the function range from forecasts of largely uncontrolled land market trends to that of a master planner determining the complete design of urban form.

The viewpoint of land use or urban form as a problem in forecasting is an extremely prevalent one. A recent publication summarizing the state of the art in land use models did not even consider the use of land use models other than as forecasting tools.[4] Two reasons may account for this forecasting orientation:

1. Most of the recent advances in land use models have been made in transportation planning studies. In most of these studies, land use represented a set of uncontrolled variables to be forecasted rather than planned. Land use was "outside the system" being planned, but was a primary determinant of the travel demand that the transportation system was being planned to serve. With land use as an exogenous input to the system, forecasting is the appropriate approach.

2. A more fundamental reason perhaps for the forecasting approach is the implicit belief that land development is determined by natural market forces beyond the control of any individual or group. Such a naturalistic view inspires the search for "a natural law" or "theory" for explaining the direction of these natural forces.

Decline of Design Approach

At the other end of the spectrum is the design viewpoint of planning which views urban form as a subject for controlled development to achieve certain design objectives.

[4] Review of Existing Land Use Forecasting Techniques, Traffic Research Corporation, Toronto, 1963.

Such is the view of the master-planner or master-architect of some years ago. In a recent paper, Britton Harris explained the reasons for the decline of the design approach to urban planning as twofold:[5]

1. "First, as a result of technological advance and social change, the size and complexity of our urban concentrations has grown enormously. Their function and growth patterns now surpass the intuitive understanding and powers of normative reduction of any single individual."

2. "Second, the relative expansion of the private market economy in urban land, and the growth of a pluralistic society, have greatly complicated the processes of decision-making and control in urban development. The master-builder can no longer impose his will upon all groups and individuals who by their actions contribute to change and to the emerging pattern of urban form at any particular time."

In one sense, the models being developed by the SEWRPC and elsewhere are a dual answer to the above very valid reasons for the decline of urban design.

The first cause of the decline is really a critique of design technology and applies to the whole field of design and not just urban design. Despite the rapid advance of science in recent decades, the technology of design has lagged significantly. Although design engineers have a much wider area of choice of materials and processes for new products for an increasingly complex set of requirements, the techniques of design have not advanced to keep pace with the needs for making better design choices. In some cases, the wider range of choice actually has been detrimental to the final quality of the product as evidenced by the fantastic rate of failure of new products in industry.

What is true for product design is accentuated for urban plan design. Complexity of urban form has indeed reached incredible proportions in modern times, and some radically new innovation must be developed to cope with the completely changed nature of the urban design problem. It is hard to contest the inability of any one designer, however great, to intuitively manipulate all the variables involved in a complete urban plan design.

With a mathematical model such as the land use plan design model, however, and its means of practical implementation, the computer, it is hoped that the many variables and conflicts involved in urban design may not only be resolved, but resolved in an optimal fashion according to the plan objectives. The details of this land use plan design model will not be presented here. A technical report now in preparation will provide both a theoretical description and the experimental results to date.

The second cause for the decline of design implies that even if urban complexity can be overcome, the plan design cannot be implemented because of the pluralistic distribution of decision-making in our society. Difficulties encountered in urban plan

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[5] Britton Harris, "Some Problems in the Theory of Intra-Urban Location," Penn-Jersey Transportation Study, P. J. Paper No. 3, 1962.

implementation offer testimony to the truth of this assertion. The situation may not be hopeless, however, despite the diversity of goals and decision-making responsibility. To be solved, however, the problem must be specifically stated. One way of stating the problem, often used in economic policy problems, follows:

1. The objective of land use plan implementation is to bring about the target plan design. The variables describing this plan (land uses in different areas) are known as the target variables.

2. These target variables may be influenced by certain other variables known as the controlled variables which are subject to governmental decisions. These variables are those associated with public works programming, such as highways and water-sewer facilities, and land use controls, such as zoning and subdivision regulations.

3. These target variables are also influenced, however, by uncontrolled variables determined by private decision-makers, such as land developers, builders, and households.

Problem of Land Use Plan Implementation

The problem of land use plan implementation, stated succinctly, is how to achieve a given set of target variables representing the land use plan design using the controlled variables considering the possible adverse influence of the uncontrolled variables. The situation resembles that of a ship captain piloting his vessel toward home port (target variable) steering the ship (control variable) in the presence of wind and seas (uncontrolled variables) continuously driving the ship off its course. The purpose of the land use simulation model is to help determine the steering signals (controlled variables) needed to guide land development so as to reach the homeport of the plan design (target variables).

In the land use simulation model, land development is viewed as a process, and the changing pattern of the land is analogous to series of flows in a complex chemical processing plant. The flow analogy is a direct one inasmuch as the movement of households from one location to another is treated as a flow. Some of the hypothetical valves regulating these flows that determine the future land pattern are under the control, at least indirectly through the public officials he advises, of the planner. Other flow control values are determined by other people, such as land developers and households, with other interests.

In using the land use simulation model, the planner must experimentally determine a set of land use control policies and public works programs to implement his plan design. He may discover, of course, that the government does not possess even enough indirect controls to shape land development to the plan design. Such a discovery represents important knowledge, however, and prevents the naive self-deception about the realities of plan implementation sometimes characteristic of urban planning. If a plan cannot be implemented, it either should be changed (if it is not really wanted) or public controls should be strengthened to achieve implementation.

The remainder of this report will be concerned with a description of the economic and land use simulation models which have just been introduced as part of a comprehensive planning process. A brief description of the common characteristics of both models will be followed by an explanation of the status of each.

SIMULATION MODEL CHARACTERISTICS

Both the regional economic simulation and the land use simulation models are dynamic process models which generate a synthetic history of the system variables over a period of time. Starting from a given set of initial conditions, the difference equations used in the model permit the calculation of the change in the system variables during the first time interval. The new state of the system then becomes the new base for the change computations of the second time period. If A is the initial residential land area and a function dR expresses the change in residential land use in a given time period then

$$R_t = R_{t-1} + (dT)\,(dR)$$

where

$$Ro = A$$

and

$$dR = f\,(x_1, x_2 --- x_n)$$

R_t - residential land area

dT - iteration time

dR - rate of change of residential land use

$x_1, x_2 --- x_n$ - other model variables influencing the rate of change of residential land use

In general, the difference equations are sequential[6] rather than simultaneous although an exception to this general rule exists in the land use simulation model.

Both the regional economic and land use simulation models are made up of a large number of equations of the type illustrated above. Four classes of problems exist in the development of simulation models of this kind:[7]

1. The formulation of the basic functional relationships involved in the model.

2. The development of a computer program of the model.

3. The estimation of the parameters for the model relationships.

4. The validation of the model.

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[6] Sequential as used here implies that when the equations are properly ordered the solution of each may be based on initial condition and previous equation solutions without simultaniety.

[7] Kalman J. Cohen, Computer Models of the Shoe, Leather and Hide Sequence, Prentice-Hall, Englewood Cliffs, N. J., 1960.

The rationale for each of these problems in the two simulation models will be explained and related to the current state of model development.

It is well to recognize that these simulation models represent only a part of a large number of similar model development efforts in urban planning and other fields now underway in this country and other parts of the world. The work of the Social System Research Institute at the University of Wisconsin on national economic simulation models,[8] the program of Jay Forrester and his associates in industrial dynamics at the Massachusetts Institute of Technology,[9] and many unpublished proprietary simulation models developed by individual industrial firms are only a few of the programs proceeding along the same general lines.

