THE USE OF COMPUTERS
IN PLANNING:
LAND USE MODELS

by

KENNETH JOHN WHITWELL

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ABSTRACT

TITLE: The Use of Computers in Planning: Land Use Models

AUTHOR: Kenneth John Whitwell

SUMMARY: This thesis examines several areas of computer usage in Community Planning, with particular emphasis on the state of the art of urban systems modeling. Several examples of computer model usage are reviewed, and an evaluation is made of the usefulness of this particular tool in the practice of community planning.

The paper concludes that models provide a method of organizing various theories concerning the functioning and growth of urban activity systems, and a means of gaining knowledge about the many relationships involved. The use of these models to achieve specific predictions concerning the growth of any particular city or region runs into problems of accuracy, data reliability and unexpected situations, as well as being hampered by the lack of comprehensive theories of urban systems.

ACKNOWLEDGEMENTS

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Thanks must also be given to the Ontario Department of Municipal Affairs and the Ontario Housing Corporation, which made information available to me.

To complete the acknowledgements, a comment must be made on the "method of operation" of this paper. It represents several years of gathering information from books and articles, and from many conversations with friends and colleagues. This process was originally directed simply by interest, and because of that, sometimes failed in precision. Later, when directed by formal studies, it became more academic. But basically this paper remains the result of a long period of digestion and fomentation of material, mingled with relevant working experiences. Hopefully, the result contained here is a unified and reasonably comprehensive treatment of the subject. And so thanks are due to the many people who, since 1964, have served as sounding-boards for these ideas.

K.J. Whitwell

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CHAPTER I

INTRODUCTION

Purpose and Organization

The purpose of this paper is to examine the usage of computers and the "systems-analysis" approach, and to provide a short survey of the present state of the art of urban systems models in Community Planning. Particular emphasis has been placed on the application of computers to simulate community growth or change through the use of Land Use or Simulation Models. The usefulness of the modeling technique will be evaluated, and the implication for the future of the methodology of community planning will be examined in the light of recent developments in both computer hardware and in the programming or software capabilities.

The paper is divided into five main sections. The first section examines the concept of models and modeling in general, and determines the place that computer models hold in the overall class of models. Having set the basis for models in section one, sections two and three are an introduction to computers. Section two reviews the history of computers and provides a brief description of hardware capabilities as well as explaining the logic and limitations of these machines. Section three examines uses, both historic and current, of computers in planning. Such topics as accounting procedures, statistical techniques, mapping and graphing, information storage and retrieval, and geocoding are covered in this section.

The fourth section is the heart of this paper. This section reviews and evaluates a particular example of computer use: that of Land Use or Growth Allocation Models. The development of this technique from its beginnings as an offshoot of traffic models is traced, and the empirical and mathematical foundations of the type of model, and the underlying assumptions and view of society that are inherent in the model structure, are examined. Several concepts of population growth and the model designs associated with them, particularly those from university research centres, are examined in order to attempt to trace the direction of future developments.

The fifth section is basically a summary of the findings of the paper. In addition, however, it attempts to show how the use of computer models as a planning tool fits in with the more conventional tools of the planning profession. The overall costs and benefits of computer usage and the associated systems techniques are assessed from the standpoint of the community planner. New techniques and developments in computers and programming, trends in usage, and current research projects in modeling are combined to produce a possible picture of the future uses of computers and the changes in planning emphasis that will result from the application of these developments.

Orientation

The orientation of this paper is threefold: one, as an academic exercise, the subject matter is critically examined, and careful logical steps in the development of the thesis are followed. References are checked and acknowledged and a great deal of material is gathered into one paper for the edification of the reader. Secondly, it is an attempt to provide useful information to the practising planner or planning student. It provides an overview or resume of the subject of computer usage in planning, as well as a more detailed account of the application and concepts of Growth Allocation Models. However, even in the detailed parts, the paper is written by a planner, for planners, and in the language of planning, rather than in a mathematical or computer-systems oriented terminology. Finally, this paper is directed to computer experts and systems engineers, not as an attempt to inform them of computer or modeling concepts, but rather to help them understand the needs and requirements of planners in the area of computer oriented techniques.

Introductory Note

In the section on Land Use Models, particular emphasis is placed on the Empiric Model as developed by Traffic Research Corporation, now, Kates, Peat, Marwick and Co. in Canada. This model was used successfully in Boston and at the time of writing this paper the company was in the final stages of a land use study of Metropolitan

Winnipeg using a variant of the Boston model. At one time it was hoped that this paper could include a writeup of a land use study on which the author had assisted. Unfortunately, for various reasons the particular modeling application involved did not proceed beyond the preliminary investigation stage, and so this paper is restricted for its data to published reports, books, and documents.[1]

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[1]See Appendix C, p. 130, for further information.

CHAPTER II

MODELS AND MODELING

Introduction

Conceptually, a model can be viewed as a means of representing some aspect of reality. A model is not a duplication of all aspects of the reality being portrayed, but rather an abstraction of those factors from the total which are necessary to solve the problem or achieve the goal for which the model was designed.

> A model can be a theory or a law or an hypothesis or a structured idea; it can be a role or an equation or a synthesis of data; it can be a reasoning about the real world by means of translations in space (to give spatial models) or in time (to give historical models).[1]

Of course, it can, with equal ease, be a three dimensional object which physically and visually depicts a real-world entity. In any case, a model is a "simplified structuring of reality which presents supposedly significant features or relationships in a generalized form."[2] Because some factors are excluded to obscure incidental detail and highlight fundamental aspects, models have varying degrees of probability and a limited range of conditions over which they apply.

The applicability of a model to a given situation must be known in order to evaluate the correctness of the model's conclusions. Also,

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[1]Richard J. Chorley and Peter Haggett (ed.), Socio-Economic Models in Geography, (London: Methuen & Co., 1967), p. 21.

[2]Ibid., p. 22.

because of the selectivity of the input factors, a model is constantly in need of improvement as new relationships and factors appear, or as changes take place in the relative importance of the included relationships.

A successful model is thus one which eliminates all of the unnecessary detail and concentrates only on that which is essential to fulfill its purpose, and one where the relationships included in the model are specific and precise enough to generate a high level of accuracy. Unfortunately, it often happens that a successful model is very hard to modify. Because the structuring is so tight, and all the relationships so precise, the introduction of a new variable necessitates the complete restructuring of all the relationships in the old model in order to maintain the same level of accuracy. A more loosely-knit model, with a greater degree of slack in its parameter values and perhaps a "fudge-factor" to handle unexplained variances, might not provide the same accuracy as the successful model but it could be modified with new information without a complete rewriting of all its equations.

Planners and Models

To many planners, the concept of a model conjures up a picture of a three dimensional object depicting the layout of a new housing development or a new building. This particular emphasis may be related to the number of architects who are involved to some degree in the planning field, and who, traditionally, have viewed themselves as the designers of structures. This viewpoint may also be part of a stream of thought in planning which sees physical goals regarding the layout and structure of community activity which are to be achieved. This could be described as the Utopian view of planning.[1] Both of these viewpoints are, however, somewhat blind to the characteristics and motivations of the people that are supposed to inhabit either the building or the community.

To the extent that people are involved or planned for, they are seen to possess those characteristics that would be in harmony with the ideal plan or situation. One consideration which seems necessary in an ideal society is a type of social organization that encourages people to behave in socially beneficial ways, but can permit within its ideal structure contrary patterns of behaviour. For example, in a Utopian society, what challenges exist for the young? If the ideal situation has been achieved, then by definition any change would be for the worse and would have to be prevented. How does one cope with boredom? If a pattern of action is developed where each man (as in Utopia) need work but six hours a day, what does he do in the rest of his time, and what does he have to look forward to in the years ahead? Finally, if over time a society is developed which is

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[1] Utopia, written by Sir Thomas More in 1516, describes an ideal agricultural society in a perpetual state of harmony. Not only is there no description of the process by which the present society changes to the ideal, there is also no indication of what types of change would take place after the ideal is reached. Utopia, like Plato's The Republic, does not contain any idea of social dynamics; although people may fill different positions within the system, the framework of the society remains unchanged. For a fictional account of what befalls a society in equilibrium see Ayn Rand, Anthem, (New York: Random House Inc., 1948).

static and unchanging, how does this society react to external ideas and intrusions, to say nothing of outside threats?

The emphasis of the Utopian planner appears to be on physical structures; how do plans or structures relate to the day-to-day ideas, actions, hopes, plans, and enjoyment of the inhabitants? After the final plan has been completed, the houses painted, the courtyards landscaped, the grass cut, the flowers planted and the shade trees put in place, then a few people, always happy, smiling, pleasantly dressed, unhurried, and with angelic intent are added to round out the picture. The results, if the plan is put into effect, are disasterous. Monumental public housing projects, out of scale to the inhabitants, and with little nooks and crannies to encourage criminal activity, are one result. An example of this situation can be found in the public housing in St. Louis, Missouri. University Avenue in Toronto, an example of a well planned street, with height restrictions on buildings, prohibitions of signs, wide open spaces with trees, flowers, and boulevards, is an empty wasteland with all the human interest of a graveyard: Yonge Street, unplanned, noisy, garishly lit and crowded, provides a heart and centre of interest to many of the people of the city. Yonge Street could be improved, of course, but to prevent this improvement from destroying the human interest, (in the way traditional planners are trying to "improve" Toronto's Yorkville by tearing down dirty coffee houses and building clean parking garages) the planning for Yonge Street must be a step-by-step process in keeping with the desires and interests of the people who are supposed to benefit from the planner's handiwork.

In this context of model thought and social viewpoint, the predisposition of some planners to place great emphasis on the preparation, design and use of maps is worth mentioning. Like a physical model, a map is also a static tool, a snap-shot of reality which, while capturing the situation at a given moment, provides little or no information as to the process by which the pictured situation was arrived at, how it is changing, and whether or not it is functioning properly according to some scale of judgement.

Change in Model Emphasis

The change in the emphasis in model type came about during and after the introduction of computers into general use. This is not because of the lack of need before that time, although there is some truth to that point, but rather because the development of complex models requires a means of handling large quantities of data in a short period of time. This handling ability permits the testing of academic concepts, experimenting with new ideas, and the application of theories to real life situations.

Basically, the change in model use is part of the trend away from placing importance on "what is" to placing it on "what changes"; from objects to the various relationships between objects. Although static representations are useful to provide checkpoints, they no more portray the situation in an urban environment than a picture communicates the history and progress of a motoring holiday.

In the planning profession this change in emphasis is the change from physical objects and plans of subdivision to computer traffic models, urban simulation and land use models; from static goals and predictions to conditional and probabilistic objectives. The change is away from the planner who feels that his professional knowledge entitles him to make long range plans and goals for the society; away from the planner who is convinced that he knows what is good for people better than the people themselves or their elected representatives. It is a change towards the situation where the planner acts as a resource person, working with the people of the city, helping them to achieve their immediate goals while at the same time, with his wider field of vision and interest, preventing the conflicts between different points of view that can arise if planning is left to self interest groups. It is a change away from a society with known and relatively unchanging goals and values, to one with a wide variety of values, often in direct opposition, which, in addition, are in a constant state of change.

Systems Analysis

The change from a static viewpoint of reality, where change is an anomaly, to that of reality as a situation of constant change, required the introduction of a way of organizing a series of constantly changing impressions so that some sense and order could be made of them. This method of organizing a number of changing situations is known as systems analysis.

One definition of a system is as follows:

> An abstract system, or simply a system S, is a partially interconnected set of abstract objects a_1, a_2, a_3...., termed the components of S. The components of S may be oriented or nonoriented; they may be finite or infinite in number; and each of them may be associated with a finite or infinite number of terminal variables.[1]

Other definitions have been less mathematical; one for systems analysis states: "Systems analysis is the selection of elements, relationships, and procedures to achieve a specific purpose."[2] Let us say that a system is composed of elements or objects, the relationships between these objects, and the rules which govern the changes in the relationships. Systems analysis would then be the selection of objects or relationships associated with a given problem in order to study them and determine the laws that operate within the system, other relationships and objects that were unknown at the start, and possibly, the relationship between the studied system and others.

Systems analysis was first used by the United States army to organize and overcome the problems of logistics during the Second World War.[3] Great numbers of men and a vast amount of material was in constant movement from one part of the world to another. Not only had the army to keep track of who and what were where, and what field commander needed certain men and materials, but the movement pattern had to be changed constantly as new priorities, enemy activity or

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[1]Lotfi A. Zadeh and Charles A. Desoer, Linear System Theory: A State Space Approach, (New York: McGraw-Hill Book Co., 1963), p. 65.

[2]Van Court Hare, Systems Analysis: A Diagnostic Approach, (New York: Brace & World, Inc., 1967), p. ix.

[3]John W. Dyckman, "Planning and Decision Theory", Journal of the American Institute of Planners, XXVII, no. 4, (November 1961), p. 337.

political maneuvering took place. The method of organizing such a situation is to conceive of it as a system with men and materials moving from place to place, virtually ignoring the stocks of men or material that exist at any given moment in time or place in space, and to concentrate on the flow and flow characteristics of the entities through the system.

This concept of viewing a part of reality as a system of entities or transactions moving through a series of steps or blocks has the advantage that it can be represented mathematically if limits can be established to the rates of flow and amounts of stock in any one location. Thus the representation of the system becomes a series of mathematical functions and equations. As with all equations, different weighting values, functions and inputs can be tried experimentally in order to understand better the internal workings of the system, and to predict the actual results if certain hypothetical changes took place in the real system. By abstracting and determining correlations between various pieces of information and activities, and then by interpreting the results, the experimenter can gain insight into the workings and causal relationships within the system.

Probabilistic Models

In attempting to fit strict mathematical equations to the interactions of reality, it soon became apparent that certain situations were not capable of representation in a simple, deterministic way. Questions of highway design, shopping centre parking lot size, or the number of ticket windows required in a theatre centre all involve a number of probabilistic variables that may or may not be related in any understandable way.

The technique of handling such situations as these involves careful study to determine the range of values for every step in the total system. For example, if the goal is to construct a shopping centre parking lot that will be able to hold 95% of the total number of cars which want to use it on the busiest day of the week, one must determine the frequency of the arrival of automobiles at each hour throughout the day, and get maximum, minimum and mean arrival rates. These figures, plus the absolute number of cars expected, could be determined on a ratio basis from another shopping centre in the area. The second point to determine would be the average and statistical distribution figures for the amount of time that people take in walking to and from their car, and to and from the various stores. Obviously, the various types of weather conditions would affect the length of time spent in window shopping, and in walking from store to store. Next, one must determine the average time that a shopper spends doing his shopping. This time is related to the type of shopping, to the type of store, and to the crowding of the store and the sales desks. It soon becomes apparent that as the parking lot becomes more crowded, the length of time that the average car spends in the lot increases due to the congestion both in the lot and in the stores. To determine the number of cars that would want to use such a parking lot at one time, requires the simulation of a day's shopping patterns using a random number to determine the arrival rate, the number of arrivals, and the length of time that an individual car would remain in the lot. Running through the simulation once for each car it is possible to determine for that day the maximum number of cars in the lot, or wishing to enter the lot, at any one time. Such a calculation by hand, for about a thousand cars, would take at least two hours. However, to achieve useful averages and to determine peaks, it would be necessary to simulate several hundred days. As each step of the calculation involves a probability, such a series of runs would indicate the maximum number of cars when all figures, (arrival rate, duration, weather and congestion) were at their maximum value. In addition, such a series of calculations would show what percentage of the time each number of cars was reached. If 95% were the goal figure, then a parking lot size could be determined in which that percentage could find parking space on the week's peak day.

Due to the large number of calculations involved, and the time required to perform them, the science of probabilistic simulation had to wait for the arrival of computers before it could be used. This type of modeling has become the special activity of Operations Research, and is used in many activities where the required figures cannot be determined explicitly and where causal relationships are unknown. Operations Research is a phrase coined during World War Two which has been replaced by a succession of other names since.

It is now called by its original name again and there is even an Operations Research Society. O.R. could be defined as a sub-set of systems analysis concerned with those systems which include probability distributions and which cannot be solved by deterministic equations. Phrased slightly differently:-

> O.R. is the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to the problems.[1]

Such situations usually involve the operations of people, where predictions of the actions of one individual are not possible, but overall averages, rates and distribution functions can be determined for large groups of people. To aid the person using such a system of modeling, the large computer companies have developed special prewritten package programs. The package developed by IBM is known as the General Purpose Systems Simulator (GPSS)[2]. A coding language has been developed to use this program, and the end result is that the user need only describe the steps in the procedure and the averages and probabilities as determined by observation, and the program does all the calculations and produces many statistical figures and summaries as output. Although such a technique would seem to be a

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[1]C.W. Churchman, R.L. Ackoff and E.L. Arnoff, Introduction to Operations Research, (New York: John Wiley & Sons, Inc., 1957), p.18.

[2]General Purpose Simulation System/360: User's Manual, (White Plains (N.Y.): International Business Machines, 1967), Document #H20-0326.

natural tool for planners who must deal with large numbers of people and many probabilistic distributions, and although the programs have been used frequently and successfully by many industries to plan such things as layout or number of pumps in a roadside service station, GPSS, to the best knowledge of the author, is not being used by any planning department in Canada.

Cybernetics

One other general area of modeling is that of cybernetics. Actually, cybernetics might be more accurately thought of as a method of controlling real world processes rather than representing those processes in a symbolic or abstract way. However, the theory and concepts of cybernetics represent a real-time model, and the actual application of the model as a control process could be viewed as an incidental operation.

Cybernetics is the science of control and communication, and the name itself means "steersmanship". Many of the theories involved are complex and mathematical, but one simpler aspect is the concept of feed-back. This is applicable to a dynamic system, and involves the mechanism whereby results of an operation at some point affect a previous step or steps of the process, thus changing the process so that the next results are different than they would otherwise have been. In a simple qualitative example, as the output increases, a change is made in the process to slow down the production, while as the output decreases, the production is speeded up. This is known as negative feedback, and results in oscillations in the rate of production. Such oscillations may eventually disappear or dampen as the production rate becomes such that the output attempts neither to speed it up or slow it down. On the other hand, the oscillations might become more and more pronounced if the reactions to the first signal are so large that they produce even stronger signals the next time. This is an example of an unstable negative feedback. On the other hand, the feedback might be such that activities of a certain type generate a signal for increased production of that type of activity. Such a process is called positive feedback, or growth, and continues until some limit is met, or until some other process takes over. The parking lot which becomes more congested as more people use the stores, becomes even more congested because of the longer duration due to crowding within the stores, then more congested still due to the line-ups of cars trying to get in and out of the lot. Thus traffic confestion is a positive feedback and continues until some other process takes place, namely more drivers returning home or going elsewhere.

Cybernetics is concerned with "machines", electronic, mechanical, neural or economic; and deals with how these machines operate in a generalised sense. The greatest use of cybernetics has been in the biological sciences, as an aid to understanding how individual entities and groups or colonies grow, change and adapt to changing conditions and stimuli. The basic question of cybernetics is "Why this particular result and not some other?"

> Cybernetics envisages a set of possibilities much wider than the actual, and then asks why the particular case should conform to its usual particular restriction. In this discussion, questions of energy play almost no part -- the energy is simply taken for granted. Even whether the system is closed to energy or open is often irrelevant; what is important is the extent to which the system is subject to determining and controlling factors. So no information or signal or determining factor may pass from part to part without its being recorded as a significant event. Cybernetics might, in fact, be defined as the study of systems that are open to energy but closed to information and control -- systems that are "information-tight".[1]

Although a city is not "information-tight", it would seem that the science of cybernetics would be applicable to the study of cities and the various processes that go on within them. The lack of information isolation could be overcome by determining the nature and extent of information and control form outside that was received by any given city. If the inner channels of communication and their contents were known, the residual changes in the city could be attributed to the information coming in from outside.

Robert C. Wood, U.S. Undersecretary of Housing and Urban Development, wrote about city systems:

> John Ebergard...compares a city's hardware systems to those of the human body: -- the metabolic system -- the network which provides

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[1]Ross Ashby, An Introduction to Cybernetics, (New York: John Wiley & Sons, Inc., 1963), p. 3.

> for the ingestion each day of huge quantities of water, supplies, food and fuel and the consequent production of waste in the form of sewage, garbage, trash and air pollutants; -- the cardio-vascular system -- the horizontal and vertical paths of movement, and subways and trains, highways and automobiles, sidewalks, stairways, and people; -- the nervous system -- the information -- communication network of the city which makes it possible for its many parts to keep in touch, for it to be (at least potentially) managed as an entity, or for signals to be emitted at the proper time in order for the other systems to remain under control; -- the enclosure system -- the combination of skeletal subsystems.....which surround the hollow places of the city in which the life of the city goes on.[1]

Richard L. Meier has written a book in which he studies the growth and interactions within a city from the point of view of information exchange.[2] He feels that the purpose of a city is to facilitate the flow of information between persons, to store this information in some way until needed, and to create or discover new information. Urban problems can be viewed as a breakdown in communication, while progress or change is brought about by new information or means of exchange. In an article in the Journal of the AIP, Meier and Hoshino examine the cultural changes in Japan and relate these

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[1]Robert C. Wood, "Application of Computers to the Problems of Urban Society", Socio-Economic Planning Science, (London: Pergamon Press, 1968), p. 211.

[2]Richard L. Meier, A Communications Theory of Urban Growth, (Boston: M.I.T. Press, 1962).

to the new sources of information input from foreign publications and countries.[1] Such a study of information flows in Canada, and within certain cities may give the planner a better understanding of the reasons for the persistence of poverty or a poverty-mentality in certain areas, and, conversely, the reasons for growth and rapid change in other urban areas. In addition to being descriptive, such an understanding might facilitate prescriptive action for certain social conditions.

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[1]Richard L. Meier, and Ikumi Hoshino, "Cultural Growth and Urban Development in Inner Tokyo", Journal of the American Institute of Planners, XXXV, no.1, (January, 1969), p. 8-9.

In the Japan study, Meier and Hoshino concluded that the causal steps in cultural and economic change included the following:

1) Foreign cinema, television, magazines and artifacts are exhibited.

2) Extensive foreign travel with cameras document overseas successes.

3) The volume of public face-to-face interaction in varied entertainment areas sets up a continuous demand for new things to talk about.

4) Foreign images, reinforced by discussion, stimulate fads and styles while indigenous experiments aim at regaining the initiative for local producers.

5) Curiosity induced in the public creates new markets for products and services.

6) Foreign technology is licensed and experiments undertaken to adapt the technology to local conditions.

7) Public and private institutions expand to meet the new demands and are forced to advertise their appeals.

8) Differential growth rates appear in both culture and economy, and less educated sectors of society and less accessible urban communities are left behind. (This creates a number of stresses, some of which become evident only when they foster disturbances.)

9) A rapid rate of obsolescence develops as firms and households are constantly alert to the conditions of their public image. This releases powerful forces of status maintenance in a way that allows them to be used for development ends.

10) Planning the future is aimed primarily at maintaining the impetus of growth and is pragmatically applied to specific locales, agencies and functions.

Thus an understanding of urban processes, predictions of future activities and patterns, and planning either to eliminate undesirable situations or to produce desired ones, all require that in a conceptual model of the urban system, cybernetics and information theory must be included. As Meier and Hoshino conclude:

> A quick acting, wide-open cultural system, as sensitive to content of public communications in the world's pacemaking societies as to its internal trends, seems to be one of the best instruments for overcoming serious internal bottlenecks and structural defects. The planning that accompanies it is unspectacular, but the pace of improvement in measurable economic well-being is unprecedented.[1]

Conclusion

An understanding of models progresses from the simple to the complex. At the first level models are a representation of physical objects, and this stage includes pictures, layout plans, three-dimensional objects, and maps. The model represents a frozen instant of reality. While useful as a historical record, it is not a method which promotes understanding of the processes which gave rise to the situation depicted, nor of its future developments. In addition, qualitative comparisons between different areas and at different times are difficult to make.

The second step in the modeling process involves the shift of emphasis to processes and flows, and away from objects and situations.

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[1]Richard L. Meier and Ikumi Hoshino, op. cit., p. 9.

The process-oriented emphasis includes the concepts of systems and systems analysis. The modeling procedure becomes more abstract and mathematical; trends and changes can be identified and directions plotted. Comparisons become possible between different systems and between the state of the same system at different points in time. Systems analysis, besides providing the framework for dynamic models, offers other contributions to urban problem-solving. These include the following:

> First, the emphasis on considering total processes rather than individual units; second, the emphasis on the relationships -- "intersections" - between various processes; third, the emphasis on the use of models and/or field experiments to examine the effect of changes at different points in a given system; fourth, the emphasis on an interdisciplinary approach, on communications not only between engineers, psychologists, politicians, and anyone else who can contribute to understanding how the system works; fifth, the emphasis on identifying goals and balancing them off against other goals as possible courses of action are examined.[1]

This shift from physical models to those of a mathematical type required the use of machines capable of performing many calculations in a short space of time. And so dynamic models could not be developed without computers. On the other hand, the arrival of the computer has provided facilities for a great deal of experimenting so that the academic community has been able to develop many new and powerful modeling techniques. One of these involves the ability to handle probabilistic functions through the use of systems simulation.

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[1]Wood, op. cit., p. 211.

In this way, modeling concepts have changed from deterministic to a more random type. People in groups do not follow strict physical laws, but their movements can be studied by the new statistical methods. On top of the probabilistic ideas and concepts come those of cybernetics and information theory. Not only must the planner's conceptual framework of society include the ideas of information transfer and feed-back loops, but his actual use of such models must include feed-back from reality from time to time, in order to maintain the correspondence of the model to the society it is supposed to represent. Otherwise, he loses the accuracy of his predictions and the usefulness of his prescriptions. Finally, of course, information theory gives the planner a new tool to use when he wishes to implement the changes that he has prescribed. Citizen participation becomes not just a "good" philosophical concept, but a necessary step in making changes in a closely-knit, highly interactive society where cultural and social change move hand-in-hand with economic change.

The inclusion of information and control concepts into the urban model adds one more level of abstraction. While a model that represents the flow of people or goods must be abstract and mathematical, at least the entities being modeled are visible. In modeling a system of information flow, however, not only is there the abstraction of flow, but also of the entities themselves (bits of information). While one can make the choice in modeling a city and its people as to whether to use a static or dynamic model, no such choice is possible if information is included. In this case, some mathematical abstraction and the volume of entities and points of intersection involved, comes the need for a high speed computing device to run the model.

CHAPTER III

COMPUTERS

Introduction

> Computers intelligently applied to city planning can discharge a number of roles. They can, first of all, be used to obtain, process, store, and retrieve information. Second, they can be used in the analysis of information. Third, they can be used to make predictions. Fourth, they can control systems in the real world or, more correctly, they can generate control signals. Finally, it is believed that computers can find solutions to problems.[1]

What is this marvellous machine that can do so much?

Brief History of Computers

The 1880 census of the United States took approximately seven years to compile and report on all of the gathered information. It was apparent to the government that the 1890 census would take even longer, and that possibly by 1900 the point would be reached where information from the next census was starting to arrive before the completion of the preceding one. To eliminate such a situation the government employed the invention of a Mr. H. Hollerith, that of a punched card. The concept behind the punched card was that it represented a unit-record, the finest breakdown that would be required for the purpose of the analysis, (an individual person for the census requirements), and that the one card could be used in the calculation of many different totals. In this way, all of the cards from any one

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[1]Britton Harris, "Computers and Urban Planning", Socio-Economic Planning Science, (London: Pergamon Press, 1968), I, p. 224.

city could be run through a machine which would count the number of cards that had a hole punched in a certain column. For example, the number of males would be totalled, and then the same cards could be used to count the number of females, for which the cards would have a punch in a different position in the same column. By using more than one column at a time, a much more detailed accumulation could be achieved. For example, the number of white females between 30 and 39 years of age with more than grade 8 education could be found from the same deck of cards if corresponding codes had been punched in them.

From that time on, more and more varied machines were produced to perform tasks using punched cards. Accounting machines were developed with up to 40 counters to add many figures and pieces of information and to print totals automatically at different times during the run. Such machines were programmed to perform their functions by the use of a removable plug-board which had wires joining various sets of holes. Such a board established electrical circuits so that information from selected columns in the input card would be added to selected counters, and detail lines or totals would be printed at preselected intervals and placed at predetermined positions. In fact, by the mid-nineteen fifties, large calculators had been produced which could multiply various numbers, store the answers in counters composed of electronic circuits, and punch the results back into the input card or into another card. By then, however, the unit-record equipment had already been superceded by the stored-logic computer.

The first electronic computer was developed by Eckert and Mauchly at the University of Pennsylvania in 1946, while one of the earliest commercial computers was the Univac, produced by Remington Rand in the early 1950's.[1] The concept behind a computer is that of a number of storage positions which can each contain a single bit of information, and this bit can be part of a storage counter or part of an instruction.[2] The computer storage positions are electronic devices which can be either 'on' or 'off'. Two types of circuitry are involved; one turns the position on or off, while the other is used to test the status or value of the position. At first, these positions were part of electron tubes, but are now magnetic bits which are controlled and tested by minute transistorized circuits.

Each core position is numbered and machine instructions tell the control mechanism either to add the contents of two positions, to subtract or to move information from one place to another. A number is stored by first translating its value to a binary number and then using enough storage positions to contain all of the binary bits within the number. Thus 4 would be represented by 100, 3 would be 011, and 4 + 3 would be 100 + 011 and the answer if 111 or 7. Using electronics as opposed to mechanical devices produces a fantastic increase in speed, and also an increase in accuracy. Instructions

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1 -- A History of Data Processing, (Toronto: Sperry Rand Canada Ltd.) p. 29.

2 In the IBM/360, 8 bits are grouped into a single addressable position, which can represent either a single alphabetic character or 2 decimal digits.
-IBM/360, Principles of Operation, Form #A22,6821, (Poughkeepsie, New York: International Business Machines, 1964), p. 7.

occupy positions in core and the total size of the machine is related to its number of storage positions. As the core size is increased, the number of possible counters is also increased, as is the number of potential instruction steps, and hence, problem complexity. As an example of changes in the last twenty years, the IBM accounting machines of the mid-1950's had up to 80 positions of counters, (ten 8-digit numbers or eight 10-digit numbers etc.) and performed approximately 120 calculations per minute. The IBM 1401 of the early 1960's usually had about 8,000 positions of storage, and if 4,000 were used for program instructions, there would be capacity for four hundred 10-digit or five hundred 8-digit numbers. The calculation rate would approximate 2,000 calculations per second, or 120,000 per minute. By the end of the 1960's, the IBM/360 machines often had up to 256,000 core positions and calculation speeds of over 1,000,000 per minute. Obviously the power and capability are available, but how is it used?

Programming Logic

Programming logic consists basically of following a single transaction through the system. A number enters the computer from a punched card or some other external device. It is added to a total accumulator or has some other operation performed which is dependent on the programming steps and the identification of the number. The logic often depends on identifying a number either through its position on the input card, or by means of an identification code accompanying the number. Instructions test input codes and signal the start of a specific set of operations as a result of the test. A code, or perhaps a change in a number from one card to the next, triggers a set of instructions. In addition to external codes, the results of internal operations can be tested, and certain sets of instructions performed as a result of those tests.

Whether the trigger for performing a specific set of operations is from an external device, or due to an internal result, the programmer has always had to anticipate the situation, instruct the program to perform the test, and then produce the instructions that the computer must follow as a result of the test. Even in those situations of complex programming where the results of a given operation are used to change preceding instructions for subsequent transactions[1], the programmer must still know what kind of situations to expect, or else risk the program being unable to continue due to invalid instructions, or having the program produce completely useless results. Thus a computer and its program are only as effective as the person who wrote the program and gave the machine its instructions.

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[1]The following are examples of changes, made by the author, in a program for an IBM 1401 by the program instructions:

- Move the code for No Operation ('N') into the place of the previous code for a Move Operation ('M').
- Move an 'N' in place of a branch instruction.
- Change the address of a branch instruction in order to perform a different routine.

When the programmed instructions have been carried out, the program is changed.

Computer Devices

Although the control logic is only as capable as its programmer, the limiting factor in computers has been, until very recently, the type of input and output devices available. Now, with the flexibility of the more recent control circuits in computers, and with the use of electronic controls in more and more non-computer devices, almost any machine that includes some type of electrical control can be hooked up, in some way, to a computer system.

The following are some of the devices that can be connected to a computer:

Card Readers: can read standard cards with 80 characters of information per card, and at speeds up to 1,000 cards per minute.

Card Punches: 80 column cards can be punched with output information with speeds up to 500 cards per minute.

Line Printers: High speed printers can print 130 character lines with speeds up to 1,400 lines per minute.

Optical and Mark Sense Readers: These machines can read specially drawn marks on cards or pages of paper. Some can read magnetically coded numbers on cheques, while others can read typewritten and machine produced letters. Development is progressing on machines that read hand written numbers.

Micro-film: Some machines can read microfilm by scanning the film, while others produce microfilm and photographic prints as computer output.

Magnetic Tapes and Discs: These machines are used as temporary off-line storage by computers, with the computer usually doing both the reading and the writing, although non-computer produced magnetic tape can also be read.

Tele-processing: Typewriters and cathode ray tubes (CRT) can be connected to a computer and provide the ability to put information into a computer, interrogate the status of some particular file, ask for mathematical calculations, and receive nearly instantaneous answer-back from a location a few feet away from the computer, or thousands of miles away.

Plotters: The standard, two-dimensional flat bed plotter or a drum plotter can be connected to a computer to produce maps, graphs and engineering and architectural drawings.

Magnetic Sensing Inputs: In the control system for Metropolitan Toronto's traffic light system, the presence of an automobile is detected by a device buried in the roadbed which registers a signal if a metal object is immediately above it.

Control Devices: The output of a computer can be used to control any electrical device by switching it on or off, or by changing the quantity flowing through it. Nonelectrical flows, such as oil in a refinery, can be controlled by electrically operated valves, which are in turn controlled by the computer.

With this large number of devices available, information can be captured from many different sources, often as a by-product of an operation which must be performed anyway. The issuing of license plates, enrollment of children at school, connections by an electrical utility or telephone company, unemployment insurance payments and building permits are all sources of information which the planner could use in creating and maintaining a model of an urban society. Rather than having to collect this information through a manual process of scanning files and then keypunching, it would be possible to have this information transferred electronically through normal telephone lines from the point where it was being created, (E.G. the electrical utility office) to the computer used by the planning department to run their model. Input from a traffic control computer would give information as to the number of automobiles travelling in the city and their routes, and this information would not only permit better planning to be done for the future, but it would also provide a means of checking present assumptions and evaluating the accuracy of past predictions.

Limitations

The practical limitations of computers are the time required to run very big jobs and the cost of the machines. At $5 to $10 million per machine system, the benefits derived must be fairly obvious and valuable. The would-be user of the machine must have a clear idea of what he wishes the machine to accomplish, whether it can do that job, what it will cost to acquire the machine, and also of the alternative costs if the machine were not used.

Secondly the machine can only perform as it has been instructed. The user must know not only what he wants, but also how this goal is to be achieved, in order to give his programmer precise instructions.

The greatest limitation in using a computer for urban planning is the lack of knowledge as to the precise nature of the functioning of a city. Future predictions are made more difficult when present functions and relationships are imperfectly understood, even with the complete availability of necessary information. The use of models is one means of experimenting with a city, (where real experimenting is forbidden), and from the results of some of these runs, knowledge is gained which permits the next series of models to be more accurate.

CHAPTER IV

THE USE OF COMPUTERS IN PLANNING

Data Tabulation

In all planning operations, a certain amount of raw data manipulation must be undertaken. As information regarding a city on a block by block basis is gathered, it can be placed in one or more 80-column "IBM" cards. It can then be added and printed on a standard electrical accounting machine. Such tabulations are transferable to a simple computer system with a corresponding increase in throughput and accuracy, and a much greater flexibility in the format of the end report which is printed.