Most land use models, of the non-design variety, aimed at forecasts of future land use; however, have not been dynamic simulation models, but rather single stage forecasts of land use for a given point in time. An exception to this general situation is the Penn-Jersey regional growth model which combined simulation and linear programming using a five year iteration time. Model practitioners have generally recognized the inherent desirability of a dynamic simulation model, but most projects have been limited by a lack of data having to make use of data collected for other purposes.

REGIONAL ECONOMIC SIMULATION MODEL

The SEWRPC land use-transportation study must base its plans for future regional land use patterns and highway-transit networks on forecasts of future population and employment in the Region. These forecasts are necessary to determine what plans the Region will need and what plans the Region can financially support.

Model Objectives

The objective of the regional economic simulation model is to provide a series of conditional forecasts of regional population and employment that are sensitive to policy variables such as the rate of investment in certain industries and the state and local governmental tax structure. The primary focus is on a potential employment-population gap that seems to be developing in the Region.

The specific forecasting needs of the land use-transportation study are based on the lead time requirements of various activities in the planning process. To implement a plan, certain commitments, such as land acquisition (or reservation), must be made in advance. Facilities must be designed to satisfy expected usage during their life cycle. Forecasts must be of sufficient accuracy to allow these commitments to be made with confidence. In general, the forecasting accuracy requirements become less stringent for longer period forecasts, but specific forecasting accuracy requirements must be determined based on the technical and political nautre of the planning function involved. The most direct use of the forecasts provided by the model, as indicated in the previous sections of this report, is to provide the basis for the determination of future land use requirements.

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[8] Guy H. Orcutt, et al, Microanalysis of Socioeconomic Systems: A Simulation Study, Harpers, New York, 1961.

[9] Jay W. Forrester, Industrial Dynamics, Wiley, New York, 1961.

Another important use of the model, not possible with traditional time series extrapolation, is the determination of the effects of the land use-transportation plan on the regional economy. The "feedback effect" of the plan will be determined by varying the transportation cost inputs, as they are affected by the plan, in the model.

An additional use of the model, not now part of the program of the SEWRPC, but of great potential importance for the Region, is that of industrial development. The model should be extremely useful in evaluating the effects of local governmental decisions on the regional economy and the relative importance of individual industries in this economy.

Model Organization

The regional economic simulation model is a flow model. It can be physically visualized as analogous to a large chemical processing plant with a myriad of pipes interconnecting processing facilities. Rather than chemical liquids, the model flows represent the flow of materials, finished products, and money in the regional economy. These flows in the model interconnect various industries each of which receives certain flow inputs (materials, capital equipment, etc.) and produces certain outputs (finished goods or services).

A diagram of the model is shown in Figure 2. This diagram illustrates the basic nature of the model flow pattern, although for the sake of simplicity not all of the flows are shown. The three primary exogenous or "outside" variables are government, consumer, and foreign purchases. These variables must be forecasted as outside inputs to the model. They are illustrated in the upper right hand corner of the diagram.

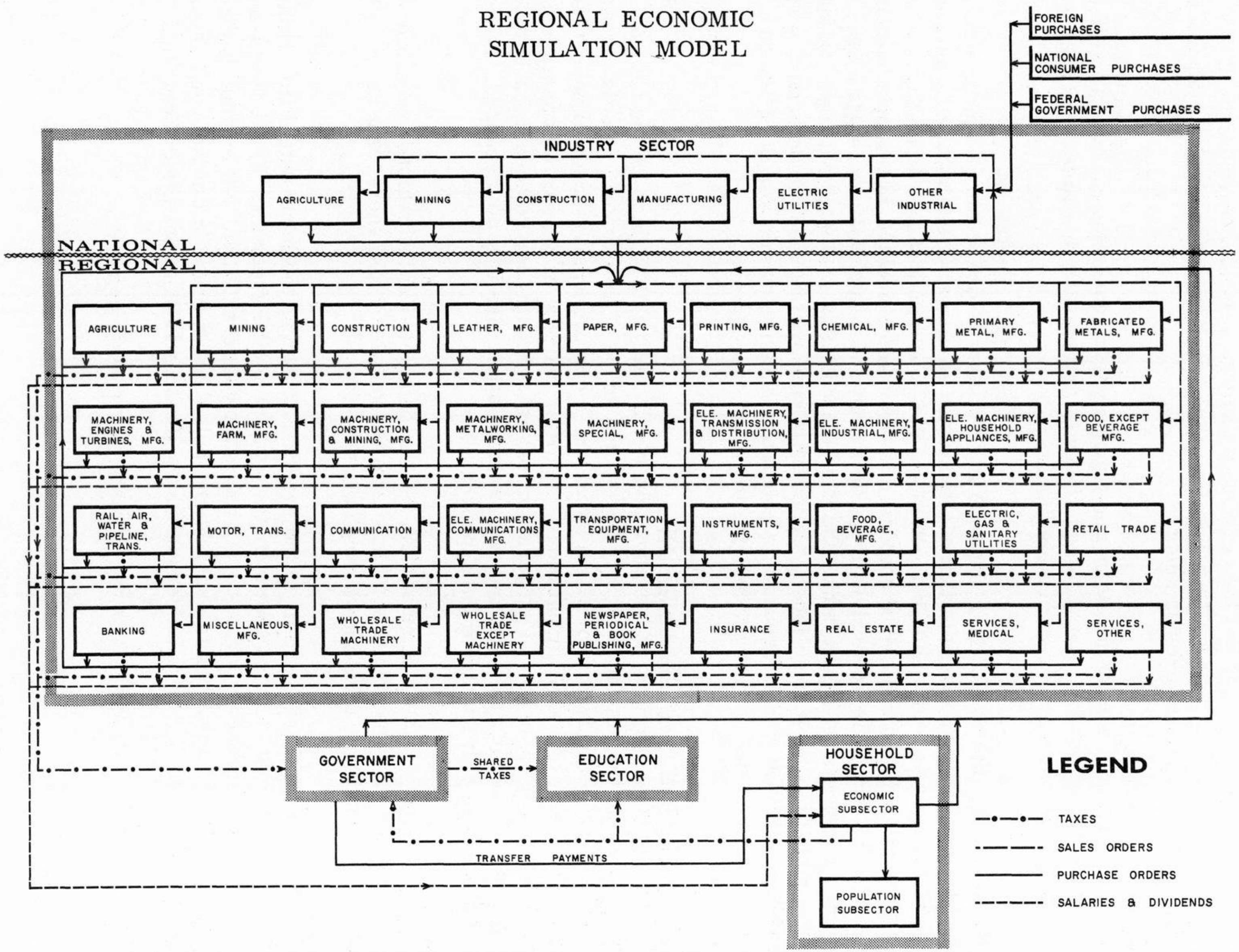
These consumer, government and foreign purchases flow to the industry (or business) sector of the national (and regional) economy. This flow subdivides between industries based on an input-output structure. The input-output structure designates the sales and purchasing pattern between industries. For example, a major purchase of electric utilities is coal. This purchase would be represented in the input-output structure by a percentage of electric utility purchases ordered from the mining industry. The other input-output interconnections are accounted for in a similar fashion.

The upper part of the model diagram represents the national economy. The lower part depicts the regional economy. Government, consumer, and business purchase orders flow into the regional economy. A more detailed input-output structure interconnects the industries, governments, and households in the regional economy. The regional economy differs from the national economy in that it is a "closed" economy. The national economy is "open" in that government, consumer, and foreign purchases are determined outside of the model. The regional economy is closed in that households (consumers) and government both consume goods and services and produce goods and services in the regional economy. Government is paid for these services through taxes and households by wages, salaries, and dividends.

Inside each of the industries, "bookkeeping" computations are made to account for the short term flows of materials, goods, and money. Employment of hourly and salaried personnel depends on the level of industry sales and personnel productivity.

Figure 2

REGIONAL ECONOMIC
SIMULATION MODEL



The key decision that modifies the flow pattern of the model over time is the investment decision. Investment in plant and equipment results in new levels of output and employment in an industry. In the model, investment takes place in response to anticipated sales and profit and the current capacity to produce. Investment in the public sector occurs in response to needs for public facilities and services as limited by funds available from taxes and debt.

The investment decision is the primary dynamic element in the model. The effects of changes in public (tax or investment changes) and private investment policies will be reflected through the investment decisions.

In summary, the model is a dynamic input-output feedback simulation model. It is behavioral in its approach in that it attempts to simulate the way industrial investment decisions are actually made in the Region and not how they should be made. The model is organized into a number of sectors that are interconnected by an input-output matrix. The model is recursive in its operation and sequentially generates a synthetic time history of the Region during the period from 1946 to 1963. After the validity of this model has been established, a number of runs will be made to determine a series of conditional regional forecasts of population and employment for the 1963-1990 period using a variety of private and public policy assumptions.

Formulation of Model Relationships

A complete description and explanation of all the relationships of the regional economic simulation model is clearly beyond the scope of this report. Simulation models do not lend themselves to brief explanations. A comprehensive technical report detailing all aspects of model formulations, computer programming, parameter estimations, and validity tests is now in preparation and is scheduled for release in January 1965. In this article, only the primary classes of relationships will be discussed. Examples of each class will illustrate the approach taken.

Three primary classes of relationships are formulated in the regional economic simulation model. These classes include external relationships, short term internal relationships, and long term internal relationships.

External Relationships: refer to the equations defining the input-output flow relationships between the sectors shown in the system model diagram. These flows include sales and purchase orders, taxes, and salary-interest-dividend income payments. An example of such a relationship is the sales order equation for the sales orders of the regional electrical machinery industry (Standard Industrial Classification 36):

S036C = (PV020) (P3620) + (PV031) + (PV037) (P3637)

where

S036C - industry 36 sales orders - capital goods

PV020 - industry 20, total capital goods purchase orders

P3620 - the percentage of industry 20 capital goods purchases ordered from industry 36

PV031 - industry 31 total capital goods purchase orders

P3631 - the percentage of industry 31 capital goods purchases ordered from industry 36

PV037 - industry 37 total capital goods purchase orders

P3637 - the percentage of industry 37 capital goods purchases ordered from industry 36

In the above equation industry 36 is selling capital goods to industries 20, 31 and 37. Each of these industries make a total capital goods purchase (PV020, PV031 and PV037) some fraction (P3620, P3631 and P3637) of which is purchased from industry 36. Although only three customer industries are represented in the above equation, any number may be represented depending on the input-output matrix. There must be an entry (PV0XX) (P36XX) in the sales order equation for every capital goods customer (industry XX) of industry 36.

Since industry 36 is also a non-capital goods producer, its sales order equation would also include terms for component purchases by other industries.

S036N = (RP35) (R3635) + (RP36) (R3636) + (RP37) (R3637)

where

S036N - industry 36 sales orders, non-capital goods

RP35 - industry 35, total non-capital goods monthly purchase orders

R3635 - the percentage of industry 35 non-capital goods monthly purchases ordered from industry 36

RP36 - industry 31, total non-capital goods monthly purchase orders

R3635 - the percentage of industry 36 non-capital goods monthly purchases ordered from industry 36

RP37 - industry 37, total non-capital goods monthly purchase orders

R3637 - the percentage of industry 37 non-capital goods monthly purchases ordered from industry 36

In the above equation, industry 36 is selling non-capital goods to industries 35, 36, and 37. Each of these industries makes a total non-capital goods monthly purchase order (RP35, RP36 and RP37), some fraction (R3635, R3636 and R3637) of which is sold by industry 36. There must be an entry (RPYY) (R36YY) in the sales order equation for every non-capital goods customer (industry YY) of industry 36.

Some manufacturing industries, such as foods, would be limited to non-capital sales orders alone.

Typically, external relationships are almost self-defining once the input-output structure is established, and the only problem becomes one of parameter estimations. All of the external relationships in the model follow the format of the above sample equations.

Short Term Internal Relationships: include the sales, purchasing, production, and financial accounting functions of the firm. These equations are computed on a monthly cycle in the simulation model. The most complex relationships in this class are those related to productivity since this variable is dependent on the past history of investment. A more typical relationship in this class is the purchasing equation:

$$RP = (S)\ (RFG)\ (PI)$$

where

RP - the raw material, parts and service purchase orders

S - monthly sales volume

RFG - the fraction of total sales dollars that is spent on raw materials, parts and services

PI - the percentage increase in the price of goods each month. (PI is actually 1 plus the percentage increase.)

The raw materials purchase equation (above) relates purchase orders to sales through the use of RFG, the fraction of purchased materials and services in finished goods. PI, the percentage increase in the price of purchased goods and services, is used to account for inflation.

External relationships and short term relationships, it will be noted, are really only mathematical representations of an input-output structure and the operational flows in a firm. Although the short term internal relationships are somewhat modified in non-manufacturing industries such as retail trade and financial institutions, they are basically similar and easily formulated.

Long Term Internal Relationships: The really critical and difficult-to-formulate class of relationships are the long term internal ones which center on the investment decision. The model has as its primary focus, long term trends in economic output and employment. The investment decision plays a key role in these trends since it provides both the product and process for the industry of the future. The validity of the model largely depends on the proper formulation of the investment decision. At the present time, a number of investment decision formulations are being tested. Some use simple payback period decision rules. Others involve more complex determinations of future profitability. A simplified version of one of the formulations follows.

The annual investment decision contains a review of sales trends, return on assets, and capacity. If new capacity is indicated, the available money is invested. The annual investment decision is made in the sequence enumerated below:

First, the total investment needs are determined. Then, the money available is computed; and, finally, the purchase orders are placed.

The total investment needed is the sum of working capital needed to maintain the present sales level and new capacity needed to meet the sales forecast. The working capital needed is determined from present sales volume (smoothed monthly sales) and the working capital necessary per dollar of sales. The new capacity needed is determined by smoothing and forecasting annual sales, and comparing the forecasted sales volume with the present plant capacity.

The money available for new investment is based on the expected return from the new investment and on the average amount of capital that can be raised per dollar of expected return by the simulated industry. The expected return on new investment is computed from smoothed annual return on assets and the new investment needed. The total capital available is the product of the expected return from the new investment times the average amount of capital that can be raised per dollar of expected return.

In the investment decision, the total capital available is divided between new working capital and new capacity and the capital goods purchase order is placed.

From the above discussion, it is apparent that the success of the model in representing regional economic activity is primarily a function of the formulation of the long term relationships and the accurate determination of model parameters.

Estimation of Model Parameters

A simulation model is a hungry consumer of data. Many first attempts at simulation model development are overwhelmed and defeated by an initial underestimation of the data required for effective model operation. The regional economic simulation model project was no exception to this unexpected need for a large volume and variety of information input. Although the basic data needs of the model were known at the beginning of the program in 1962, many detailed data requirements were not apparent until much later in the program.

At the present time, the economic data collection phase has been completed, and the program is now in the midst of reducing the data to obtain the model parameters. The size and complexity of this economic data reduction was such (230,000 punched cards are involved) that a special series of computer programs have been developed to transform the raw data into the model parameters. A complete discussion of these programs will be included in the technical report in preparation which has been mentioned previously. For this article, only a general summary will be provided to indicate the basic approach to parameter estimation.