The following description of a use of computers is from the Minneapolis Tribune of the early 1960's.

> The future....of the commercial area at 27th Ave. and Lake St. depends to a certain extent upon an electronic computer. ...Playing a role in any integrated improvement of the area will likely be an extensive city planning commission report being drawn with the aid of electronic data processing.
>
> Future action by community leaders may be based on conclusions drawn from such unlikely bits of data as these:
>
> Four percent of the residents of central-southeast Minneapolis travel ½ to 1 1/16 of a mile when they patronize a variety store.
>
> Some 92.5 percent travel more than three miles to visit an appliance store, but only 8.9 percent go that far to a drug store.
>
> 72 percent of the women travel more than three miles to buy an expensive dress....but only 54 percent go that far for a cheap dress.
>
> The city's survey of the 27th and Lake area is the first of its kind in the country....This is the first time a city planning unit has combined market surveys, home interviews and data processing to obtain such a high degree of analysis....With the help of the computer, city planners have (obtained vital data)

> about shoppers in the study area. Correlating all of this and drawing conclusions which will be helpful in guiding planned improvement of the area have been made easier by electronics. Computing the distances people travel for various items would have been practically impossible to do by hand, said Mr. John Cummings, principal city planner in charge of the project.[1]

Such applications as the Minneapolis study are well known now in planning departments. These applications depend upon the computer's speed in performing many simple calculations. However, the jobs are basically the same as those which were being performed by manual methods. Although useful, nothing new has been added to the planner's understanding of problem-solving.

Traffic Control

If community planning is viewed as the preparation of plans and the making of decisions to change the future of the community, then the control of traffic would not be a function of community planning. On the other hand, if planning is seen as a method of improving the framework of the city, both short-range and long-range, an improvement in traffic flow, as much as design of new routes and transport devices, is a part of the functions of the city planner. In either case, traffic control provides a means of implementing a city-wide policy that necessitates the view of the entire metropolitan area

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[1]Harry H. Fite, The Computer Challenge to Urban Planners and State Administrators, (London: MacMillan and Company, Ltd., 1965), p. 11-12.

as one system. From the traffic control system, the planner can acquire data on the day to day movement patterns of the population as well as on trends over time. Hence correlations and tentative causal relationships between the movement of people and new developments, urban growth and city renewal can be established. The first, and still one of the largest integrated traffic control systems in the world was established in Metropolitan Toronto.

The original pilot study for the system was authorized by the Metropolitan Toronto Council in 1958. The problem was to devise a control system which not only determined the most desirable setting for individual lights (based on relative demand of each of the streets involved), but also the relationships between different signal times, settings, off-sets and phase times so as to produce a minimum total traffic delay throughout the entire system.

> The logical answer was that the computer should collect its own data, process it and place the resultant solution into operation through direct control of the signals, which would result in both the timing of the individual signals and their system relationship being subject to continuous and instantaneous adjustment in accordance with traffic demand.[1]

Small buried metal detectors were installed in the road surface at the approach to every signalized intersection. Each of these detectors, several thousand in number, is scanned every second to determine if an automobile is present at that point. The number of cars entering, leaving and waiting to enter (queue lengths) can be

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[1]Metropolitan Toronto Department of Roads, Biennial Report 1961-1962, (Toronto: Municipality of Metropolitan Toronto, 1963), p. 33.

determined for each intersection, and calculations can be made to discover the number of turning movements. Overall, there was expected to be a thirty percent improvement in traffic movements.

> It was evident that only a total systems approach could reach the goal. Little would be accomplished if traffic moved faster at one corner or even on one street, only to feed into a jam somewhere else. Traffic strategy had to be planned and executed for the street network as a whole -- more than 1,000 intersections.[1]

By 1969 more than 650 intersections were controlled by the central computer while the ultimate goal is 1550. It is estimated that more than 9000 vehicle delay hours daily are saved by the system. An investment of $3.9 million is producing the same results in increased capacity that otherwise would cost from $30 to $50 million in new construction costs.

In addition to these savings, however, are those that result from the reports and statistics produced as a by-product of the operation. Only with knowledge as to what exactly are the results of new highway construction on the surrounding land use, or the results of new development on highway usage, can a planner make meaningful predictions of future trends, to say nothing of making correct prescriptions to overcome existing problems. Does new highway construction depress the value of an area through which it passes, due to increased noise, pollution and through traffic, or does it increase the value due to increased accessibility? If the result is a change from

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[1]Fite, op. cit., p. 57.

one type of land use to another, is this change in the best interests of the city as a whole? Could highway construction be used as a means of stimulating urban renewal? If congestion on downtown streets is reduced, is the resulting time saved, later spent by increased sprawl in the countryside? Are time and distance trade-offs?

Many of these questions, obviously, cannot be answered simply by having data on traffic flows and volumes. However, the traffic figures are necessary to relate to information on land use and assessment. Although there is a vast amount of data to be handled, the analysis is possible if all of the various bits are properly identified and if a system has been designed to manipulate them.

Geo-coordinates

The basic concept of a geo-coordinate system is that every point on the ground can be referenced as being so many feet or miles east or west and north or south of a given control point. As the area becomes larger, the co-ordinate system based on a two-dimensional surface with the two main axes becomes distorted because of the curvature of the earth. Thus for the whole country, a system is being developed which is corrected every three degrees of longitude so as to cover the country accurately.

Once the system of co-ordinates has been established, the data for any area can contain, as an identifier, the co-ordinates of the place, or of its mid-or corner point. With this system, data relating to population, economic activities, land use, transportation routes and topographical features can be analysed and correlated to reveal relationships between aspects and variables of the environment. With a co-ordinate system to identify data, computer mapping becomes a possibility. In addition, urban data banks can be organized with the co-ordinate system providing identification of all other information. Other means of data bank organization are possible, but one based on geo-coordinates would appear to be the easiest and most flexible for an urban data bank.[1]

The Dominion Bureau of Statistics is working on a pilot study for geo-coding census information, and hopes to be able to produce data from the 1971 census for the larger urban areas on a geo-coded basis. The smallest unit of reporting would be a block face, but rather than force all users to conform to census tracts or municipal boundaries, information will be aggregated by the Census Bureau for whatever areas the user requires.[2]

Computer Mapping

A computer printer produces lines of output with 132 characters per line. Thus it is possible to use the printer to produce straight line or bar graphs. Then a graph (or other statistical results of

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[1]E. Weatherhead, "Geocoding - A Technique in the Development of Urban Information Systems", Ontario Economic Review, VIII, no. 5, (Sept. - Oct. 1970), p.4.

[2]Ibid., p.4.

calculations) can be positioned on the output page in such a way that a plastic sheet with an outline map of the area under study can be placed over it. The results of the calculations of each sub-area or district fall within the boundaries of that area on the map. If a photograph is then taken of the result, it is possible to obtain a series of maps all produced from one original overlay map, and each one showing the areal result of a different set of calculations.

It is also possible to have the computer produce a map composed of different fill-in characters representing densities or other calculations for each sub-area. The boundaries between areas in this type of mapping are not accurate, but an overall pattern can be produced to portray graphically some aspect of the society. The "Opportunity-Accessibility Model for Allocating Regional Growth" in the May, 1965 Journal of the AIP[1] contains an example of such a computer produced patterned output. In this case an outline map of the area has been superimposed on the computer output to give scale and orientation to the final map.

Using the printer to produce a map results in an inaccurate outline, because the printer must produce its output by means of a 132-character line, and with only 6 or 8 lines per inch. In addition, the

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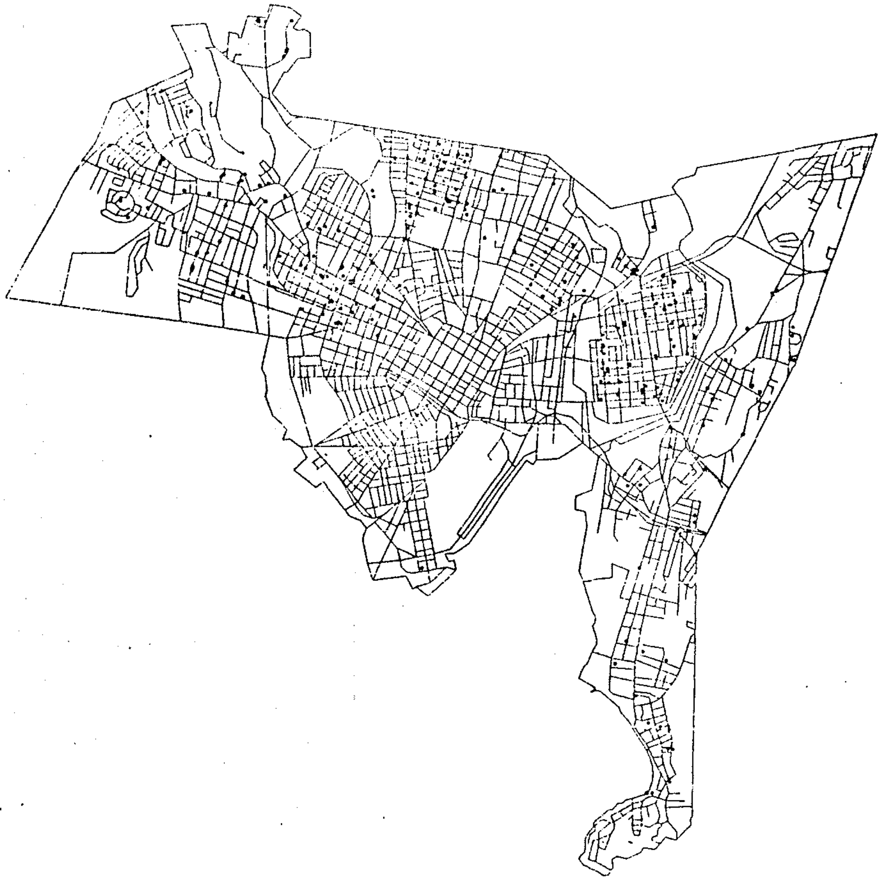
[1]George T. Lathrop and John Hamburg, "An Opportunity-Accessibility Model for Allocating Regional Growth", Journal of the American Institute of Planners, XXXI, no. 2, (May, 1965), pp. 98 - 101.

exact map size and boundaries must be known beforehand in order that the computer position the results in the right place and at the correct scale.

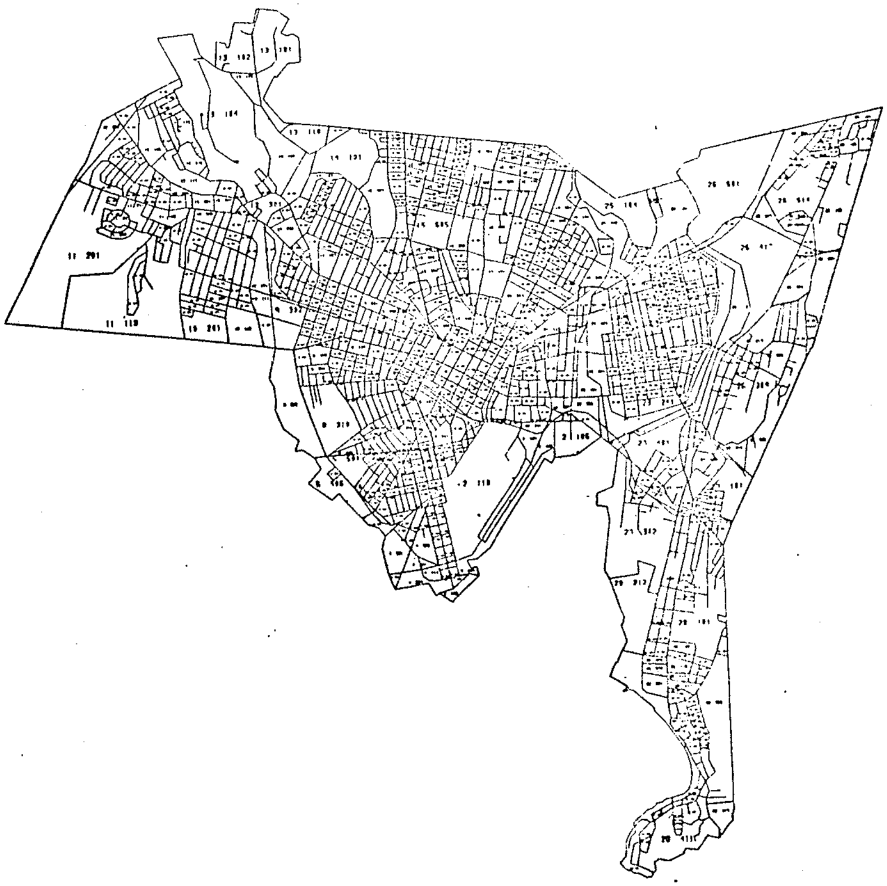
With the addition of geo-coordinate identification to the data, it becomes possible to use a plotter to map the output. A plotter usually consists of a drum, the rotation of which over the map defines the x-axis, and a pen which moves to define the y-axis. If the incremental moves are small enough, (1/50th or 1/100th of an inch) then curves and map outlines can be drawn to an accuracy equalling the incremental amount. If the boundary of a piece of property is defined by a set of points joined by short straight lines, and if the co-ordinates of each point are known, then the computer, through the plotter, can draw a map to any scale requested. To reduce the amount of effort required to get all of the desired co-ordinate points into the computer in the first place, it is possible to have a map scanner read an existing map and translate all of the boundaries into digital information, i.e. co-ordinates. If two points on the input map are given co-ordinate values in the standard system of the data bank, then the values as created by the map reader can be translated into the standard values. Thus, not only can the map be reproduced in whole or part, at any desired scale, but all other data from census reports, assessment, or traffic statistics which are identified by geo-coordinates can be related to the information on the input map, and can be plotted on output. (See an example on the following page.)

Figure 1: EXAMPLES OF COMPUTER PLOTTING[1]

Geospace Plotter Outline Map Showing Incidence Occurrence--Police Calls



Geospace Plotter Outline Map Identifying Tract and Block Areas



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[1] George P. Leyland, "Computer Mapping--Here and Now", Papers Presented at the Conference on Small-Area Statistics, (Washington: U.S. Government, 1969), p. 20.

If the geo-coordinates are used as the legal description for land transfer and registry systems, a survey or land registry data bank can be set up. As this would contain information concerning building types and land use, such a system would permit the creation of land use maps and statistical reports for the city or any specific part of it, were such information required. The output so produced would be as up-to-date as the day it was printed.

Data Banks

A data bank is a collection of all the data relevant to a given system, so organized that it can be up-dated and retrieved when required. Before the advent of computers, only a book library with a cross index card classification system could have been considered a data bank. Unfortunately, if large, such a library cannot be organized to allow quick access to a desired bit of information. Still a greater problem is that of retrieving a collection of data relating to two variables, for example, data on the educational level of persons who were recent immigrants to a given area and who also were employed in service industries. On the other hand, a small library, although more amenable to data retrieval, is often lacking in sufficient information to answer fully the requests made of it.

With the use of computers it becomes possible to store a great volume of data and to retrieve it quickly. In addition, the computer system does not run into the problem of having the required information already out on loan to someone else; the base information is actually recreated each time it is sent to an output or display device. Within the computer system, data is usually stored for future use on a peripheral device. This is usually a magnetic tape, which has the disadvantage of sequential storage. The whole tape must be searched to find a desired piece of data, but on the other hand the cost per unit of data stored is considerably less than with disc storage. Each storage location on a disc is directly accessible, which means a great saving of time in information retrieval, but it must be balanced against a greater cost in dollars. IBM has produced a compromise between these two devices, a data cell, which contains many strips of magnetic tape, each of which is addressable but has a retrieval time greater than disc drive.

Although location of specific data requires a large number of program steps and searches of directories and indices, these steps are performed at computer speeds, measured in thousanths of a second, and produce results which are almost instantaneous from the standpoint of the relatively slow reaction speed of the human operator. However, despite the speed and power available, it is still necessary to have some system of organization and identification which will permit various pieces of information to be related to each other. In the construction of urban data banks, the linking element or common identifier that is easiest to use and most flexible for expansion of the bank and growth of the city is the geo-coordinate of the location of each piece of information.

> Our social system is based upon three basic economic factors: land, capital and labour. Land is obviously related to the co-ordinate system. Capital in the form of factories, plants, machinery, are all situated on land and can be related to co-ordinates. Labour can be related to co-ordinates relative to the location where a person lives and the location where he works. The three basic items in our capitalistic system can all be related to co-ordinate location. It is therefore possible to use geocoding as the common identifier in the development of a general information file or urban data bank.[1]

Information in such a data bank could include property description, economic factors, social information and information regarding transportation and communication between each piece of property and the rest of the system.

In addition to the actual data, it is necessary to have routines to handle it; such programs constitute a Data Management system. In his article, Smith outlines some of the requirements of such a system:

> It is not sufficient to simply have a system which is a large ledger for the storage and retrieval of data. Because of the tremendous volume of data it is implicit that the programs developed go a step further and permit manipulating, calculating, sorting, and re-sorting the data for the purpose of making effective management decisions.
>
> The management program should be developed to handle any type and amount of data...The program should accept information with any system of identifiers...Geocoding is a common identifier which permits the initial integrat-

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[1]Ralph A. Smith, "The Development of the Ontario Co-ordinate System and its Relationship to Urban Data Banks and Data Management Programs", a paper presented to the Metropolitan Toronto Region, Government Data Processing Users' Group, Cooksville, September 14, 1967, p.7.

> ing of various records which may be filed in their own unique way...The program should include the ability to re-organize information in the computer according to any common data base selected by the user.
>
> The program should be able to select information in the data bank and add, subtract or integrate the data with other data, thereby creating new, significant data... The program should receive and print out information in a simple format familiar to the individual or department requiring the service. Any intermediate steps to translate the data should be performed by the computer.[1]

One such data management system in operation is the Canadian Socio-Economic Information Management System (CANSIM) developed by the Dominion Bureau of Statistics. The purpose of this system is to tie together and make available to the user all of the census and other sets of data collected by DBS.