Two general approaches to the estimation of the parameters of the regional economic simulation model are possible. The first approach, common to most econometric models, is that of regression analysis. Varying levels of statistical sophistication are possible in regression analysis ranging from an independent simple linear regression for each relationship in the model to a simultaneous maximum-likelihood estimation. Some of the most important recent advances in econometric research have been in the area of advanced simultaneous regression techniques.

A second approach to parameter estimation is sampling. The behavior of a small number of firms and households may be considered typical of the larger groups of which they are a part. Parameters may be estimated from microscopic analyses of the sample and a subsequent expansion of the results to the entire class of firms or households.

The sampling approach was selected as the primary approach for the regional economic simulation model for the following reasons:

1. A validity test of the model was considered desirable using the 1946-1963 history of the output variables. If these historical data were used to determine the model parameters, they could not be used as an independent test of model validity.

2. The behavioral approach used to ascertain investment decision rules through firm interviews was more conducive to a sampling approach.

3. The complex nature of the model and the existence of many inequality relationships made a regression analysis approach of the simultaneous kind exceedingly difficult, if not impossible.

The last reason would seem to make the first two extraneous, but sampling was actually more consistent with the concept involved in the model.

Data sources included both primary and secondary sources with the principal primary sources being:

1. Surveys of selected firms in each regional industry group.

2. State corporate tax records.

3. State industrial employment and payroll records.

4. Household survey data of the land use-transportation study.

The second source, state corporate tax records, was the most valuable, providing the majority of the data used for parametric estimations. The third source in thc form of industrial employment data was also critical in that it provided data at the industry level to provide a basis for sample expansion. The other three sources provided data only for sampled firms and households. Although it would have been theoretically possible to obtain the total universe of corporate tax records, the sheer volume of the data involved made sampling an economic necessity.

External input-output parameters at the regional level were estimated from the purchasing records of sampled firms. Because of the uneven quality of these records which ranged from detailed commodity classifications to estimates of purchasing personnel, a confirmation of the estimated parameters was sought from a regression analysis of regional and national sales-purchasing data. The sampled data constituted, however, the primary data source. Because statistical analyses are still in process, final results cannot be released at this time. National input-output parameters were based on the recently computed Department of Commerce matrix based on the year 1958.

Most of the internal parameters were estimated directly from the values determined in the sampled firms. Although most of these parameter estimates were simple time series averages, some parameters, such as personnel and capital equipment productivity, required regression analysis at the firm level. Again, such regression analysis should be distinguished from aggregate regression at the industry level.

The greatest complexity in estimating parameters was encountered in the long term internal relationships associated with the investment decision. The existence of inequalities in some of the decision rules tested was particularly troublesome. Attempts to use linear programming as a regression tool were not very successful, and some of the investment decision rules were modified to ease the problem of parameter estimation.

Model Validation

Since model validation tests will not be completed until the end of 1964, it is not possible to report any detailed results in this area. The results of all of the test runs will be available in the final technical report to be published in January 1965.

One of the advantages of the firm sampling approach, as previously mentioned, is its potential for model validation using historical variables as a basis for comparison with the synthetic time histories generated by the simulation model. Although the parameters cannot be considered purely the result of sample estimation since a regression was used to check the input-output structure, the independence of the two sets of data, sample firm behavior and aggregate historical variables at the industry level, was sufficient to provide some degree of reliability.

The difficulties of model validation, even with an independent data source, are only too well known. It can only be hoped that the pragmatic test of usefulness can overcome any basic philosophical doubts.

Computer Programming

The data reduction, statistical analysis of model parameters and the actual simulation runs were all performed on an IBM 1620 with 40,000 core memory positions and two IBM 1311 disks with 2,000,000 memory positions each. The model itself and most of the data processing programs were coded in Fortran II-D. Although Fortran II-D proved quite satisfactory for the simulation model itself, data reduction would have been expedited by programming the data processing routines in the 1620 symbolic language, SPS. The complexity and number of these programs did not permit time for such programming. Programming time was saved at the expense of operating time. When time permits in 1965, it is intended that the economic data reduction programs will be converted for greater efficiency in future updates of the data.

LAND USE SIMULATION MODEL

Model Objective

The objective of the land use simulation model is to provide a means of testing regional land use plans for feasibility of implementation. The emphasis is not on forecasting but on plan implementation. The model is intended to test the effectiveness of certain controlled variables in achieving a given target plan in the presence of many uncontrolled variables. Controlled variables will represent the implementation tools of land use planning: zoning and subdivision regulations, freeway and street location, open space reservation, etc. Uncontrolled variables will include the behavior of households, private land developers and builders, and exogenous inputs such as population growth and employment.

Although its primary use will not be in forecasting, one of the applications of this model at the SEWRPC will be a simulation of current trends in the land use pattern with the existing public works programs and land use controls in the Region. In one sense, such a simulation is a forecast since none of the public control variables would be affected by the regional plan. The purpose of this simulation is to present for public consideration the desirability of the emerging land use pattern without a comprehensive regional plan.

Most of the land use simulations, however, will be concerned with the experimental design of policy to implement a target land use plan. The end product will be a set of public works programs and land use regulations needed to achieve the regional land use plan.

Model Organization

Like the regional economic simulation model, this model is also a dynamic behavioral feedback simulation model. It is classified into five primary sectors:

1. Residential
2. Industrial
3. Services
4. Special
5. Agricultural

In the residential sector, the decision-making behavior of "household-type" units are simulated in conjunction with the related decisions of land developers and builders. Variables influenced by the land use planner, as later reflected in governmental policies, are programmed to achieve the desired land use pattern. These controls tend to constrain or modify the behavior of households, land developers, and builders.

The industrial sector in current model tests is being treated exogenously with industrial employment in each zone being programmed in the light of the land use plan. A second experimental endogenous version of the sector is now being tested for later incorporation in the model. In this latter approach, "firm types" determined from an industrial classification select new industrial sites based on their particular requirements and the costs of land and taxes. Although the endogenous approach, if successful, has a certain appeal in that it provides a behavioral explanation of industrial location decisions, the exogenous approach may be more in keeping with the planning approach decided earlier in this report. If the sites of industrial employment are a powerful influence on residential and service-related land development, then implementation of the target plan will probably require a governmental influence on these decisions. If such influence can take the form of providing land with the characteristics needed by the various industrial groups at prices they are willing to pay, then the exogenous and endogenous versions of industrial land development should be similar.

The service sector of the model embraces all land uses, the location of which are primarily dependent on accessibility to residential and industrial land. Such land uses include not only local retail and service establishments but also schools, local streets, and neighborhood parks. A dual interdependency exists for some of the land uses in this category, such as retail trade and schools, since their location is dependent on residential and industrial land use, but they also influence this same residential and industrial land use pattern in a feedback fashion.

The special sector includes all non-industrial exogenous inputs to the model most of which are the result of governmental decisions. These include the major freeway and arterial network, regional park and open space areas, and rail-utility rights of way and terminals.

The agricultural sector is treated in a residual manner in the model with such land being transferred to other land uses during the simulation period. Such a representation does not imply an endorsement of the gradual disappearance of agricultural land in the Region. In fact, such representation is intended to emphasize the need to consider the relative economic and aesthetic worth of such land in the land use plan design to provide the need for the formulation of policies to prevent this conversion of agricultural land should it prove desirable.