> When fully developed, the system will provide machine readable data, from a large base, possibly encompassing the total output of published statistics from DBS and other data sources. Manipulative capability, to be incorporated into the system, will allow users to select a series, and any one of a variety of standard statistical techniques to be applied to that series.[2]

Because of the unrelated character of much of the data, the CANSIM system is not based on a single identifying variable, but rather on a hierarchical base structure. This is basically a tree-fashion organization, where each piece of data is part of a larger group, and that group plus other groups is part of a still larger

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[1]Ibid., p. 9.

[2]Dominion Bureau of Statistics, "Introduction to the Canadian Socio-Economic Information Management System (CANSIM)", Canadian Statistical Review, XLIV, no. 3 (March, 1969), p. v.

group; the process continuing until the largest group is the entire data bank. Given any piece of information in the bank, it is possible to move up the tree and determine what its group; move sideways and find out what other pieces of information are associated with it, and move down the structure to discover what finer breakdown of data, if any, is available. An example of this structure might be the population of Canada. Level one is the total population, level two has two entries, one total male, the other total female population, and the sum of these two must equal the higher level; level three might be population by age group, with the sum of the level three entries equalling the corresponding level two entry.

This system is very similar to a Generalized Information System developed by Prof. B. Hodson of the University of Manitoba. His system permitted the addition and retrieval of information through a series of decisions made via a remote typewriter or Cathode Ray Tube (CRT). If the specific identifier of the information requested was known, it could be retrieved directly. Otherwise, the information could be retrieved through a number of steps. A CRT screen would first display a number of broad categories of information. The person using the system would choose the one of these which was appropriate, and a new set of entries would be displayed, corresponding to the next level of detail breakdown within the major category selected. This process of choosing more and more detailed categories would eventually result in the desired information. If a particular set of data were defined by two variables, then it could be retrieved by following one of two routes through the system; for example, the last choice in "Winnipeg Educational Levels:" might be by Census Tract, by school district, by sex, by age or by occupation, while the last choice in "Winnipeg Census Tract Information:" might be population, housing, employment, educational levels, etc. Thus, information concerning educational levels by census tracts could be obtained by making the corresponding choice in either of the two categories. This method of organization allows data to be added in or changed at any position of the structure. Additionally, new sets of data can be added to the system by simply adding one more choice to a given level, or one more level to the structure. Such an organization would be very useful to a planning department in a municipality which wished to start a system of data organization and to use a simple one while more information was being added and coded. Geocoding would then provide an increased flexibility for the system when it became possible to add such a variable, but it would not be a necessary part of the total operation. The organizational method is growth oriented, and additions are made as they become available. Data from many different sources is available to be manipulated, analyzed, and then used to aid in decision making.

> A study of data structures for on-line information systems has been made and a successful technique has been developed. Initially used for a hospital information system it appears the data structure is suitable for all types of data systems, including educational, accounting, marketing, manufacturing, inventory, computer assisted instruction, personnel, etc. Embryonic systems in these latter areas have been developed and are to be extended.[1]

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[1]Bernard Hodson and Katherine McLaughlin, "Generalized on Line Information System", a project report, November 1967, p. 1.

Problem Solving

One of the difficulties in using a computer for assistance in planning is that all variables must be quantified. In some way, many of the qualitative aspects of a community must be translated into terms which are open to manipulation and evaluation. Even without a satisfactory transformation, planning decisions must still be made; unfortunately subjective evaluations take over and, although not necessarily apparent to the planner, these feelings are conditioned by the individual's past experiences. The intuitions and "creative decisions" of the practitioner may appear to be self-evident and universal in their application, but the disagreements among various planners would seem to disprove such claims.

One method which facilitates objective[1] decisions involving non-quantifiable variables has been developed by Sussex Research of Toronto. Basically, the method is to have the various people and professions involved in a planning study evaluate relationships between pairs of variables on a zero to ten scale[2], and then use cluster analysis to group these variables in a Q-mode. The analysis for each pair of variables was based on the mean of the judges, and it was claimed by the authors that it tested disagreement in scoring.[3]

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[1]"objective" is used in this context in an operational sense - to mean "non-personal, mean or statistical".

[2]There was no negative scaling used; the absolute values were being measured.

[3]Sussex Research, Report to the Community Planning Branch, Ontario Department of Municipal Affairs, September 29, 1969.

A study of the town of Inuvik in the North West Territories was prepared by Mr. Walter Wright of Sussex Research. This town was chosen to provide an example of their method and not to produce a working town plan. Because of this emphasis, estimations were used in some places where more accurate data was not readily available. Inuvik is a rather simple example of a city to study due to its isolated position and resulting lack of extraneous or exogenous factors, and to its having a quite clearly understood set of economic and social problems. Because of this, it was felt by Sussex Research that this example presented a good demonstration of their technique, although perhaps the results are not generally applicable. The problem-solving approach which was used consists of the following steps: research, analysis and application of data. The method has been designed to handle both hard data (facts and figures) as well as soft data (opinions, evaluations and prejudices).

Research consists of gathering data on both social and physical phenomena, including historical data and economic development trends. Obviously, the existence of a data bank for the area under discussion would significantly decrease what is the most time-consuming and costly step in the entire procedure. It appears evident that two sets of data banks would be necessary for adequate planning: one set of data, possibly organized by geographical location and geo-coordinates if available would be updated constantly to provide an accurate representation of the city as it exists - conceptually an urban model; the other data set would provide snapshots at intervals of time - a time-series data bank, perhaps organized by a hierarchical structure.

Analysis, step two of the problem-solving approach, involves the creation of an inter-relation matrix. A square matrix is produced which lists all the factors in the community's organization that appear relevant for planning. These factors are arrayed on both the side and the top of the matrix, and inasmuch as the relationships are reciprocal, only one half of the matrix is used. The matrix is then filled in with values for the intersection of any two variables ranging from zero to ten; zero indicating no relationship and ten a very strong one. This relationship may be causal, historical or geographical. For situations where adequate hard data exists for both factors of the relationship, statistical correlations (multiplied by ten to enable comparison to intercorrelations of soft data), are used. A particular entity may be represented by several variables, one for its causal or historical aspects, one for its social, and perhaps one for its locational relationships.

For many of these relationships hard data is not available, and a subjective factor must be used. In this situation, the advantage to the problem-solving method is that persons from different backgrounds can evaluate relationships between variables as they see the situation from the viewpoint of their own discipline, and points of divergent opinion can be noted quickly. These points of disagreement are subjected to further study in order to determine some type of objective compromise.

The purpose in constructing this matrix, besides providing a tool to highlight areas of disagreement, is to relate all of the factors which are associated with the problem into a single common system which is subsequently available for analysis. The goal of the network is to cluster the relationships into groups which have stronger intraconnections that interconnections. In Inuvik, four matrices were created: local-descriptive; regional-descriptive; local-prescriptive and regional-prescriptive. The prescriptive matrices indicate the kinds of relationships that the people who were interviewed desired, or that the experts, including planners, felt would benefit the town.

When the matrix of the interrelationships has been constructed, and the differences of opinion ironed out or compromised, the information from the matrix is used as input to a series of computer-based factor-analysis programs. These group the variables into clusters based upon the relative strength of the relationship bonds. Any one variable may be part of several clusters with different levels of significance in each case. The contents of these clusters indicate the structure of the problem or the socio-economic pattern, and provide relevant information to aid in setting up teams and objectives that are most applicable. In Inuvik the variables fell into three broad groups which could be loosely identified as relating to government, hunting and other land-based activities, and fishing and related activities including the curing of fish at shore locations. With this knowledge, a study team could be created which was composed of three groups; each group would know which variables were its concern and which other group was responsible for the others. To portray the situation pictorially, three overlapping circles could be drawn representing the three broad classifications, and the name of each variable in the analysis would be written on the diagram either in one circle only, in the area common to two circles, or in the centre part common to all three circles, depending on the clustering output of the computer program.

In Inuvik it became apparent that the function of government bore no relation to the economy of the region in either its location for its activities, or in the type of people employed. On the other hand, three variables - Eskimo population, permanent white population and regional transportation - were common to all aspects of the economy and social organization. (Government functions were closely related to the transient white population.) With only three clusters and approximately twenty variables, this case is a simple example, producing results that an experienced planner could perhaps have achieved after an examination of the town. However, the advantage of this method is that it can be used by many different professions and provides a common and somewhat neutral organizational structure with which to plan. Moreover, the method becomes increasingly useful as the problem becomes more complex, particularly for those highly involved urban situations that are beyond the capabilities of one man to study and plan.

The use of the results, or step three, is actually performed during the analysis. The organization of the planning team, the structure of the problem-solving operation and the provision of a common basis of understanding are all part of this step of using the results of the analysis. In addition, the differences between the descriptive and the prescriptive matrices give information as to what parts of the social structure must be changed to achieve the desired results.

This type of model, while not eliminating biases, nevertheless makes them highly visible as a specific value between two variables. Different persons, working with the same set of variables, can note the choices of others and can comment on a particular value choice if it appears to be quite different from the rest. The technique, however, is not in competition with some completely bias-free approach but rather is contrasted to the present method of planning. Here the biases and prejudices are just as strong but are hidden, and less susceptible to review by experts in different fields.

Conclusion

The review of the use of computers in planning has traced a development that is one of increasing complexity, and to a degree, one of historical sequence. The first uses of computers are usually those which simply take over an existing procedure. The use of computers to accumulate, total, analyse and print out information is included in this first step. At this stage, the computer is being used mainly for its increased speed of operation. One advance is added when the computer collects its own information in "real-time", and possible uses this information to effect some control in the "real-world." A traffic control system, which bases its decisions on data collected from the streets and traffic that it is controlling, is an example of this stage in the development of computer use. With the advent of larger computers and more peripheral equipment, various types of graphs and maps can be produced as output. The introduction of a system of geo-coordinates which is necessary for some types of computer mapping provides a common identifying variable for setting up and using an urban data bank. The bank can contain time-series or historical information, and then provides input information for a problem-solving program, which itself represents an intriguing approach to the problem of handling non-quantifiable variables. The next step in the progression into more complex computer operations is the use of the time series and the more up-to-date simulation data banks. These, along with various theories of urban growth and function, produce a method of predicting the growth and change of the distribution of the various land uses within the community. Such a method, in addition to providing predictions, would also have the ability to test alternative goals, theories and plans, and thus to evaluate proposed governmental policies and decisions. Such are the objectives of those computer programs called Land Use of Growth Allocation Models.

CHAPTER V

LAND USE MODELS

Introduction

A land use model consists of a series of computer programs which attempt to predict the changes in land use within the area under study. This is done either through the allocation of the expected total growth in each land use type to a number of small sub-areas or regions, or through the prediction of change within a small area due to its internal structure or position relative to all other areas. In the latter case, a total for the entire area of the net change in each land use classification is calculated from the totals for the individual areas, and is then compared to an independent estimate for the entire area. Differences between the two are resolved by changing each sub-area's figures by a ratio so that the sum equals the independent total. In the former case, the total is the starting point, and is distributed until used up.

The usefulness of such models, in addition to straight predictions of land use change, is in evaluating and better understanding the effects of different policy and planning decisions that are being proposed or considered. The creation of the model, and the experimenting with it provides an increase in knowledge and understanding of the workings of society, and the various reactions to different stimuli. With this knowledge, and with experience in working with the model, it should become possible to run the model procedure in reverse as a design exercise; given the social structure and land use pattern that is desired at some point in the future, what decisions today and over the intervening years are necessary to achieve the stated goals? At the present time this use of models is in its infancy, and design is performed through a number of trial-and-error runs. However, some of the simulation models try to approach this point by examining changes over a long period of time and predicting what levels of equilibrium would result from different policies, and postulating the long term causal relationships between actions today and results in the future.

In the May, 1959 Journal of the AIP, the entire issue was devoted to a discussion of computer models. At that time Alan M. Voorhees wrote:

> As the City Planning profession matures, the need for revision and improvement of professional techniques is increasingly evident.
>
> The usual procedure of preparing land use and transportation plans by analyzing facts on population distribution, employment, economic factors, social patterns, and travel habits is yielding to more precise techniques of evaluation. These more accurate techniques are based on research - research indicating that people are predictable, that mathematical formulas can be developed to express travel behaviour and to forecast land patterns. Such tools can give valuable guidance in the analysis and design phases of city planning.
>
> Equipped with these techniques, a planner should be able to predict fairly accurately the consequence of varied governmental policies on land development. With them he has the means to evaluate the impact that improved transportation services, extension of sewer and water systems, zoning laws, etc. will have on land development. Also, these techniques make it possible for the planner to estimate

> traffic volumes and patterns resulting from different arrangements of land use or from various transportation solutions.
>
> Ideally suited for land use and traffic forecasting, such mathematical techniques provide the planner with quantitative results. Using them he can estimate the number of people who will live in an area or the number of trips that will start from a district - valuable information in laying out parks, schools, and highways. In brief, these procedures provide better data upon which to base planning judgment and thus help to improve the quality of plans. These mathematical techniques involve several steps, equations, and formulas, and are often referred to as models. More simply, a model may be described as a mathematical statement of observed relationships.[1]

Although most of the work and interest in models has been generated in North America, planners in Britain are becoming aware of computer models. In a recent article in the Town Planning Review, Margaret Camina provided a review of some applications of American models for her British readers. One of the reasons for the lack of involvement of British planners may be their orientation to working towards what they consider an ideal society, as opposed to the American practice of discovering the society's direction, and then trying to change those aspects which are undesirable. "The application of mathematical modeling techniques to planning is gradually gaining acceptance in this country (Britain) although early American work - in the late fifties - was not always well received here because it emphasized forecasting and, by implication, trend-planning."[2] Whether

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[1]Alan M. Voorhees, (ed.), Journal of the American Institute of Planners, XXV, (May, 1959).

[2]Margaret M. Camina, "Plan-Design Models: A Review", Town Planning Review, XL, No. 2, (July, 1969), p. 119.

the possession of a forecast of a probable future implies that one must then do trend-planning is a debatable point. Even in the context of British planning thought, it might prove helpful to be able to predict development pressures, commercial location, and the transportation implications of a new town on the regional network.

Most of the examples in the TPR article are related to linear programming where an objective function is known and it is desired to maximize or minimize this function subject to stated constraints. These are not land use models, although one example is a land use design model for South-Eastern Wisconsin which attempts to minimize development costs subject to the regional land use demand.[1] The difficulty encountered in the use of linear programming as a technique to design a land use pattern, is that all of the relationships must be expressed in terms of linear equations.

> Design standards are inherently non-linear, double the facilities not necessarily being required for double the population. In addition, land use decisions tend to be discontinuous as, for example, developers think in terms of estates of a few possible sizes, with intervening acreages not being equally attractive to them, as the model assumes. Schlager is attempting to formulate a dynamic programming model; this would allow discrete and non-linear functions to be considered but there is no standard solution procedure available.[2]

Despite the limitations of many of the present models and the problems still to be overcome, Camina concludes that models can help the planner to make better decisions. She notes the striking need for

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

[2]Camina, op. cit., p.125.

data to use these models: "planners may often have relied on intuition, but when a prescriptive model is to be programmed, there is no escaping the need for adequate information."[1] This is a point which has already been mentioned with reference to data banks, and will be mentioned again as both the biggest cost factor and the greatest stumbling block to effective model usage.

Models and Systems Analysis

In attempting to find solutions to problems with a large amount of input data, many diverse and sometimes conflicting objectives, and a number of possible solutions, some method of organizing the approach to the problem and its solution must be utilized. One method of structuring the approach to such a complex problem is systems analysis. This consists very generally of four broad steps:

1) Define the problem. Goals must be formulated, objectives found, and constraints and deficiencies noted. The problem must be structured as a system - with elements or objects and with the relationships that join these elements.

   The first step in the analysis of any particular system is to isolate the system's elements and forulate the logical rules governing their interaction. The resultant description is known as a model of the system. The model is usually limited to those aspects of the system which are of interest or appear to be pertinent to the analysis.[2]

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[1] Ibid., p. 128.

[2] *General Purpose Simulation System/360: Introductory User's Manual*, (White Plains N.Y.: International Business Machines, 1967), Document #H20-0304, p. 1.

2) Develop an information base. Collect data and assemble it in a usable manner. Through research learn the various causal relationships and statistical correlations, and develop forecasting and review techniques.

3) Propose and evaluate alternative plans. The new predicted facilities and system organization must be compared to the goals, deficiencies and constraints of step number one. The various alternative plans must be evaluated on functional, economic, social and aesthetic grounds.

4) Implement and update the selected plan. Organize and finance construction where necessary, manage the implementation over time, and make changes to the implementation in order to react to changing conditions and factors.

The use of models enters into this method of systems analysis at several points. The creation and development of the model in the first instance requires the discovery of the correlations and causal relationships of the second step. On the other hand, once the model is created and calibrated, i.e. made to fit the relationship values of a particular city at a given time, still more other correlations can be uncovered through the operation of the model. To perform its operations, a land use model requires an extensive data base, and this requirement is frequently the most costly and time-consuming to satisfy. On the other hand, the model provides the facility to analyse a large amount of data and to produce some meaning out of what is otherwise an unwieldy and incomprehensible collection of figures. Finally, as part of step two, the model provides the prediction of the future once the data has been gathered and analyzed and the interrelationships discovered.

As part of the evaluation procedure of the third step, the use of a model facilitates the running of a number of alternatives in a short period of time, and this results in an understanding of the situations that would occur if different policies were followed. In this way, the model helps to provide the information necessary to review and evaluate the outcome of various plans and proposals. Evaluations of alternatives may include some cost/benefit analysis which itself can be best done on a computer due to the many calculations involved. One advantage of the computer-based model is that the data necessary to perform the evaluation has already been collected and entered into the system. Not only is the largest part of the cost of program evaluation already undertaken, but this amount of data is available for as many alternative plans as desired. One of the practical problems facing planners at the present time is that with the cost and time involved to produce a number of alternative plans, a committee, having discarded several plans that do not meet the minimum requirements, will choose the first one that achieves consensus and satisfies these basic requirements, even though it is conceivable that a far better plan might be produced after more study and preparation.[1]

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[1] This point was raised by Mr. Grahan Adams, director of Extension and Field Services of the Ontario Department of Municipal Affairs, as one of the problems encountered in local planning in the province.

In addition to producing results that can be evaluated by a cost/benefit program, the output from the model run can be fed directly into a transportation model. This requires that the land use predictions are on a small enough grid to be used in the origin-destination or flow pattern of the transportation model. If this is so, then it is possible to determine the transport costs, locations of congestion, routes taken, and time delays in movement that would result from each of the alternatives.

Finally, the model can provide assistence in step number four of the systems procedure, that of implementation. With a method of feed-back from on-going indicators, e.g. building starts in different locations, the predicted results can be compared to actual results and the model then refined or modified where differences are indicated, in order to increase the accuracy of future predictions. Through this comparison of the actual to the predicted at different times, it becomes possible to detect changes in the environment that were not foreseen when the model was first run, and having detected them, to advise changes in public policies and decisions to adapt to these new conditions.

Systems theory and systems analysis is more than just the use of models, however sophisticated, and a recent review article in the Journal of the AIP discusses systems theory and its application to planning.[1] The concept of the theory is that there are principles for

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[1]James Hughes and Lawrence Mann, "Systems and Planning Theory", Journal of the American Institute of Planners, XXXV, no. 5, (Sept. 1969), pp. 330 - 333.

systems that are true independent of the particular component elements of any given system. To apply the general theory to a particular case, one must determine how the attributes (elements and relationships) of the particular system relate to those of the general system. In other words, one must understand both the general theories and the specific system to be able to define the particular in the terms that the general theory requires, and hopefully, the design and use of models provides some of this understanding.

The use of increasingly complex computer models in planning,and the greater tendency among planners to view urban society as a system, is part of the spread of general systems theory into the social sciences;

> This spread has relevance to planning in that, first, it can eventually provide greater understanding of specific material peculiar to urban and regional planning. In other words, the complex, dynamic, and highly interrelated cultural, social, political and spatial phenomena that define the environment of planning may be modeled or formulated into quantified, understanding of the process of public policy formulation and possibly provide the basis or model of an optimal policy formulation procedure.[1]

One of the models developed from general theory is the Planning, Programming and Budgeting System or PPBS. In PPBS, long range goals for the different parts of the system are broken down into measurable objectives, alternative means of achieving the objectives are examined, and these are correlated with the budgeted monies available in the fully refined PPB System. PPBS is thus:

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[1]Ibid., p. 331.

> the process by which objectives and resources (ends-means) and the interrelations among them, are combined to achieve a coherent and comprehensive program of action for any organization conceived as a whole. [A basic assumption] is that a unit of government can determine its policies most effectively if it chooses rationally among alternative courses of action that are placed in order of priority on the basis of anticipated benefits and costs for each alternative.[1]

The limitations mentioned by Hughes and Mann for PPBS apply generally to the use of systems organization and theory in community planning. Basically, these limitations include political interference in an otherwise rational system; the difficulty in anticipating and planning for the strength and direction of social changes; the difficulty in quantifying the variables of social organization; the differences between cities and towns in their interrelations, priorities and values; lack of sufficient accurate data or comprehensive social theory; inadequate staff and resources in planning departments; and distortions of all results because of the tendency to measure what is easily measured.[2] However, it is only through constant improvement of existing models and procedures by experimentation and evaluation that eventually some of the limitations will be overcome, and the modeling technique made available as a common tool for community planners.

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[1]Harry Hartley, "PPBS, The Emergence of a Systemic Concept for Public Governance", General Systems, XIII, (1968), as quoted by Hughes and Mann, op. cit., p. 332.

[2]Ibid., p. 332.

Types and Uses of Models

There are many types of models available to the interested planner. The most frequently used group is transportation models, which predict future travel demands, volumes and routes given the present population by small area and present travel characteristics. The characteristics would include number of cars per family, average family income, average travel distance and time to various destinations, and type of employment. This information for the present, plus the expected population for a large number of zones must be given as input before the output showing demands and routes can be produced.

Another major group of models, more limited in use due to large data requirements and limited theory, is land use models. These predict the future population and land use patterns given the present pattern and population distribution plus some estimate of the future population growth. Such a model can be used to provide the population estimates necessary as input to the transportation models. Some land use models, often called Growth Allocation Models, distribute the growth of various types of land use to districts within the area being modeled. Others examine each district separately and calculate its future pattern based on physical features, known plans, stated policies, and the accessibility of that district to other centres of population and major commercial areas. The totals for any land use type for all districts are then pro-rated to make them equal to an independent predicted figure for the future totals. Transportation plans are usually taken into consideration when determining accessibility, which in turn affects the relative attractiveness of a district, while public plans such as those for reserved green space, overall density requirements, and excluded uses are used as restraints on growth. The fact that the land use predictions of this type of model are used as input to a transportation model, while the transport plans that are made as a result of that model are used as input to the land use model, makes accurate predictions from either model extremely difficult.

In this and further discussions, it must be kept in mind that in no way does the use of computer models diminish the need for competent planners. The model is a tool, and is only as useful and accurate as the extent of the knowledge that is used to create it and the experience that is necessary to understand and implement the conclusions. Models usually require exogenous estimates of total population growth, of changes in the labour force and employment ratios, and of expected income levels of the population. In return, the models cannot evaluate the resulting situations except in a quantitative, cost/benefit manner. Social welfare and aesthetic evaluations must be made by a planner or politician, and as well, the planner must decide how much relative emphasis is to be placed on the cost or economic factors and on the congestion and time delay results.

Planners with experience in the functioning of cities are not only necessary in the model design stage, but also during implementation.

The model works on abstractions based upon the best understood relationships from the past; even were no unexpected situations to arise, the output results would still have to be checked carefully by planning professionals for accuracy and reasonableness in the light of changing trends. In addition, machine or logic malfunctions, totally unexpected situations, or invalid input data would cause errors of the type that require trained people to identify and correct. The only way in which the use of a computer model reduces the role of the planner is that repetitious calculations are eliminated. On the other hand, the possession of more facts and a better understanding of how a city functions and grows, increases the responsibility of the planner and gives him more choices in his decision making. When the limitations of the model-use process are known, it becomes more apparent that this method serves only as a tool for the decision-maker, and can be improperly functioning or incorrectly used.

Although models were originally designed for predictions, two other uses have evolved which appear to be of even greater importance. One of these is evaluating proposed public decisions as to their effect on the future of the area. Insofar as the model uses controlling factors such as land use restrictions, location of public services such as sewers, water supply lines and schools, and highway location and capacity in the calculations of the land use pattern for the future, a change in one or more of these variables will produce a corresponding change in the pattern. Various alternative outcomes and their desirability can be compared and evaluated, and conclusions drawn concerning the best policy decisions to be made and followed at the present time.

The other important use of models that has evolved lies in the area of research into how a community actually functions and grows. A vast amount of data must be collected for any model-assisted study, and it must be ordered in a systematic and meaningful manner. To use it, it is necessary to know what effect some variables have on others. For instance, in looking at income levels and the use of a car to travel to work, does the use of an automobile as contrasted to use of public transit increase with income, or does this relationship simply appear to be the case because those people with higher incomes are more likely to own a house in the suburbs? Is it this home ownership at a distance from the place of employment that governs the proportion of the population driving cars to work and not the fact of higher incomes? This question becomes meaningful and the answer important when people with higher incomes begin to live in apartments or homes in the downtown area, and plans for future roads and public transportation facilities are under discussion. Furthermore, the corresponding equations must be built into the model because one might wish to compare the results of increasing downtown densities on public expenditures for roads and transit, in order to decide whether it would be a beneficial plan to encourage the redevelopment of downtown areas through tax rebates to higher income residences.

This type of knowledge concerning the causal relationships within the city is vital to a planner in making decisions which affect the city, even if a computer model is not used subsequently. But the gain in knowledge is much greater if the model can be used to ascertain the results of alternative plans. The calculations required are much too involved and numerous to perform without the use of a high speed computer, and definitely a number of alternative plans could not be run and their results compared. Then the additional cost of a cost/benefit program on the computer would be negligible, since all the material required is in the program, but without a computer it would not be a justifiable expense.

The drawback to the use of models, in addition to that of a planner discovering that his pet project is not as good as he imagined, lies in the time and cost required to collect all the data. To a large degree, the accuracy of the model's output is completely dependent on the quantity and calibre of the data collected. If some particular variable is not included in the model, then any subsequent change in that variable would not and could not be predicted or analyzed by the model.

However, effective planning requires this data in any case in order to produce, evaluate and update plans. The computer model does not necessitate work beyond that presently required (although possibly beyond present performance) but rather means that the collection of data can no longer be put off, for the model cannot process guesses or intuitive knowledge.

Examples of Computer Models

Some of the earliest computer models were those produced by aeronautical engineers who were using physical models in the design and testing of new aircraft. These people realized that the laws of flight and aerodynamics could be programmed for a computer and alternative aircraft designs evaluated by specifying, mathematically, the characteristics of the particular design. Then they ran the model program which would use these characteristics plus the laws of flight to determine aerodynamic patterns and predict aircraft performance. In this way it becomes possible to run many more tests than would be possible if a physical model had to be created for every design variable. The total cost of testing is less; with more alternatives the chances of success are greater; and the use of this computer method means that many statistics can be kept during the running of the tests. These, plus various reports, can be printed automatically without the extra effort that would be required were a man to record the results of his own tests.

Transportation engineers were the next group to use computer models in their work. Because of the large quantities of data which their planning involved, programs were written in an attempt to depict by means of a series of mathematical equations the transportation characteristics of large urban areas. Over time, and after much experimentation, it was concluded that a modification of the Newtonian theory of gravity was accurate for depicting the characteristics significant to the transportation planner in making designs to handle predicted traffic volumes. The model equations are of the type:

$$V_{ab} = K \times G_a \times G_b / D^N$$ [1]

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[1]Dr. Soberman, Lecture notes taken in the course in Traffic Engineering, University of Toronto, 1966 - 67.

which states that the volume of traffic V between district a and district b is proportional to the number of trip generators (homes, offices, jobs, stores etc.) in district a multiplied by the number of generators in district b, and that this traffic volume is inversely proportional to the distance between the two districts. For accuracy, different equations would be constructed for each type of trip generator, with different values for K to indicate that some types of land use generate more traffic than others, and with different values for N to indicate that distance is more of a deterrent for some trip purposes than for others. The values to be determined for each equation would come from study of present day travel characteristics modified by trends and expected developments, and then one equation would be constructed for each trip purpose and for each pair of districts in the city under study. The model is calibrated, or made to fit a particular city at a particular time, by substituting present trip generation entities in each zone or district, and present volumes as found by origin-destination studies for the number of inter-zonal trips. This substitution and the subsequent solving of the equations produces the values for the parameters K and N in the equations.

Further refinements and increasing complexity take place when the model is calibrated by applying it to two or more known time periods and adding more parameters and variables. Separate equations for different land use or trip purposes cannot be used because there is an inter-dependence between various trip types. For example, in a one car family, if the father takes the car to work, the pattern of shopping trips, rides for children going to school, and visits to friends and relatives through the day will be different from the case where father leaves the car at home. Thus, complex equations must be used to relate different trip purposes and social characteristics (job types, income, homes with more than one car) and to find trends in travel patterns, modal splits, relation of car travel and distance to employment, and the effects of social values on travel characteristics.

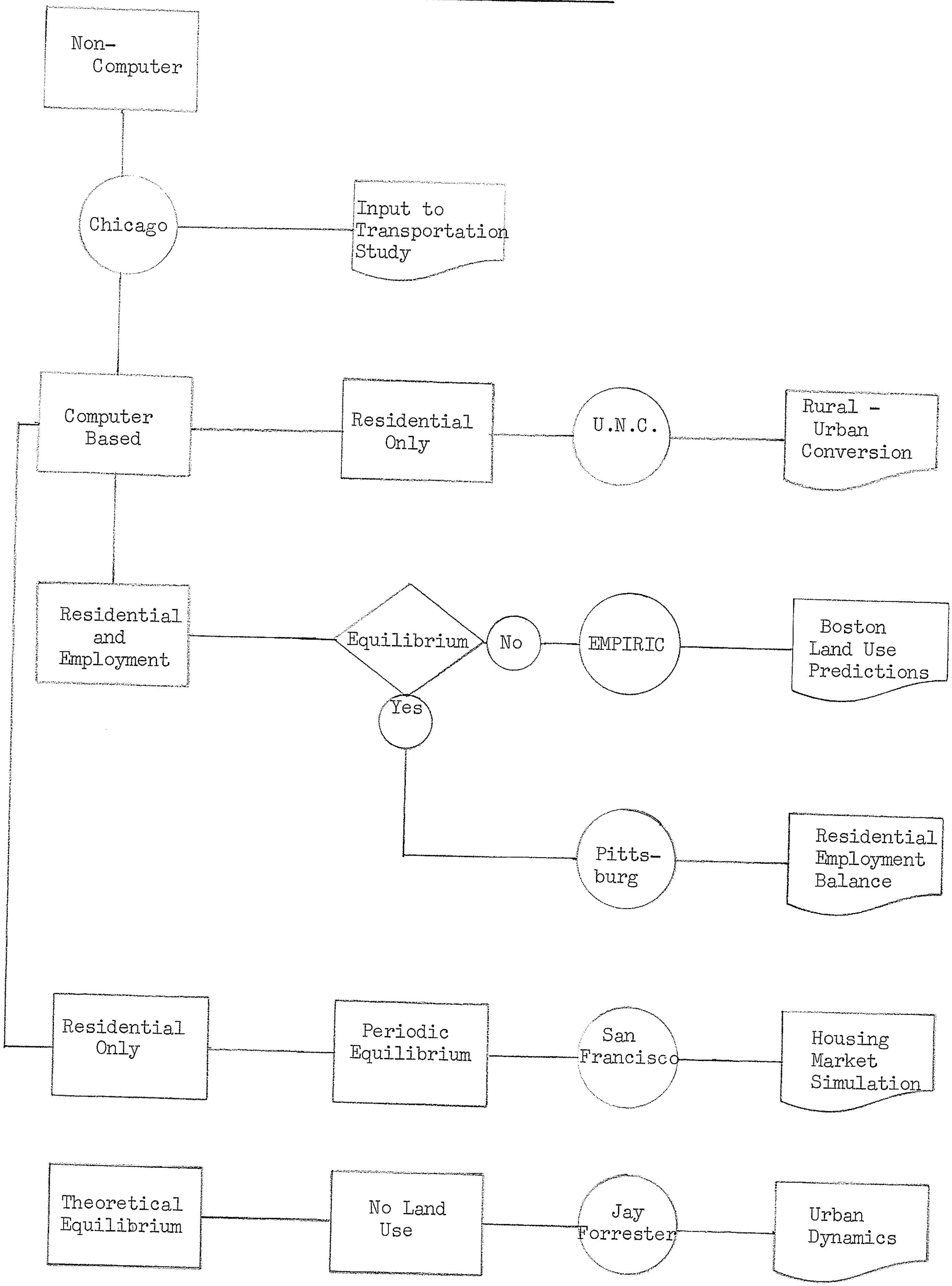
To use a traffic model after it has been calibrated, traffic generators, such as future population and employment by traffic zone, must be predicted and used as model input. These predictions, plus any other exogenously determined variables, must be fed in before origin-destination, volume, congestion and time-delay statistics can emerge. As more and more variables are used, and different equations are involved in order to improve the accuracy of the model, it becomes increasingly important to improve the accuracy of the estimates of future population and employment by traffic zone. And so, from traffic models a need arises to develop and refine a technique to predict population and employment growth trends with minimum difficulty and maximum accuracy.

Several examples of models to answer the needs of traffic engineers are given here. In addition to traffic engineers, planners involved in other aspects of community growth became interested in models which predicted land use change, or at least explored the residential land market. On the next page, there is a flow-chart which attempts to link these examples in a meaningful manner. The Chicago and Boston models are closely linked to the needs of traffic engineers, the University of North Carolina model is a theoretical one which attempts to depect the process of rural-to-urban change. The Pittsburg model attempts to explore the process of city growth, while the San Francisco model is concerned with the residential housing market as a tool for assistance to the study of urban renewal requirements. The model of Urban Dynamics by Jay Forrester is not a land use model, does not require large amounts of data input but is reputed to have had a great effect on the entire issue of federally supported urban renewal in Canada; it has been included for its general interest and its effect on the thinking of Canadian city planners.

Chicago Area Transportation Study

One of the earliest land use models was developed for use in the Chicago Area Transportation Study. It is officially called the CATS Density-Saturation Gradient Model for Land Use Forecasting, and the purpose of the model was to forecast the future land use by major categories. These are residential, commercial, manufacturing, public open space, public buildings, transportation, communication and public utilities and streets, and the study was done for the Chicago Metropolitan Area by square-mile traffic analysis zones.

Figure 2: Examples of Land Use Models



The model was developed at CATS by its research and planning staff, and is documented in a technical report entitled Land Use Forecast.[1] This model is much less rigorous than many of its successors, involving, as it does, a great deal of staff judgment with ad hoc decisions introduced at many points in the process. The present location of major industrial areas and regional shopping centres, and known plans for near-future developments are related to present trends and are used to extrapolate the land use changes and patterns for one district or one zone at a time to arrive at the overall 1980 pattern. The procedure was not programmed for a computer, but required only the use of electronic accounting machines.

The first step in the forecasting procedure was to maintain the same population density and per capita non-residential land use ratios for built up areas in 1956 through to the target date of 1980. The exception to this routine occurred in the central area of Chicago where present conditions were replaced by the redevelopment plans of the city planning department. Obviously, if plans are to be used as model input to determine the future, the model will not be able to evaluate those plans. In addition, this model excludes redevelopment to a higher density in 1980 than in1956, or in fact, any land use change in the 1956 built up area except for that part of the city which comes under the city's Redevelopment Plan.