Model Characteristic

It is convenient at this point to review some of the characteristics of the land use simulation model particularly those that differ from other land use models being developed under the auspices of other agencies. The differences enumerated below should not be interpreted as a criticism of other model development in this field. The current experimental state of land use model development does not permit anyone to assert the absolute validity of his conceptual approach. Then too, planning objectives differ, and the land use simulation model under discussion may not be ideal or even useful in other programs. In the current embryonic state of land use models, alternative approaches, even if ultimately unsuccessful, should add to the store of research knowledge in the field.

The dynamic nature of the model has been explained previously and will not be belabored again except to point out that most land use models are static in nature having been formulated to determine a land use pattern at a single point in time. Such a static approach, it is admitted, has usually resulted from data deficiencies rather than any basic disagreement about the desirability of a dynamic model.

A second important feature of the model is its degree of disaggregation. A more detailed model is consistent with a behavioral decision-making approach to model formulation. Since households differ considerably in their income, education, age, and other characteristics the use of an aggregate household in the model is subject to question. For this reason, households have been classified into types with common characteristics with the hope of obtaining stability in the model parameters. Further disaggregation has been accomplished by the subdivision of household relocational behavior into a number of subdecisions. Although disaggregation has its penalties in terms of additional data requirements, additional model segmentation was felt necessary to be consistent with the formulation of behavioral decision rules.

The sampling approach to parameter estimation described in the regional economic simulation model was also used in the land use simulation model. To implement this sampling approach, new data sources were required including special household history data collected in the home interview part of the origin and destination travel surveys. The use of this new household data will be described in a later section concerned with parameter estimation in the land use simulation model. Another important new data source, the soil survey, also plays a critical role in the site selection decision of the land developer in the residential sector of the model.

Finally, the all encompassing characteristic of the model lies in its emphasis on the control rather than the forecasting function. Such emphasis is consistent with the generally accepted primary use of simulation models as vehicles for policy formulation. This "if-then" usage of a simulation model requires less information concerning the uncertain future values of exogenous variables than an equivalent forecasting usage. For this reason, conclusions may be drawn from model results with a higher degree of confidence.

Residential Sector Formulation

Primary emphasis in this section will be placed on an explanation of the residential sector of the model. This sector is fundamental to the operation of the model with the industrial, service, special, and agricultural sectors in an auxiliary role. The operation of the residential sector revolves about three primary decisions affecting the development of residential land:

1. The decision of the land developer to subdivide land for residential use.

2. The decision of the building contractor to build a dwelling unit or group of dwelling units.

3. The decision of the household to rent or purchase a dwelling unit.

This set of decisions, constrained by zoning, subdivision regulations and other restrictions imposed by local governments, combine to determine the residential land use of the Region. The time sequence of the decisions is not necessarily in the order listed. The household may dictate both the site development and house construction. It is also recognized that the household is the ultimate cause of the process since the sequence cannot continue if he refuses to buy or rent.

The residential sector submodel is subdivided into two subsectors--the central subsector and the zonal subsector. The central subsector is the central clearinghouse for all households relocating within the Region. New households, in-migrating households, out-migrating households, and households transferring from one zone within the Region to another one are temporarily located within this subsector until they are relocated at their new location. New households originate from an outside input to the model determined from population forecasts developed in the regional economic simulation model. In-migrating households are also an outside input from the economic model. All three of these relocating household sources are allocated to either one of the other zones or to out-migration.

The other subsector of the residential subsector is the zonal subsector. A zone is an area of land, varying in size from a quarter section (1/4 square mile) to a township in size (36 square miles), that will provide the basic areal unit in the model. At the present time, it is intended that the transportation zones will be used wherever practicable. Some modification will undoubtedly be required in certain areas, but all modifications will be formed in terms of the basic areal data unit, the quarter section.

To understand the zonal subsector, it is necessary to explain the concept of a household type. The validity of any system simulation model depends on the stability of the variable relationships and parameters used in the model. These relationships and parameters must be stable over time and over a range of outside inputs to the model. Experience tells us that households vary considerably in their behavior depending on the characteristics of the household. The concept of an "average household" is elusive since any behavior peculiar to such a household is the result of combining a wide variety of units of differing behavioral patterns. The relationships and parameters used in a model for such a household will probably not be stable since the composition of an "average household" is continually changing because of changes in the number of different types of households.

To provide the necessary decomposition of households into types, all relationships in the model are subclassified by household type. A separate set of relationships and parameters are determined for each household type in the model. In the zonal subsector equations the number of households in each household type is recorded. This number is modified as a result of:

1. Incoming households from the central subsector.

2. Departing households relocating in a new zone or out-migrating.

3. Aging households being transferred to the next older household type or being received from the next youngest household type.

Incoming households to each zone are determined by the number of households designated for relocation in the central subsector together with a number of factors determining the attractiveness of the zone. Accessibility to employment, shopping, and population groups together with the quantity and quality of available housing influence the overall zonal growth coefficient for each household type.

Household locational decisions may be subdivided into three subdecisions:

1. The decision to move.

2. The selection of a basic housing unit type package.

3. The selection of a particular site location.

This subdivision of the "where to move" decision into two subordinate decisions involving housing unit type selection and subsequent locational preference seems a natural one and was useful in providing statistical verification of the accuracy of the model representation of this decision process.

In model operation, a relocating household of a certain type will leave its originating zone and be transferred to the central subsector where it will be matched with an available housing unit type consistent with the locational preferences of the moving household.

To provide a classification of household types useful in simulating the above decisions, a special kind of statistical analysis of regional household data is required. The primary basis selected for household type classification was the housing unit type preference. Essentially, this involves matching household characteristics such as age (of head), family income, family size, and education (of head) with housing unit characteristics such as structure type, market value of house and land, and owner or renter status. Other characteristics, such as water and sewer services and lot size, may be added to the housing unit type pattern as necessary.

A technique known as taxonomic analysis was used to determine the household and housing unit type classification. The criterion for classification was a good match between the household and its housing type preferences. In a good classification, each household type would be distributed among a limited number of housing unit types.

In the taxonomic approach, the quality of the match would be measured by the aggregate similarity ratio which is defined as the ratio of the number of a household type included in a group of housing unit types. In a typical case, a household type might match four housing unit types with an aggregate similarity ratio of 0.96. This means that 96 percent of this household type was included in these housing unit types. The other samples might be scattered in a number of other housing unit types too numerous to include in the classification. The aggregate similarity ratio could always be improved, of course, by adding more housing unit types, but an unwarranted number of housing unit types of low density representation do little to improve the usefulness of the match.

The turnover rate (decisions to move per month) can then be determined for each of the household types. Ideally, the variance of the turnover rate within each household type will be small.

After the relocating household is matched to a housing unit type, the site selection subdecision must be made. Presently, this subdecision is based on accessibility measures for each zone. The matched households will be distributed to zones with appropriate housing unit type vacancies. The concept here is that once the household has decided to move and has selected its housing unit type, site location will be based on geographical considerations of accessibility to work, shopping, and other population groups. This use of accessibility differs significantly from the ordinary use of accessibility in regression-type models where the total change in population in a zone is related to accessibility alone. The approach here differs in the following respects.

1. Accessibility is a limited decision factor since it comes into play only after the decision to move has been made, and a housing unit type has been selected.

2. The weighting of accessibility will be varied to account for the differences in the importance of this factor for each household type.

The logic of the approach is clear in that the only consideration remaining after the decision to move and housing unit type selections have been made is geographic accessibility. Any remaining unexplained variance in the pattern should be the result of an incomplete formulation of the housing unit typology or a random element in the decision not capable of further explanation using this approach. In the actual case, some unexplained variance will remain. If this variance is not too large, it will not seriously jeopardize the usefulness of the model since this variance may be explicitly formulated in the simulation model.