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[1] John Hamburg and Robert Sharkey, Land Use Forecast, (document #32-610; Chicago: Chicago Area Transportation Study, 1961).

The second step of the procedure is to examine land that was vacant in 1956, and to exclude from future calculations the possibility of development of any of that land designated as public open space, or expected to remain as private open space. Land for manufacturing was then removed from the vacant land inventory, based upon existing zoning laws and the exogenous determination of favourable sites; land for railways, streets and airports was excluded, based upon trends and future plans; and then the land remaining was designated as potential commercial and residential. Local commercial land was to be determined on a per capita basis, while regional shopping centres were located according to present trends, plans and estimates of regional requirements.

With other uses then allocated, the residential population for 1980 for each zone was calculated. This figure was derived from the overall residential density based on 1965 values. It was modified by staff decisions for particular zones with special features and ammenities, multiplied by the total land area of the zone, and then multiplied by a figure equal to the percentage of the zone's residential potential to be filled by 1980. This percentage is based on a curve which relates the density of the zones to the distance from the zone to the Central Business District, as determined in the 1940 to 1956 period and adjusted so that the total of the 1980 expected population is included under the curve. Finally, streets, public buildings and recreational land were set aside based on the 1956 per capita figures.

When figures have been determined for each zone, they are added and, where necessary, multiplied by population factors to change from land area measurements to labour force or population figures. Trends in net employment density, sales per square foot, automobile use as related to income etc. are all used in arriving at the total 1980 expected figures. These figures are then compared to independent predictions for labour force and population and the land area figures modified systematically if necessary, to achieve agreement. The figures for each area are determined separately with no inter-zonal competition for different activities; nor are the zones compared with regard to relative merits except for the one factor of distance from the Central Business District.

A great amount of staff judgment is used in this technique, and it is therefore open to subjective decisions and values. No thought is given to land use succession, or to the previous location of new residents or establishments, or the future locations of activities which move out. No new trends are permitted; no renewal or change in existing areas is involved; and no provision is made for changes in the existing pattern due to the construction of new public services, including roads. If the distance from the CBD is the only relative variable to determine the desirability of one area over another, then it appears that decisions made before the introduction of a new road system would be quite different from those made after the new roads were built.

Finally, this model was not tested to determine its accuracy. Such a test might have involved the prediction of the 1956 land use pattern using only the information and pattern available several years before. Unfortunately, the lack of a computer program meant that such a test would have doubled the time required to produce a prediction. Furthermore, a model which involves staff judgment cannot be tested fairly, for the decisions that one thinks one would have made several years previously are biased by hindsight. Additionally, even had the prediction to 1956 been quite accurate, there is no way to evaluate the accuracy of judgments made today for the future.

It must be kept in mind that the purpose of this model was to give traffic planners some idea of the future locations of population growth. There was no thought that a generalized model would be produced that could be used to examine and evaluate alternative plans or assumptions. Despite its shortcomings, this model has a great value as the beginning step towards learning the problems and relationships in an urban area, and towards the development of more comprehensive models. It is also one of the very few models ever seriously used in conjunction with a transportation plan.

University of North Carolina (UNC)

The Institute for Research in Social Science under F. Stuart Chapin at the University of North Carolina has designed a land use succession model. This model was created in its first form in the early 1960's, and a brief write-up appears in the Journal of the AIP.[1] The theory

[1] F. Stuart Chapin Jr., "A Model for Simulating Residential Development", Journal of the American Institute of Planners, XXXI, No.2, (May-1965).

underlying its construction involves concepts of land use change, or more specifically, the prediction of the incidence of conversion of rural or vacant land to urban residential purposes as the total population of the area increases.

> The conceptual framework followed in developing this model envisions the residential location decision of a household as being conditioned by: one, the scope of choice and intensity of residential development prescribed in the general plan and by zoning regulations; two, what the producer offers - not only the type of shelter package and the price, but also the accessibility the site offers to major employment centres, schools and shopping, and the proximity of the site to utilities and thoroughfares; three, what the household purse allows; four, what the household activity patterns call for; and five, what the taste norms of the household dictate.[1]

The area under study is divided into geographical cells of about 2.5 acres each. Those cells which are already developed are removed from the system, as are others which are scheduled exogenously for non-residential development or for retention as open space. The remainder are available for conversion to residential use with the maximum population determined by the density limits of official plans or zoning by-laws. Alternative plans for densities or the location of non-residential development or open space will result in different constraints, and the running of the model shows the results of these alternatives on the residential land use pattern.

A measure of the attractiveness of each cell available for development is determined, based upon its initial assessed value, its accessibility to areas of employment, the provision of sewers and the accessibility to major streets and elementary schools. Within each cell the probability of development of each lot is proportional to

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[1] Ibid., p. 121.

the cell's attractiveness score relative to all other cells. Using random sampling techniques, new residential development is allocated, one new lot at a time on a probability distribution related to the cell's attractiveness. This allocation continues until all of the total expected new growth has been distributed.

One fundamental question on the philosophy of this model is its method of allocating growth. Why would all good lots in relatively attractive areas not be developed before less attractive cells are developed? This model's relative distribution function is linear, i.e. if one cell is twice as attractive as another, it receives twice as much development, and it is not at all clear that this type of development pattern happens in reality. If it is alleged that in fact developers do leap over desirable land and build in areas with lower attractiveness values, then perhaps there are other factors which should be taken into account in determining attractiveness scores; for example, the need to have a single piece of land of a minimum size in order to achieve economies of scale in the construction of a residential subdivision.

This model is completely demand oriented, and this demand is fixed outside the model. Nothing that is done in creating the future residential pattern will affect the net migration of population into or out of the area; and no entrepreneurial skill is allowed, for a cell's attractiveness cannot be increased either by a better than average house design or subdivision layout, or by a lower than average house cost. In addition, no provision is made for withholding choice land from development until a higher price can be obtained. No competition for land use is involved; non-residential uses are allocated to certain cells, and there is no chance that one of these users might bid for residential land if a certain level of accessibility or other measure of attractiveness were obtained. There is no rezoning or change in density or possibility of inconsistent land use types. No thought is given within the residential group to the origin or destination of a person who moves, or to what social characteristics he is likely to possess. The lack of involvement in the origin of new residents is part of the total ignoring by the model of any renewal or redevelopment of those areas which are presently built up.

Although this model is definitely not comprehensive with regard to urban growth, it does try to isolate those factors which result in different choices for residential location. One of its points that is receiving further stress in future modification is that the activity patterns of a household exert a strong influence on location decisions.

> It is a premise of this work that location decisions (which we purport to simulate in our model) are instrumental forms of behaviour for accomodating the day-in-and-day-out activity patterns of individuals and families.[1]

With certain activity patterns, a household requires certain locations. Accessibility is always important, but the relative im-

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[1] Ibid., p.123.

portance of different destinations will change. However, a certain inertia exists, for many reasons, which prevents frequent moves during the lifetime of a family. In fact, it appears that the longer established a household has been in a given location, the greater the inertia and hence the greater the improvement required before a locational change takes place.

A great amount of data must be collected to develop the statistical parameters regarding locational change and inertia. It is planned to improve this model by the introduction of different accessibility or attractiveness values for households at different stages in the life cycle. The model will be run to show not just residential growth, but also residential growth and change by family type over a period of time, as well as the aging of the population as the model predicts successive increments of the future. Further, model improvement would involve the inclusion of redevelopment of existing residential areas as both the population and the housing stock are over the time interval of the model's predictions.

This model is not a land use model, nor does it allocate any activity type except residential. Its purpose, rather than improving the understanding of future growth in any city planning department, is to attempt to isolate the reasons for different choices of residential location. Employment and shopping locations are distributed not as output from some model but as given input to this model in order to determine how they influence the locational decisions of the residential population. With this purpose and approach in mind, one major criticism of the model's philosophy is the failure to include existing residential areas as subjects for locational decisions and as factors in overcoming locational inertia.

The Pittsburg Urban Renewal Simulation Model

The present Pittsburg model is an adaptation of one originally created by Ira S. Lowry.[1] The original model allocates retail employment and residential employment in a pattern uniquely consistent with a given spatial distribution of basic employment. It is thus an equilibrium or ideal state model with no time dimension. The new modification includes a prediction of the location of basic employment and has changed the resulting retail and residential uses so that they are incremental, i.e. based on the pattern of land use types in the preceding period. The model has, in this way, been made more sensitive to policy decisions.

The Pittsburg urban region was divided into mile square tracts, and the activities to be allocated were distributed to these. For residential land use, households were allocated based on the accessibility of each tract to places of employment, with the total number being proportional to the total employment of the region. The limit to the number of households per tract is determined by a density figure, which is related to the distances from places of employment. For the

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[1] Ira S. Lowry, A Model of Metropolis, (document #RM-4035-RC; Santa Monica: The RAND Corporation, 1964).

distribution of retail activities, each tract is given a desirability value based on its accessibility to residential population (consumer markets). The total number of employees per tract must be either zero or above a preset minimum figure, and from the number of employees, the number of stores is calculated. An iterative process is used to distribute retail and residential population figures because each one depends on the other for the calculation of the relative attractiveness values. Through this process a point is reached where the numbers are in balance; the number of stores provides the attractiveness for residential location, and the number of residents provides the consumer market. The iterative process is not meant to demonstrate a theory of changes over time, but is rather a mathematical technique to achieve a situation of equilibrium. This type of equilibrium (non-time-oriented) suppresses all questions of land use succession or migration patterns for residential and retail establishments.

The modification of the model uses roughly the same mathematics, but commences with the distribution of activities at one point in time and then calculates the change to the next time period,rather than arriving at an atemporal equilibrium.

The steps involved in the operation of the present simulation model are:

1) Projection of employment figures for the region, the county, and the city for a number of time intervals. Then, using probable participation rates, the estimated total population

is calculated and divided into subgroups by age, sex and race, using independently derived small area projections.

2) Distribution of the "basic" part of this employment total (site-oriented, or indifferent to residential location) throughout the city, based on such criteria as present employment concentrations, land use plans and accessibility to other concentrations of employment and to the regional transportation network.

3) Distribution of residential and consumer oriented activities at certain distances from the basic employment and utilizing the iterative process mentioned above. In other words:

> Given the attributes of employment located previously, households of a certain size are located within a specified distance, and at predetermined locations, creating service employment again at specified distances from the households. This new employment generates new households which produce additional service employment. This process repeats itself in the model until it is approximately stabilized.[1]

It was felt by the modelers in Pittsburg that there were two benefits from this type of exercise; one is the actual predictions for the specific area, and the other is the experience that was gained from the construction and running of the model, and which is useful for other planners and model builders. One of the most important

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[1]Wilbur A. Steger, "The Pittsburg Urban Renewal Simulation Model", Journal of the American Institute of Planners, XXXI, no. 2, (May, 1965) p. 145.

gains was in the field of data, data management and its value and cost.

The conclusion in the Pittsburg study was that a great deal of understanding was gained through the construction of such a model. The planners and other model-makers co-operated on it, and not only was information gained through its running, but also from the collaboration of the various people and professions involved with the construction. The co-operation between different professions and various involved non-professionals appears to be one of the greatest benefits to be gained from the employment of computer modeling.

The reports for this model do not include any estimation of the accuracy that could be expected from its output. Additionally, it appears that a full validation of the model (having it predict a known point in time) was not carried out. Nevertheless, even without predicted figures, it appears that the gains in mutual understanding are sufficient justification for the exercise.

Traffic Research Corporation: The Empiric Model

Traffic Research Corporation (now Kates, Peat & Marwick in Canada) developed a growth allocation model for the Eastern Massachusetts Regional Planning Project (Boston) which they called the Empiric Model. In general, this model reallocates population and employment among various geographical areas within the region to correspond to the changes over time in regional totals and in the quality and quantity of local public services and transportation networks.[1]

The model is incremental in nature, so that the steps are related to successive time periods and not, as in the first Pittsburg model, to a mathematical technique to produce equilibrium. The operation of an incremental model is based upon reality as it exists up to and including the immediately preceding step. At any step, additional exogenous changes can be introduced, thus permitting the operation of the model not only to commence with the situation as it exists in the present, but also to include specific planned changes or developments at some predetermined point in the future. This method of allocating population and employment totals throughout the entire region permits the inclusion of central city decline and the redevelopment of presently built up areas, unlike most other models, which only allocate new development on previously vacant or agricultural land.

This model could be said to represent the "black box" concept of modeling. It does not pattern itself on some theory of urban growth or change, nor does it contain explicit analysis of the behaviour of people in making locational changes. Rather it involves a statistical analysis of many locational choices in the past, or of the results

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[1]Traffic Research Corporation, Empiric Land Use Forecasting Model: Final Report, (Boston: Traffic Research Corporation, 1967).

of these choices, and the correlation between these decisions and various measurable environmental and accessibility factors at the corresponding point in the past. What goes in is related to what comes out, and there is a minimum of concern with what steps take place in the process internally.[1]

The model is run by solving a series of simultaneous equations which determine, independently, the share of the regional total of population and employment that is to be allocated to each sub-area. Simultaneous equations are of the type where certain variables are a function of other variables, and eventually a function of themselves. For example, the amount of retail employment in any given sub-area may be determined in part by the total of all retail employment in the region, but to determine this overall total, the individual figures must be summed, and they depend on the total for their calculation. The method used to solve such a set of equations is a stochastic one, in which the final answer is determined by a set of calculations which start off with an estimate, work through repetitious calculations with increasing accuracy, and gradually zero in on the answer which puts the equations in balance; at which point the equations can be solved and real values found for the variables. The use of this technique eliminates the "chicken and egg" problem of which land use should be

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[1]c.f. the B-52 bombers. These planes had a black box in the cockpit which received one set of radar signals and emitted a second, scrambled set. The working mechanism of the box was mysterious and unimportant to reading the signals.

allocated first. Does residential growth follow jobs, or is the relationship reversed? In this model these two, plus other variables, are determined simultaneously.

The design of the Empiric Model for the Boston region involved the satisfaction of the following criteria:[1]

1) The model must recognize and depict the simultaneous and interrelated nature of factors in the development of a metropolitan region.
2) The model must be able to accept as input variables, any planned changes in the highway and transit transportation systems.
3) Output must include the important categories of population, employment and automobile ownership. In this way, the model provides information which can be used as input to a transportation model to forecast trip origins, destinations and modal splits.
4) The forecasts must be made for areas which are small and numerous enough to permit meaningful inputs to a transportation model.
5) The model should be constructed so as to allow recursive operations of relatively short time intervals. This method of forecasting permits new values for construction of facilities to be input at various times in the future. In this way,

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[1]Ibid.

the model can produce information which is directly useful for the programming of public works projects by comparing the alternative outcomes of the decision for or against the building of a particular facility,and of the timing or staging of projects which are planned for construction.

In addition to the above criteria, which were strongly oriented to the subsequent use of output data for some type of transportation model, several other criteria were also used:

1) The model should accept other, non-transportation policy decisions as inputs. In effect, its output should be a systematic estimate of how a region would develop under the influence of regional growth rates and planning policies relative to utilities, zoning and open space as well as transportation.
2) The model should allow for reasonable budget limits on operating costs of the model.
3) Input and output needs and formats to the model should be compatible with other needs, i.e. input to transportation networks within the model should be in the same format as, and the nodes and links compatible with, a subsequent traffic prediction model.

The framework for the model consists of a series of simultaneous linear equations; each equation relates the change for one variable within a zone to a change in value of the variable being located at the beginning of the time period. More specifically, there are two types of variables involved in the model: "located variables" which are those for which figures are to be predicted; and "locator variables" which cause or influence the occurance of the located variables.

> The change in the subregional share of a located variable in each subregion is proportional to: one, the change in the subregional share of all other located variables in the subregion; two, the change in the subregional share of a number of locator variables in the subregion; and three, the value of the subregional shares of other locator variables. This concept is expressed by the following equation system:
>
> $$\Delta R_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} a_{ij} \Delta R_j + \sum_{k=1}^{M} b_{ik} (Z_k \text{ or } \Delta Z_k)$$
>
> where: i or $j = 1,2,i,j,N$: number of located variables (a total of N equations.)
>
> ΔR_i or ΔR_j = change in the level of the i th or j th located variable over the calibration or forecast time interval.
>
> Z_k = level of locator variable k at the beginning of the calibration or forecast time interval.
>
> ΔZ_k = change in the level of the k th locator variable over the calibration or forecast time interval.
>
> a_{ij} , b_{ik} = coefficients expressing the interrelationships among the variables.
>
> $k = 1,2,..k,..M$: number of locator variables.
>
> There is one such equation for each located variable. The a and b coefficients are determined by simultaneous regression analysis of the data from two past points in time (that is, the model is calibrated on the basis of a past period of time.)[1]

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[1]Donald M. Hill, "A Growth Allocation Model for the Boston Region": Journal of the American Institute of Planners, XXXI, no. 2, (May, 1965), p. 113.

The model distinguishes two classes of residential population: blue collar (PB) and white collar (PW), with the population figures including not only the head of the house, but all of his dependents. There are three classes of employment which are distributed: trade, or retail and wholesale (RW); manufacturing (M); and all other employment (OE). These five classes form the set of located variables.

There are three sets of locator variables which were used in calibrating the model: set one contains densities of land use, zoning practices and accessibility (by automobile) to all activities within the region; set two contains set one plus accessibility by public transit; and set three contains set two plus quality of water service and quality of sewage disposal facilities based on a normative scale with values from 1 to 3.

The model was calibrated for the 1950 to 1960 period using the three sets of locator variables. Then the 1960 population and employment figures were predicted using information which would have been available in 1950. The model was about 99% accurate in its predictions, and the errors decreased as the number of locator variables increased.

> The results show that when increased information is available on transportation systems and other planned variables, predictions are more accurate. It would appear that the more comprehensively we are able to plan in advance the various modes of transportation and other policy measures, the more accurately we will be able to predict the future location of urban activities.[1]

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[1]Ibid., p. 117.