It is possible that the site selection subdecision could be treated in a more microscopic fashion should it prove desirable. The information in the household history form will permit a more detailed analysis of employment accessibility by subareas and industries since that accessibility could be treated as another household type characteristic. A number of central subsectors might be needed to subdivide relocating households by sub-regional employment areas. The present plan is to continue with the initial accessibility approach unless the second approach promises a significant accuracy improvement.

Model Implementation of the Household's Turnover Subdecision: the turnover subdecision is very simply implemented in the model. A turnover rate (TO XX) is associated with each household type (HXX) and the households of each type departing from each zone in each simulation period are the product of this turnover rate and the number of households of that type in the zone.

HD51(I) = (TO (51)) (H51(I))

where

HD51(I) - households of type 51 departing from zone I

TO(51) - turnover rate, household type 51

H51(I) - households, type 51, in zone I

The turnover rate may be alternately expressed as a normal distribution with an average turnover rate (TOA51) and a standard deviation (TOD51) if such an approach should prove necessary.

Model Implementation of the Household's Housing Unit Type Selection Subdecision: the model implementation of the housing unit type selection subdecision is not as direct as that just described for the decision to move. Each zone will contain a limited number of housing unit types, and for that reason will provide housing for only a limited number of household types. The existence of housing unit types in a zone is dependent of the decisions of the land developer and builder which in turn are dependent on zoning, subdivision regulations, the topography, soil, and other physical and social characteristics of the area.

In the computer program, the inclusion of a housing unit type in a zone is represented by a series of equations accounting for the growth and level of that particular housing unit type in that zone.

Model Implementation of the Household's Site Selection Subdecision: site selection in the model is based on geographic accessibility. For each zone, an accessibility factor for employment, population and shopping is calculated based on the travel time from the particular zone to all other zones and the relative attractiveness of the other zones in terms of their total employment (employment accessibility), population (social accessibility), and retail employees (commercial accessibility).

Travel times between zones are inserted as an outside input to the model and may represent any existing, historical, or proposed transportation network. These times may be changed during program operation to account for planned (or historical) changes in the network. Attractiveness factors will be based on the current status of the employment, population, and retail employment variables in the model.

Relocating households are allocated to zones with housing appropriate to their type based on the accessibility factor of the zone compared to the total accessibility factor summation for the region.

The Land Developer's Decision: the land developer's decision is two-dimensional. He must determine:

1. How many lots to develop (lot quantity subdecision).

2. The location of the lots (site location subdecision).

The first of these two subdecisions is essentially similar to the production-inventory control decision in a manufacturing firm. In the long run, the number of lots developed must be equal to the number of lots sold, but in the short run, either vacant unsold developed lots or lot shortages may exist.

Because of the large number and part time nature of many land developers, the dynamic response of land development to long run demand will, in general, be less stable than in manufacturing. Overoptimistic forecasts of long run demand lead inevitably to any overdevelopment of land which later results in sharp contraction of activity to reduce the lot inventory. To simulate the behavior of the land developer's quantity subdecision, the dynamic parameters that produce this unstable pattern must be determined.

The site location subdecision is of a different nature. It resembles in many ways the housing unit type selection subdecision of the household in that a match process between a housing unit type and a land type is involved. The land developer develops a subdivision for a certain class of housing. The nature of the site and its cost (raw land and development costs) are important factors in the match of a housing unit type and a land site. The approach to determining the precise nature of the match will be similar to that previously described for the household-housing unit type combination.

Model Implementation of Land Developer's Lot Quantity Subdecision: the land development lot quantity subdecision is expressed in the model as a rate of development in terms of lots/month. The final land development completion rate in a particular zone (RLDC) is determined from a sequence of six equations which are identical in structure but have different parameters from the one zone to another.

The first equation calculates the base land development trial rate as a function of projected sales and lot vacancies. Projected lot sales are the summation of a time-average of past housing sales augmented by a trend correction.

In the formulation, the base land development rate is:

$$RLDX = PHCC + (VACD - VACL)/TLIA$$

where

RLDX - base land development rate (lots/month)

PHCC - projected lot sales based on housing constructed (lots/month)

VACD - lot vacancies, desired (lots)

VACL - lot vacancies, actual (lots)

where

$$VACD = (PHCC)\ (VACR)$$

$$VACL = RLD - HC$$

and

RLD - residential land developed (units)

VACR - vacancy ratio (months)

HC - total housing units

The term VACD reflects the amount of vacant lots considered normal as a function of the average lot sales rate.

It is necessary to distinguish between unit-lots and actual lots because of multi-family dwellings. A unit-lot is the number of dwelling units on the lot. If a single family housing unit is involved, a unit-lot and an actual lot are identical, but for multi-unit structures the number of unit-lots will depend on the dwelling units on the lot.

The base land development rate (RLDX) is modified by the residential zoning restrictions in such a way that no further land development is permitted after the zoning limit (RLM) has been reached.

$$RLDY = RLDX \text{ if } RLD \leq RLM$$

$$RLDY = O \text{ if } RLD > RLM$$

RLM - residential zoning maximum (unit-lots)

A third equation prevents a negative land development rate should RLDY become negative. Although such a negative rate is possible, as in the case of developed unsold lots reverting back to raw land in depressed economic times, it was not considered desirable in this model.

$$RLDZ = RLDY \text{ if } RLDY \geq O$$

$$RLDZ = O \text{ if } RLDY < O$$

To convert the units of land development rate to actual lots RLDZ is multiplied by the lot density factor (RDEN).

$$RLDR = (RLDZ)\ (RDEN)$$

RDEN - residential density conversion factor (lots/unit-lot)

Land development occurs over a period of time. To reflect this land development time, a land development time delay is incorporated in the model. Land development completed (RLDC) lags land development started (RLDRS) by a delay period (RDEL).

Residential land available in the zone (RLD) is increased by periodic additions of lots at the land development completion rate (RLDC).

$$RLD = RLD + (DT)\ (RLDC)$$

This completes the relationships for the lot quantity subdecision. It is now necessary to investigate the site location subdecision.

Model Implementation of Land Developer's Site Location Subdecision: two alternative formulations of the land developer's site location subdecision are being tested.

In the first formulation, site location is completely demand-oriented. The above set of equations for the quantity of lots are computed in each areal zone. Site location, therefore, is completely dependent on the demand for lots in each zone. Since this demand may ultimately be traced through the builder back to the household's decision to purchase, the entire model is demand-oriented. This version of the site location subdecision is being tested as an alternative formulation, but a second version, also being tested, considers the cost (supply) as well as the demand aspect of the development process.

In the second version of the site location subdecision, the lot development rate (RLDX) is calculated for the entire area being tested. For the Waukesha pilot test, this area would include the City of Waukesha and its environs. In general, it would include the area served by a common set of land developers. By calculating demand (RLDX) for the area as a whole, demand is considered as the source for the quantity but not the location of the lots. The lot location is treated instead as a separate decision based on the costs of land development.

In the new site location subdecision, the aggregate lot total in each time period is allocated to individual zonal areas based on a minimization of costs to the developer within the constraints imposed by zoning restrictions. Lot development costs have been determined for five classes of lot sizes based on the type of soil and the physical improvements required. Lot development costs vary significantly with the type of soil. For this reason, a comprehensive soil survey of the kind being conducted in southeastern Wisconsin is essential for simulating the development of new land in this version of this subdecision.