With the required information available, it would be best to use the third set of locator variables. However, it is at this point that the question of the utility of extra data comes into play. It is not possible to know how accurate the model will be in predicting 1980 located variables from information available in 1960. If the model is run from 1950 to predict 1960 values, after the same 1950 to 1960 period was used to calibrate the model, one would expect a high level of accuracy because of the elimination of any unknowns that might arise within the forecast period. In fact, the model's accuracy in predicting some of the values for 1955 given values for 1950 was lower than the accuracy for 1960, indicating that even when all of the factors are known, the model is not able to allocate them in the correct time interval. It also indicates that the influence and weighting of factors changed over the ten-year calibration period, and that the particular parameter values used were an average for the period. In predicting the future from today, these trends are the very things that must be discovered if correct predictions are to be made. In addition, unknown factors in the future will upset the accuracy of today's predictions. For these reasons, it is very difficult to state how much increased accuracy would be obtained through the inclusion of additional and perhaps expensive data.

One of the criticisms of this model is that the equations do not determine the level of an activity (located variable) directly, but just the change in the district's share of the regional total for that activity. Thus the share of the total activity in any given subregion is not affected by its overall magnitude. If an area accounts for 1% of the total regional activity, then it receives that 1% whether the change has been large or small. One might assume that a given area would receive a large percentage of the increase in a given activity if the magnitude of the change were small; as the magnitude increases, other subregions would begin to pick up some of the activity. The first subregion might continue to receive additional units of the activity as the magnitude rose, but the percentage would drop. However, such a situation is not permitted within the model.

The model is concerned only with net changes; the various interzonal flows that go to make up these net figures are not examined. The model is also silent on the subject of land use succession and change; it allocates the share, or change in share, for each activity and the land use implications and types and potential incompatibilities do not constrain the forecast.

Nevertheless, this model performed very well for its validation run and has been used in the Boston Region study. It predicts an end to the depopulation of the central area and an increase in private redevelopment. It permits comparison and evaluation of the effects of public policies regarding alternate transportation, zoning, sewer facilities, or water supply plans. While it may not provide accurate predictions for the future, it does show in a relative way the changes in the land use pattern that would result from these alternative plans.

A variation of this model was employed by Kates, Peat, Marwick and Company in Metropolitan Winnipeg under the auspices of the Canadian Council of Urban and Regional Research. Although a final copy of the report covering this application has not been released, it would appear from preliminary reports that the accuracy of the calibration and validation runs was lower than that found in Boston. The greatest problem in Winnipeg was the lack of data for sufficient points of time in the past to make an accurate calibration. Several variables had to be dropped from the investigation due to this lack of data, while other variables were patched using interpolation techniques to bring the data base to a common point in time. Further evaluation from this study will probably be forthcoming, but from discussions with the Metropolitan Winnipeg Planning Director, it would appear that the results are disappointing relative to the time and cost involved in setting up and running the model.[1]

The Department of Municipal Affairs of the Province of Ontario has been examining this model, or a variation of it, for a number of years, and while interested, has not yet concluded that given its other priorities and responsibilities the model would be worth the expenditure of money and time required to get it running for Ontario.

This type of "black box" model is in reality a sophisticated trend analysis, whether it contains many factors such as the Empiric

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[1]See Appendix C for further discussion.

model for Boston, or is a smaller model such as one that TRW Systems designed for the Southern California Association of Governors. This had values for past amenity factors (1 to 10) and these scores were correlated to growth in the next time period with the next future period predicted from today's amenity values.[1] In any case, such a technique is of limited use in assisting a planner to understand what exactly is happening within the city. Without this understanding of the causal chains, the planner cannot predict the results, or the probable results, of the introduction of some entirely new factor. Such a model as this would not be able to predict the shift from single-family homes to apartments if it did not contain predictions based upon an understanding of the residential land market. On the other hand, lack of knowledge of the many interrelationships within the modern city makes a detailed simulation model either impossible or extremely cumbersome and highly inaccurate. The answer would appear to be a large allocation model with a series of simulation sub-models of different activities or land markets within the urban region; unfortunately the required facts concerning the relationships between these sub-models is still unknown. One of the major purposes of the models discussed in this paper is to uncover some of that knowledge in order that accurate and sophisticated models can be created in the near future.

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[1] Population and Land Use Projections for Orange County, (California: TRW Systems, 1968).

The San Francisco Simulation Model

The San Francisco model was designed by Arthur D. Little, Inc. for the San Francisco City Planning Commission to assist in the preparation of a Community Renewal Program (CRP). The purpose of the model is to overcome the piecemeal approach to urban renewal that has existed in the past.

> The failures and weaknesses of renewal activity in the past have resulted not so much from poor planning, but from the inability of conventional methods of data analysis and forecasting to identify and measure accurately the repercussions and consequences of various private and public actions.[1]

The model attempts to overcome this situation by simulating the market for land and residential buildings within the city.

Three specific purposes were stated for the model:

1) To identify and assess the impact of alternative, long-range strategies and programs for renewal and development of the City.

2) To serve as an ongoing tool of City government - to permit City officials to keep the CRP which emerges from our current effort up-to-date in light of changing conditions and/or goals, and to have available on a continuing basis a method for testing the consequences of various renewal actions before they actually take place 'on the ground'.

3) To identify key statistical symptomatic indicators which should be maintained on a continuing basis by appropriate public agencies so that they can be aware of the rate and direction of changes affecting the City and take appropriate responsive action.[2]

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[1]Ira M. Robinson, Harry B. Wolfe, and Robert L. Barringer, "A Simulation Model for Renewal Programming", Journal of the American Institute of Planners, XXXI, no. 2, (May, 1965), p. 126.

[2]Ibid., p. 127.

The model functions by matching the expected population at the beginning of a number of two year periods with the housing stock at the end of the preceding period, modified by proposed public activities in the housing market. Predictions must be given to the model about expected households: the number, household size, race or colour, and household income for the beginning of each two-year prediction period. The housing stock (dwelling units) is classified by type of structure, whether owned or rented, the number of rooms, physical condition of the building, and the type of neighbourhood.

The output from the model provides predictions of the number of new housing units that will be built, the number demolished, the change in the physical condition of existing buildings, the number of buildings left unoccupied, and the number of households unable to find acomodation within their income range.

When the housing demand and supply are not in balance, a change takes place in the housing stock. Changes are evaluated in terms of profitability (to the owner, builder or landlord) and whether the changes and density are permitted under existing zoning regulations. In this way, the effects of alternative policies regarding zoning can be compared as to their relative effects on the number and types of housing units.

There are four principal elements to this model:

Households, the consumers of housing;
Investors, the private market suppliers of housing;

Government, whose actions affect the process of the private market directly or indirectly;
Housing stock, the supply of housing.[1]

Each type of household has a preference list of housing types within its range of rent paying ability. Starting with the household type with the greatest ability to pay, demand is satisfied from the preference list of household types. This process continues through households with lower rent paying ability until the point is reached where there are either no households left to house, or no units available for the lower income groups within their ability to pay, although there may be unfilled housing units at a higher rent level. No group is assured of having all its households located in units of the highest preference level. Thus there exist two types of demand: one from the lower income groups for housing within their income range; the other from the higher income groups for more preferred types of units.

With unfilled demand and supply, prices of housing units are altered, the profit for the investor in satisfying the demand for each type of household is evaluated, and the most profitable changes in the stock are made and the housing inventory modified. This procedure of starting with demand and altering supply is run through twice for each forecasting period. At the end of the period the housing stock is aged two years and the resulting unfilled demand and supply conditions for each household and dwelling unit type are output from the model.

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[1]Status of the San Francisco Simulation Model, (San Francisco: Department of City Planning, 1968), pp. 5-6.

In 1965 the Community Renewal Program Study came to an end and formal work on the model was halted. The model and the test runs were turned over to the Department of City Planning. Some tentative conclusions were drawn regarding the effectiveness of the program in achieving its housing goals, but there had not been time for a complete review. The consultants had concluded:

> Interpretation of the model results is even more demanding than its use. The outputs are of a form requiring skill to disaggregate and develop suitable tables, and the interpretation thereafter must be done by people who are not only acquainted with details of the model but who are also thoroughly experienced with the City of San Francisco and with the characteristics of its housing and construction activities.[1]

The City Planning Department took over the model and, after making several modifications, ran it for two years and compared the simulation output with the actual operation of the housing market during the two years. To input the existing housing stock of 300,000 units within the San Francisco area, it was necessary to use average densities for various types of units. This use of averages, plus other errors and problems, resulted in the model making incorrect predictions for 49 out of 69 areas where market activity occurred during the time that the model was supposed to simulate. As the Planning Department report states:

> Our evaluation of the model is that it is not, at present, a reliable device for simulation of the market...it would be unwise to draw conclusions from the full operation of

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[1]Arthur D. Little, Inc., Model of the San Francisco Housing Market, p. 5, as quoted in Status of the San Francisco Simulation Model, (San Francisco: Department of City Planning, 1968), p. 9.

> the model regarding the possible impact of public policies upon the housing market...
>
> ...A primary reason for the model's deficiency as a reliable simulation lies in its data. The quality and quantity of information used are simply not sufficient for the operation of a model of this size and complexity. Finally, a model as ambitious as this one has not been adequately tried under a number of conditions to test our hypothesis.[1]

The recommendations of the planning department included termination of further operations with the model, and use of the appropriated money in surveys of the housing market "to provide the information about the housing stock and its users which may, in the long run, serve the end of an improved information system that will permit improvement of the model".[2]

The San Francisco model is not a land use model, but is an attempt to understand the operation of the housing market and to determine the effects of public renewal activities within this market. Conceptually, this type of model would form a sub-model for an overall urban simulation and for regional growth predictions. It should be able to predict the shift from single family homes to apartment units as a result of a change in the factors dealing with land costs, population increase and increased travel times. Of course, such a shift would still require changes in the zoning bylaws regarding density. It becomes questionable whether a model predicting the future should use zon-

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[1] Status of the San Francisco Simulation Model, (San Francisco: Department of City Planning, 1968), p. 25.

[2] Ibid., p. 27.

ing regulations as a constraint on land use change for other than a two to five year delaying tactic. In other words, if the economic pressures indicate that changes are desirable, do zoning regulations simply follow these pressures after initial opposition and delay? This type of question would be the subject of a model which simulated the decision-making or political process within a city or province, and the answers could be fed into the larger urban simulation model to modify the restraint parameters on future growth or land use change. Without this type of knowledge regarding the processes of planning and city government, the urban simulation model must depend on reasonable hypotheses.

Urban Simulation Modeling

An urban simulation model is basically a quantified theory of the process of urban growth and change. In itself, it is unnecessary to have spatial parameters, or in other words, it can be insensitive to the location of various land use types. Rather, it is concerned with the relationships between land use types, and particularly the changes in these relationships over time. It thus provides the framework on which to hang more specific and location-sensitive allocation models.

One person who has had some influence in this field has been Professor Jay Forrester of the Massachusetts Institute of Technology. Forrester's studies have been mainly oriented to industrial operations and locations using simulation modeling techniques.[1] However, these concepts have been applied in the area of regional planning, and one such application was a study of the Susquahanna River basin.[2]

In 1962 the Columbia Laboratories of the Battelle Memorial Institute were approached by a group of utility companies in the Pennsylvania and Maryland area to perform a study of the use and need for water in the Susquahanna River basin, based on population levels and economic development. A dynamic model was created relating population, immigration, economic conditions and water requirements.

Two types of feedback loops are built into the model to operate over a period of time: a positive loop and a negative one. A positive loop is one where growth continues, and one example is the two element loop of population - births - population, where an increase in one causes an increase in the other. A negative feedback loop is one which tends towards a position of equilibrium. An example is the labour force - unemployment - migration - population - labour force loop where an increase or decrease in any element causes changes in the other values to restore a balanced system. This type of programming is dynamic over time, so that high unemployment in 1967 produces lower relative wages in 1970 and more jobs in 1975. The system is groping towards a

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[1]Jay W. Forrester, Industrial Dynamics, (Cambridge, Mass.: M.I.T. Press, 1960).

[2]H.R. Hamilton et al, Systems Simulation for Regional Analysis: An Application to River Basin Planning, (Cambridge, Mass.: M.I.T. Press, 1969).

state of equilibrium which it never reaches because of changing death rates, technological shifts and changes in the national economy. The following page contains an illustration of the population and employment subsystem, in the form of a flowchart. Births, birth rates and deaths are self explanatory, and ALE is average life expectancy. Some of these equations would contain different time periods within them if a time delay is involved. Such a group of equations would be constructed for each sub-region within the river basin.

The simulation approach was chosen because it is the least restrictive, requiring only that the variables be quantifiable and that the relationships between the variables be defined. A model was used for this operation, despite the limitations of theory and knowledge, because it may be incorrect or the data may be wrong, but it can at least be verified for logical consistency as a theory. On the question of the model's validity and accuracy, the designers concluded:

> At present there are few objective tests that can be applied. Especially there are none that can give an answer relative to a specific use of the model. So the question becomes one of whether the builder has confidence in the model for the use to which he plans to apply it - admittedly a subjective evaluation. This being so, he cannot prove the validity to anyone else, but he can answer the question for himself.[1]

In fact, it was felt by the designers that one of the major uses of the model was to guide the research effort into better understanding the relationships among the many variables in the study. The design

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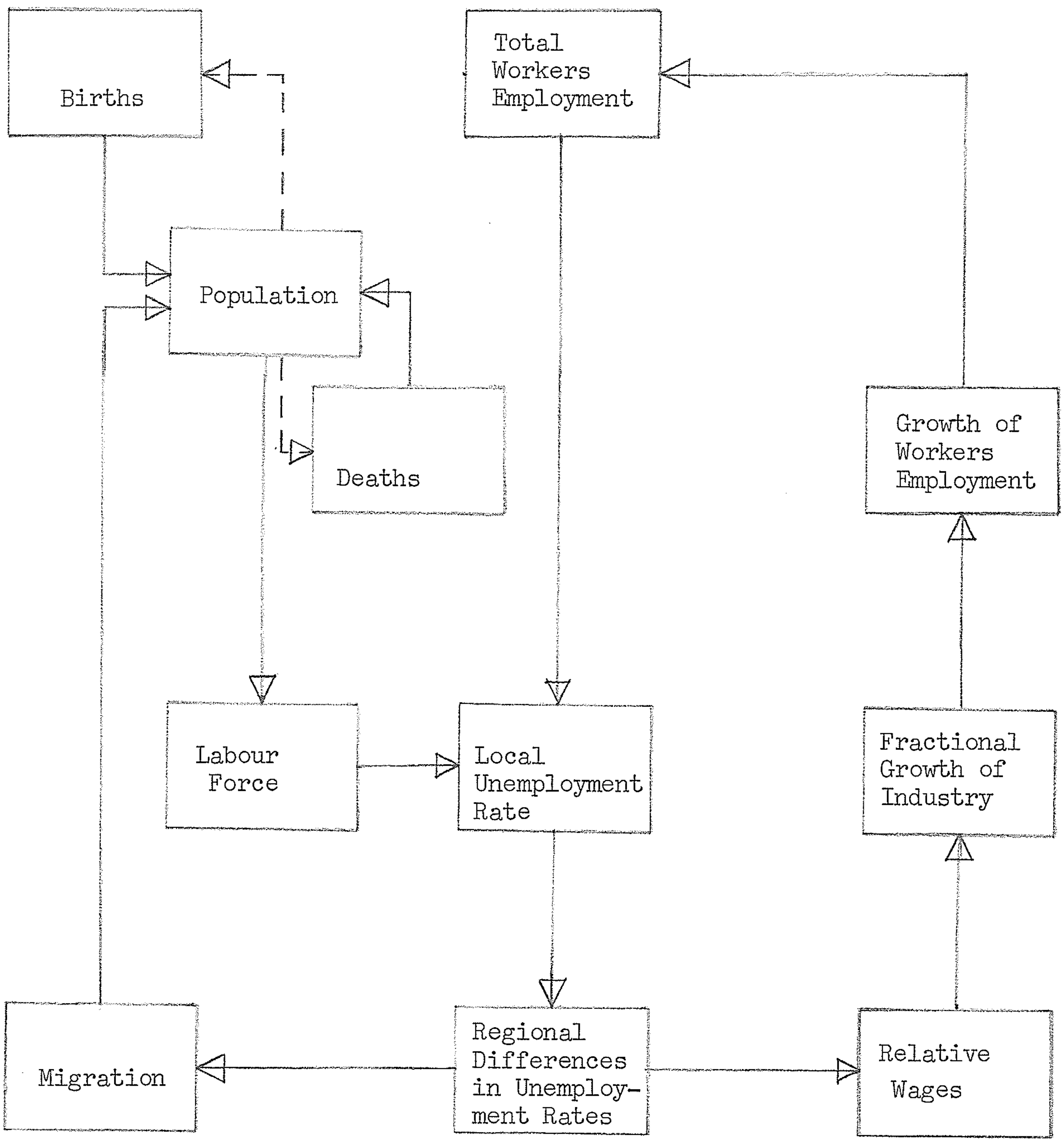
[1]Ibid., pp. 112 - 113.

Figure 3: <u>Dynamic System Flowchart</u> [1]



The equations that make up such a system are of the following form (time = k):

$$BRTH_k = (BRTHR_k)\ (POP_k)$$
$$DTHS_k = POP_k/ALE_k$$

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[1] Ibid., p. 104.

and construction of the model appeared to be more significant that the subsequent running of the finished product.

Once his dynamic simulation concepts had influenced the field of planning, Professor Forrester became involved in the urban situation directly. This came about through the many contacts he had with Mr. John Collins, a former mayor of Boston, who was a visiting professor at the Center for Urban Studies at MIT in 1968. From their discussions came an urban simulation model which has now been described in the book, Urban Dynamics.[1]

The model is a simulation of the long range (50 to 200 years) changes in the social and economic framework of a city, as a result of natural changes and of government interaction. It is a general exploration of the growth processes of urban areas and the system of interaction between industries, housing and people.