In the model, the aggregate land demand for each lot type in each period is allocated to the model zones using a linear programming subroutine. This subroutine will allocate land using the following relations:

$$\text{Minimize } C_t = \sum_{m=1}^{M} \sum_{n=1}^{N} C_{rmn} R_{mn}$$

$$\text{Subject to } \sum_{m=1}^{M} \sum_{n=1}^{N} R_{mn} + SR_{mn} = R_d + SR_d$$

here:

C_t - total private land development costs (dollars)

C_{rmn} - cost of developing a lot of lot type m in zone n (dollars/lot)

R_{mn} - lots of lot type m in zone n (lots)

S - service lot ratio (service land such as retail, school, street land etc. required to support residential development)

R_d - total residential land demand (lots)

This alternative approach is based on the hypothesis that land developers will seek out the most profitable locations for lots to satisfy the demand for lots in the area. This is not to say that he will develop the optimal number of lots since his forecast of lot sales is subject to error. The hypothesis implies only that land developers will search for the low cost locations appropriate to the type of lot.

This new formulation of the land developer's site location subdecision in no way implies a change to the behavioral approach to the locational decision of the household. The land developer is a businessman trying to advance his fortunes through land development. His knowledge of land values, costs, and sales potential is usually highly developed. Although it is recognized that there are many part-time developers who enter and leave the field depending on business conditions, these developers, too, usually possess special knowledge of land. Typically, they work in related fields such as real estate or insurance or are developing family property. In any case, they usually have an economic orientation since they are developing the land for a profit.

In contrast, the household typically has less knowledge of land values and economic potential. In general, it would seem that the household selects a house and site to satisfy certain housing and locational accessibility needs. As long as these needs can be met at a price he considers reasonable, he makes little attempt to optimize his location economically.

Builder's Decision: in the model formulation, the builder provides housing units in response to household demand. His only decision in the model is a quantity decision, and he affects location only insofar as he provides housing in the areas developed by land developers and that are selected by households. The quantity decision of the builder is formulated with the equation structure used for the land developer. The equation parameters will differ, of course, and will vary from zone to zone. Both custom and speculative builders are provided for in the formulation with the custom builder acting on specific demand and the speculative builder constructing homes for a temporary inventory.

Industrial Sector Formulation: in the endogenous version of the industrial sector an economic approach, modified by the detailed requirements of particular industries, has been taken to the basic decision of site selection. In essence, this approach is based on the theory that the site selected for a particular firm must possess certain characteristics related to the production and distribution technology of the industry. From the class of sites that comply with these specified characteristics, the firm will then select the lowest cost site available.

Industrial site selection, then, is simulated as a constrained cost minimization process. The decision is functionally similar to the land developer's decision in the residential sector in its cost minimization approach. It differs, however, in the more significant role played by technological constraints. The requirements for an industrial site are likely to be more numerous and more carefully analyzed than the requirements of a residential housing site.

The linear programming formulation of the industrial sector would take the following form:

$$\text{Minimize} \quad C_t = \sum_{i=1}^{J} \sum_{n=1}^{N} C_{in} \, I_{in}$$

$$\text{Subject to:} \quad \sum_{i=1}^{J} \sum_{n=1}^{N} I_{in} \; + SI_{in} \; + I_{id}$$

$$\sum_{i=1}^{J} I_{in} \leq I_{nz}$$

$$I_{in} \quad O \text{ if } I_{in} \; E \; J_i$$

$$\text{or} \quad I_{in} = O \text{ if } I_{in} \; E \; \overline{J}_i$$

where

C_t - total industrial land development costs (dollars)

I_{in} - industrial land for industry i developed in zone n (acres)

C_{in} - cost of developing industrial land for industry i in zone n (dollars/acre)

I_{id} - total regional demand for industrial land in industry i (acres)

S - service ratio - ratio of service land area to industrial land area

J_i - set of land meeting requirements for industry i

$\overline{J}_i$ - set of land not meeting requirements for industry i

I_{nz} - capacity limit for industrial land in zone n

Costs (C_t) of industrial land development are minimized subject to the restrictions that all the land required for each industry (I_{id}) must be satisfied, and no firms may be located in an area that does not satisfy the minimal requirements for that industry.

During each time period, total industrial land demand will be calculated based on the number of regional firms originating or moving within the Region and the new firms entering the Region. These firms will be located to particular areas by the linear programming subroutine.

The primary data requirements for the industrial sector of the model, then, are the site selection criteria for each industry or group of industries and the land development costs. The cost data is being collected for use in the land use plan design model and for general land use planning purposes. Site selection criteria will be based on the Stefaniak study[10] recently conducted in the Milwaukee area. In this study, site selection criteria were obtained for 759 plants representing all manufacturing industries in the Milwaukee area. This information is available in punched card form and so is in a form suitable for immediate analysis.

Use of the site selection criteria will require the separation of "necessary" criteria from "desirable" criteria since the basic industrial land allocation concept considers criteria from an "all or nothing" point of view. In the industrial site selection decision, all sites not complying with the required characteristics are eliminated from consideration, and cost minimization takes place within the acceptable site area. The most difficult analytical task will be the separation of "desirable" from "required" site characteristics.

The test area for the industrial sector of the model must be larger than the Waukesha pilot test area used for the residential sector test because this area does not provide a large enough variety of industries. An area, such as Kenosha and Racine counties, should be large enough to serve as a pilot test area for the industrial sector submodel.

Service, Special, and Agricultural Sectors

Land uses in the service sector such as local retail trade and services, streets, and other categories will be allocated based on service ratios required to support primary residential and industrial land uses. These service ratios for test simulation of past land use development will be based on analysis of historical service ratios. The interacting nature of the residential and service sectors should be emphasized. Service land use depends on residential and industrial land use, but an increase in service land use also influences further residential land use through the accessibility effect. Future land use plans will be based on service design standards.

Land uses in the special sector will be based on programmed inputs since these land uses are usually based on project-type decisions by government or the private sector of the economy. In fact, one of the primary areas of interest in model simulation will be the effect of the freeways and other elements of the transportation plan on land use development.

The agricultural sector in historical land use simulation will be a residual land use in that land previously in agriculture will be transferred to residential, industrial, or associated service land uses. In future land use plans, however, an attempt will be made to preserve certain agricultural lands in the land use plan design based on their productivity.

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[10] Norbert J. Stefaniak, Industrial Location Within the Urban Area, University of Wisconsin, Madison, 1962.

Estimation of Model Parameters

A combination sampling and regression approach was used to estimate the parameters of the land use simulation model.

Most of the household parameters are based on data collected using the household history form of the home interview survey. This household history detailed the home and work locations together with other data on the household and housing characteristics of the sampled households for the period 1950-1963. With this data, it was possible to classify the sampled households into type clusters and to determine their parameters for the turnover, housing preference, and site location decision formulations.

With the sampled households classified into types, parameters were estimated from the average values of historical decision patterns. The primary problem was the classification process itself. To accomplish this classification, a special set classification program was developed that would decompose a household set into subsets with common characteristics. Examples of household characteristics are the age, income, and education of the head of the household. Each subset of each characteristic is designated an attribute. Examples of attributes for the characteristics just described are: age of head of household under 35, income over $10,000, and college education.

The inputs to the set classification program are all of the selected characteristic-attributes of each sampled household. The output is a set of household types grouped according to common attributes. The minimum size of the smallest type subset is determined by the user. This size should depend on the size of sample being classified.