> As the urban area develops and its land area fills, the processes of aging cause stagnation. As the urban area moves from the growth phase, the population mix and the economic activity change. Unless there is continuing renewal, the filling of the land converts the area from one marked by innovation and growth to one characterized by aging housing and declining industry....the interactions between economic and social activity are so complex that intuition alone cannot devise policies that prevent decay.[2]

The model is based on the view of industrial dynamics as a system of feedback processes having a specific and orderly structure and

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[1]Jay Wright Forrester, Urban Dynamics, (Cambridge, Mass.: M.I.T. Press, 1969).

[2]Ibid., p. 1.

dynamic behaviour. It is necessary to organize the growth and goal-seeking processes into a computer model which can deal with the changes over a long range period. The conclusions from the modeling process are drawn as one goes along. It can be concluded that a healthy city is a more effective economic converter for upgrading the underemployed than a decaying city. It is one of the input theories of this model that "an urban area tends toward attractiveness equilibrium with its surroundings.[1] Thus good public housing would attract low income people and a new equilibrium would be established with high unemployment and poor and overcrowded housing.

The formulas in the model are of the following type (k is time now, L is next year):

$$XY_{kL} = (X_k + F_k)(Z)(A_k)$$

where: kL is the time period between k and L.

X is the total number of unemployed.

XY is underemployed arrivals (men/year).

Z is a weighting factor set at .05 (normal arrivals)

F is the labour force

A is the attractiveness for migration multiplier as perceived (1 = normal)

Thus the number of arrivals depends, among other things, on the perceived attractiveness for migration, A.

$$A_k = A_j + (D/AT)(M_j - A_j)$$

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[1]Ibid., p.5

where: j is last year

D is the time period of the model (set = 1)

AT is the time required for information to become known concerning migration advantages (set at 20)

M is the actual attractiveness for migration

A is set at '1' for the start of the model.

It now becomes evident that the perceived attractiveness for migration depends on the actual attractiveness, M.

$$M_k = (XY.N_k) \quad (H_k) \quad (P_k) \quad (U_k) \quad (B_k) \quad (C)$$

where: XY.N is the underemployed arrivals mobility multiplier (rate of upward mobility)

H is the housing per underemployed multiplier

P is the total public expenditure

U is the jobs per underemployed multiplier

B is the housing program per underemployed multiplier

C is the attractiveness for migration factor, set = 1

There are hundreds of such equations representing the theory of an urban area as seen by the model's designer.[1] Although there are only three spatial attributes to this model - central city, suburban ring and other - it provides a theoretical basis for allocation models. In

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[1]Forrester, op.cit., pp. 135 - 137.

addition, it is reputed to have had an influence in the Canadian Federal Government's cutback on expenditures for urban renewal.[1]

The results from the model conclude that the provision of public housing in a downtown center attracts into the downtown poor persons (or underemployed persons) from outside the urban area. This results in the same high unemployment and overcrowded housing conditions that existed before the public housing expenditures, but now with a higher absolute number of persons involved. This increase in the number of poor persons on the one hand, plus the growth of slum areas and the out-migration of the well-to-do on the other increases the social costs of the city at the same time as its tax base decreases. In addition, to provide space for the new housing units, older manufacturing concerns are often pulled down; if not, as least new factories are not built. The result of this is to remove some of the jobs that originally were available within the central city area. The answer, obviously enough, is to build and encourage more factories, and build public housing units in the smaller towns and suburban areas where there is no large scale blight.[2]

An article in the Toronto Daily Star reports:

> The federal government is giving serious consideration to a computer study which concludes the cities are wrong to help the poor and that present urban renewal and public housing schemes may be ruining the cities' chances

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[1]Frank Jones, "Helping the Poor Slows Cities' Growth, Ottawa Told", Toronto Daily Star, September 6, 1969.

[2]Forrester, op. cit., p. 139.

> for economic survival...Robert Andras cited the study approvingly when he announced a freeze on urban renewal schemes last month.[1]

The article goes on to speculate that the consenquences of this study may be to keep public housing to a minimum in the large cities, build more in the suburbs, place more emphasis on the attracting of industry and less on providing generous welfare benefits, and to produce "a super-cautious approach by Ottawa toward spending money in the cities because the MIT study shows that in nearly every case, federal grants distort and weaken the structure of the cities".[2]

If only a few of these conclusions are implemented by the federal government, it will make this study one of the most influencial computer models in Canadian city planning. This model does not depend on the collection of a large data base, and hence its conclusions are not specific to any given city or situation; rather the model depends on the accuracy of the theory of urban change which it contains. The test of this model's validity is whether it explains the growth of cities, the decline of some and continued expansion of others, and whether the individual equations which make up the model are satisfactory. They must be reasonable in their relationships, contain sufficient variables, and be able to react in an expected manner to sudden large and unusual situations. If the model is valid, it provides a good starting point for the planner who states, "Fine, now we know what happens. Let us build a model to show where it happens - a growth allocation model."

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[1]Jones, op. cit.

[2]Ibid.

Summary of Model Examples

The Chicago Area Transportation Study used one of the first land use models; it was run on tabulating machines and included many subjective staff decisions. Nevertheless, the results were adequate for the purpose required, that of input to a transportation model, and provided the first step towards the goal of being able to predict land use patterns accurately through the use of conceptual and computer models.

The model developed by the University of North Carolina is basically a research tool. It is a test of a hypothesis of urban residential growth which assigns a score to undeveloped land based on accessibility factors, and allocates future growth proportionally to these scores through a Monte Carlo technique.

The model study in Pittsburg has never been actually implemented, but is still in the process of improvement. It was during this study that it became increasingly apparent that adequate and accurate data is a prime requisite for a sophisticated model. The same conclusion was arrived at by Traffic Research Corporation with their Empiric Model, particularly in its application in Winnipeg. Accuracy testing of the predictive output of the Empiric model has not yet been reported at the time of this writing. The model was verified by predicting a known year from a previous point in time, but as this was the period for which the model was calibrated, no new trends or factors could enter during the prediction period. Nevertheless, this model is one of the most sophisticated examples of the "black box" concept of modeling: a method whereby input variables are correlated to output variables with little or no concern for the relationships which happen internally. Such a model represents a sophistication of the well known prediction method of trend extrapolation; the emergence of new trends cannot be predicted by the model.

The San Francisco model is more of a housing market type than a land use or location. The actual location of housing units of various types is not important, and nonresidential uses are excluded. However, as the model forecast residential building activity over a two year period, it was possible to judge the accuracy of the model's predictions. The results were disappointing, and indicated not only a deficiency in data, but also a lack of comprehensive theory of the urban housing market. Although not primarily intended as such, this model also served as an educational experience for its users, if only in a negative way.

The dynamic simulation techniques of Forrester provide an alternative approach to urban modeling. In this case, a great amount of data is not required, but a comprehensive theory is essential. However, such an approach does answer the questions that growth allocation models usually try to answer: namely, where in the metropolitan region is this expected growth going to occur? The dynamic simulation technique explains the long range changes which take place in all urban centres; it does not explain to what extent a particular centre may differ from the norm, nor does it assist the planner in making decisions concerning the city's infrastructure, except for the one point of encouraging downtown industry.

The operation of urban growth and the functioning of an urban society appear still to be beyond the grasp of the theories available to understand, model and predict.

CHAPTER VI

CONCLUSIONS

Benefits of Computer Model Use

One of the first questions to be asked by any agency doing community planning work is whether a computer model should be used in their work, and what benefits it would provide. Although total costs are not usually provided by model designers or users, the City Planning Department of San Francisco estimated that the cost of bringing their experimental model up to a desired operational state would be between $250,000 and $500,000.[1] The author has heard of estimates of about $80,000 to use an existing model in a new situation. (On the other hand, the computer running costs are very low: a fifty minute run on a large computer to predict growth figures for a city of four and a half million people in 192 districts for five five-year intervals cost roughly $300.)[2] With high costs like the above for total model development, and the realization that data collection costs will force the figure even higher, and that even after the expenditure of this money there is no guarantee of the accuracy of the results, one could quite readily conclude that the benefits are not worth the cost.

At the present time, the models that have been described have as their greatest benefit the gain in knowledge about the functions and

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[1]Jones, op. cit.

[2]David R. Seidman, "The Present and Futures of Urban Land Use Models," Proceedings of the Fourth Annual Conference on Urban Planning Information Systems and Programs, (Berkeley, Calif.: University of California, 1966), p. 121.

growth of an urban area. Models provide the ability to test various hypotheses about the city with the ultimate goal being the development of a model that actually works. The creation of a model, particularly one of the behavioural type, permits a check for logical consistency in the theories involved. In addition, the process of model design and testing encourages cooperation among different professions and backgrounds. The Susquahanna River basin study found yet another value to using a model; in discussing the benefits of its use, the study concluded:

> First, the explicit nature of such models facilitates communication of what has been studied and the weighting of the factors involved. Second, models can be used to test the impact of alternative policies, a factor extremely important to regional analysis and planning. However, a third advantage of models that is often overlooked concerns their usefulness in terms of guiding the research studies that spawn them. This advantage is gained by using the model in various stages of refinement to specify critical relationships requiring further research effort.[1]

Given that one of the purposes of constructing land use change or growth allocation models is to predict the future pattern of the urban land use types, one further question to be asked is whether accurate predictions are necessary at all. Each planning department must decide to what degree their plans and recommendations regarding public activity and expenditure are to be determined by some type of prediction concerning population patterns in the future. To some degree, the construction of subway and expressway routes do depend on

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[1]H.R. Hamilton et al, op. cit., pp. 3 - 4.

future pattern predictions. On the other hand, the designers of most predictive models use accessibility as a determinant of future growth; to that degree, highway and subway construction could be placed where it was considered desirable that growth take place rather than where it was predicted to go naturally in the absence of the new transportation facilities. Perhaps it was the idea in the minds of British planners that planning is a conscious decision to change trends that resulted in their objections to modeling mentioned by Camina earlier in the paper.

If models are primarily a tool for augmenting knowledge of market forces and growth parameters, then it could be concluded that a university environment, rather than an operational planning department, would be the best location for the design, construction and testing of computer models. After examining the problems of limited understanding of model use and operation, cumbersome analysis of results and inadequate informational support, the San Francisco Planning Department concludes:

> To become effective, the model must be used. The final point may seem paradoxical for it can be asked, 'If the model is not now operational, in the effective sense, what is the point of continuing to use it?' The answer is that only through use can the various aspects of the model be tested and proven out. Testing the effect of the data upon the results, testing the structure of the model for inconsistencies, testing the computer program to determine mechanical sources of error, these can only be accomplished through repeated trials of the model. However, this process is expensive and time consuming.

> To attempt to accomplish it as a subsidiary activity given the foregoing problems is unrealistic. Only an ability to commit both considerable amounts of time and money will accomplish the goal of making it an effective operational device.[1]

The answer would appear to be a joint effort between a university and a city planning department to design, produce and use a computer growth model: the city providing data and data collection as a by-product of other planning and governmental operations; the university providing theories, student man hours and computer expertise. The city gains predictions, the university knowledge.

Areal Extent

If it is decided to utilize a model to provide the best possible prediction of future growth, (even if not completely accurate) the next question concerns what area the model is to cover. If a planning department or agency with jurisdiction over only a limited area is going to use a growth model, such a question does not usually arise. However, if the agency that is planning to utilize a computer model is a state or provincial government, then this question must be answered.

One such as the Empiric model developed by Traffic Research Corporation creates a series of mathematical relationships linking population growth and land use change in the past to other identifiable variables within the model area. The relative growth amounts for

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[1] Status of the San Francisco Simulation Model, op. cit., pp. 26-27.

subareas are then related to an independent estimate of total growth and change. As the area covered by the model becomes smaller, the chances of random variables or outside influences become greater due to the lack of averaging out or smoothing these fluctuations. A model run at a provincial level could distribute the province's expected growth to subareas within the province. For larger cities, a further model could take the growth assigned to it by the provincial model and distribute it throughout the area of the city. Thus two models would be required to make predictions for a metropolitan area. However, the coarseness of the distribution at the provincial level would probably be too great for the results to be used by a small town, and yet the data cost to permit this provincial model to provide proper input to the city model could be prohibitively high. The conclusion would appear to be that this type of modeling technique, the black box method where predictions are based on an analysis of many factors, is best suited for a large metropolitan area and preferably one that is somewhat isolated from outside influence.[1] It is possibly for this reason that the Canadian Council of Urban and Regional Research decided on Winnipeg as the location for testing the Empiric Model. What, though, would be the best location to choose in an area such as southern Ontario? The growth patterns of the areas around Toronto are influenced by the presence of

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[1]This conviction grew out of discussion with Mr. Martin Sinclair, head of the Department of Research and Special Studies, Community Planning Branch, Dept. of Municipal Affairs. (Province of Ontario)

Toronto, the major provincial highway network and the amount of industry which the larger centres "spin off" to smaller ones. Even if the entire area around Toronto is chosen as the basis for the model, this region is influenced by Detroit, Buffalo and Montreal, and by proximity to major transportation routes to the rest of the United States.[1] The alternative to such a black box method, which requires a great deal of data to achieve statistical reliability, is to use a model which simulates the actual decisions made in deciding on a new location for either residence or employment. Unfortunately, as was discovered in Pittsburg and San Francisco, such an approach still requires a large data base, plus an adequate theory of land use change, which presently is not available.

The Future of Land Use Models

Although the construction and use of a land use model is expensive, and the accuracy of the results is not certain, it is only through continued design and experimentation that a useful working model will be developed. Several streams of development can be seen for the near future. One of these is the continued expansion of computer hardware to permit larger models and collections of data to be run and used faster, and at a lower cost than is presently possible. The development of new devices, such as more versatile optical page readers, will lower the cost of input and data collection. These machines, plus a greater use of connections between different com-

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[1]The Ford plant producing Maverick cars was located at St. Thomas because of its location between Chicago and New York, and between Detroit, Buffalo and Toronto.

puter systems, will increase the amount of data available for future work.

As historical figures are often necessary to design and calibrate a model, the information that is being collected today will provide the base information for more complex and sophisticated techniques in the future. More and more agencies are coming to use computers, and familiarization with the machines and techniques of programming is a necessary first step to having people involved with community planning question what further use can be made of available machines. At the same time, the use of computer terminals will become more widespread and more persons will have the opportunity to communicate on a back-and-forth basis with a computer system in order to try out theories that may be useful in further model design. Forrester comments that the study he performed would never have been completed had he not had a computer terminal in his office at home.[1]

With the continued increase of computer hardware and data bases, the development of theories and techniques will also continue. More planners will come to view the city and region as a system of activities involving people at various locations, and will both demand and supply hypotheses and models which explain the intricacies of the system. As the need becomes more apparent to develop a way of examining the metropolitan region as an interconnected entity, more time and funds will be allocated to the model development process.

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[1]Forrester, op. cit., p. x.

Model types discussed in this paper can be divided into two main groups: 'black box' or regression models; and simulation or behavioural.

> The main distinction...between regression and behavioural models is that the regression models allow great flexibility in the selection of parameters, and assume simple linear or non-linear relationships between the dependent and independent variables, whereas behavioural models generally involve considerably more complex structuring of the relationships of the variables, and inject considerably greater amounts of the individual analyst's views on the extent and manner in which the independent variables influence the dependents.[1]

Both types of models have had problems in the past, often related to data, either its lack of quality or quantity, and also related to the relevance of the implied theories, to stability of results, and to handling of unusual situations. One development that can be foreseen is a co-ordinating of these two approaches into one effort,

> ...in which the regression models are no longer allowed the extreme flexibility of parameter choice that they have had up to now, and will be infused with a greater structural complexity more closely resembling the manner in which urban analysts view the urban system. I see the behavioural modelists using more of the regression types of methods to obtain certain parameters needed.[2]

Whether this drawing together will result in one super model, or a series, each member of which specializes in a different technique or part of the overall problem, is not apparent at the moment. But most definitely, more urban theory will have to be included within the model design if accurate results are to be expected, and if the model is to

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[1]Seidman, op. cit., p. 123.

[2]Ibid., p. 124.

be used to increase our knowledge of available social alternatives.

Conclusion

It is obvious that an approach must be developed to permit analysis of the city as a whole, and that a computer system will have to be used because of the amount of data involved. One effect of the development of models to date has been the increase in the number of alternatives available for the planner's consideration. These model techniques will thus influence the whole framework of organizing planning problems.

> If such techniques are to become widespread, there are clear implications for planning methods as well as training. The whole art of framing a problem in terms appropriate and sufficiently precise that it has a mathematical solution needs considerable experience and expertise. Further, the planner's approach to problems may have to be changed. To make his task easier, the planner up to now has been obliged to restrict the number of possibilities examined so that he can cope with the decisions. However, prescriptive models are most useful when the problem is complex and the situation genuinely offers numerous solutions. If there are only few real alternatives, the planner can comprehend and analyse them for himself but this may not occur as often as has been thought in the past. A restrictive attitude used to be essential but if computers are available, one can afford to approach each situation more flexibly.[1]

As far as output from the computer is concerned, some of the results of the model runs produced information that was already known or at least suspected, but was confirmed by the analysis provided by the computer. For example, the Boston area study discovered that in

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[1] Camina, op. cit., p. 128.

all cases but one, the presence of an activity in a subarea at the beginning of a period of study was inversely proportional to the presence of that variable at the end of the period; i.e. the zones became more heterogenous. The one exception was low income population. In only that instance did the presence in a zone of the same activity at the beginning of the time interval induce increased growth in the regional share of the activity within the subarea. This is striking statistical evidence of the increasing concentration and ghettoism of the low income family.[1]

In the same study it was also found that increased accessibility to major roads did not positively affect the growth of low income groups, indicating that they lacked the resources to take advantage of the regional highway system. However, the high income groups were not assisted in their growth by increased accessibility either, perhaps indicating that they would rather pay higher transportation costs in time and money in order to enjoy other residential amenities which they desired. Only the very large middle income group exhibited the concern for improved highways which has been taken for granted. With these types of findings emerging from the analysis and manipulation of other variables, the planner is in a better position to understand where the changes in the society must be made in order to reduce undesirable situations and encourage desirable ones.

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[1]Traffic Research Corporation, op