Parameters relating to the lot and housing quantity subdecisions of the land developer and builder were determined by regression analysis. Using a current land use inventory and historical records of subdivision plans and building permits, it was possible to synthesize a history of land development and construction beginning in 1950. From this history, the dynamic parameters of these subdecisions were calculated with a regression analysis.

The site location subdecision of the land developer depends primarily on the relative costs of raw land and residential development. These costs depend on the topographical and soil characteristics of the area. Data from the regional soil survey provided the base for costs by zonal area. Detailed engineering cost estimates were developed for land development of varying lot sizes on three classes of soil.

In the service sector of the model, the service ratios for auxiliary land use were determined either by historical ratios or planning design standards depending on the model application. Historical ratios are suitable for forecasts of uncontrolled land development, and design standards are preferable for plan implementation.

Industrial sector land costs for the endogenous version of this sector were also based on the soil survey. There was a significant amount of common data used by the Land Use Plan Design Model and the Land Use Simulation Model. Both used the land development cost data and both required service ratios for auxiliary land uses.

The land requirements of the various industries in the industrial sector were determined by a special study made by Professor Norbert J. Stefaniak of the University of Wisconsin-Milwaukee.[11] This study provided a comprehensive analysis of the land and public facility requirements of industries in the Milwaukee area. Although this study was prepared independent of the planning program of the SEWRPC and had no connection with the development of the model as such, it has proven to be of critical value to the industrial sector of the model. In fact, the endogenous version of the industrial sector would have been impossible without this study.

Model Validation

The general approach to model validation parallels that of the regional economic simulation model. Comparisons will be made between the synthetic history generated by the model and the actual history of land development in a past period.

To reduce the volume of data reduction during initial model tests, a smaller pilot area was selected within the Region for a miniaturized version of model operation. This approach has proven to be a wise one since the need for data reduction on a regional basis would have significantly delayed the experimental program.

The test area selected was the City of Waukesha and its surrounding area. As a test area, Waukesha has the advantage of a certain degree of employment-self sufficiency apart from the Milwaukee area. The area had a population of about 11,000 households in 1963 and a growth of more than 30 percent between 1950 and 1960. Analysis of the samples indicates a fairly wide representation of age, education, occupation, and income groups.

Tests now being conducted with the Waukesha area are scheduled for completion by the end of 1964. The results of the Waukesha pilot tests will be published in January 1965.

Computer Programming

The data reduction and model programs for this model like the regional economic simulation model were coded for the IBM 1620/1311. The problems encountered were somewhat different in that no significant loss in data reduction time was experienced with the Fortran data reduction program. Problems were encountered, however, with the running time of the model. Current experience indicates the need for 8-10 hours on the 1620 for a regional simulation run. Efforts are being made to reduce this time within the framework of Fortran. Translation of the model program into the 1620 symbolic language will be attempted if running time reduction is not satisfactory. Complete details of the data reduction and model programs will be available in the technical report.

CONCLUSION

Simulation model development is a demanding and time-consuming task. The model development program now in progress in SEWRPC may be considered over-ambitious by some, but it certainly cannot be viewed as irrelevant to the exceedingly complex problems now facing regional and urban planning agencies. In conclusion, it might

[11] Ibid., footnote 10.

be well for the writer to clarify the basic ideas of the article of which he is confident and those of which he is still uncertain.

Although it is impossible to be certain of anything at this current stage of economic and land use model development, the following concepts related to the models explained in this article have withstood the test of time, at least in the mind of this writer.

1. The functional role of the three models, economic, land use design, and land use simulation, illustrated in Figure 1 and described in the first pages of this report, would seem to be established. Whatever form the ultimately successful models take, these three planning functions: socio-economic forecasting, land use plan design, and land use plan implementation will be significantly improved through the use of mathematical model techniques.

2. The requirement for a new emphasis on land use plan design is probably the most important concept advocated in this report. The lack of activity design models as compared to forecasting models is difficult to understand when the end of objectives of planning are clarified and understood.

3. The land use plan design model seems closer to practical realization as a tool in plan design than the other models are in forecasting or plan implementation. This comparatively advanced state of plan design models, despite the meagre effort that has been expended in their development, is the result of:

    a. The significant advances made in linear and dynamic programming in other fields in recent years.

    b. The general availability of the data as compared to the data required for simulation models. Most of the data, such as the land use and soil inventories, are necessary even in an intuitive approach to plan design.

4. The general structure of the regional economic simulation and land use simulation models is believed to be sound and worthy of further development.

On the debit side of the ledger it is important to admit certain doubts and reservations to prevent unwarranted claims and enthusiasm regarding the immediate benefits of models in planning.

1. Typically, any planning tool, such as a mathematical model, even after a satisfactory experimental validation is accomplished, is only slowly adopted in the planning process because of the need for the user to acquire a "feel" for the model in application. Even a model as conceptually sound (in the opinion of the writer) and as potentially useful as the land use plan design model will require a shakedown period of a few years before it really begins to affect plan design.

2. The need for additional time and money for improvements in data collection, reduction, and analysis for all of the models described, but particularly the

simulation models, is only too evident. The statistical makeshifts and short-cuts, taken in the early development effort, could certainly be improved in the second round.

When one considers, however, that both the mathematical foundations and the means of computational realization, the digital computer, are less than two decades old, he feels a surge of optimism about the prospects for mathematical models in the urban planning of the future.

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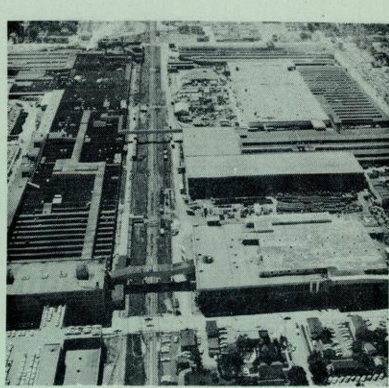
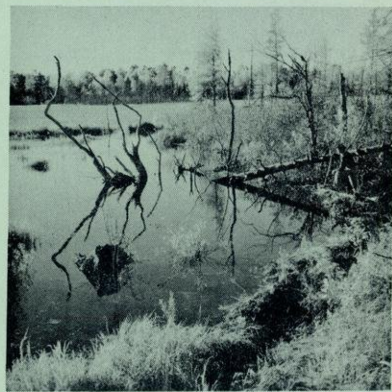
THIS IS SOUTHEASTERN WISCONSIN

Important vital statistics on the Region and percent of totals for the State of Wisconsin.

Land and Water Area (sq. mi.)	2,688	5%
Population (1960)	1,573,620	40%
Resident Employment (1960)	612,723	42%
Resident Unemployment (1960)	24,174	41%
Resident Labor Force (1960)	636,897	42%
Resident Man'f. Employment (1960)	253,292	52%
Resident Non-Man'f. Employment (1960)	359,431	37%
Disposable Personal Income (1960)	$3,572,000,000	46%
Retail Establishments (1958)	15,780	33%
Retail Sales (1960)	$2,045,000,000	42%
Property Value (1960)	$8,726,000,000	46%
Total Shared Tax (1960)	$62,777,000	54%
Total State Aids (1960)	$35,474,000	26%
Total Property Tax Levy	$239,380,000	50%
Total Long Term Public Debt	$378,592,000	55%
Total Highway (miles) (1960)	8,740.45	8.9%
Value of Mineral & Non-Metal Production (1961)	$15,494,487	20.08%
Total Vehicle Registration (1962-1963)	633,540	36.8%
Auto Vehicle Registration (1962-1963)	551,188	40%
Truck Registration (1962-1963)	55,950	23%
State Parks & Forest Areas (acres) (1963)	12,546	3.02%





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SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION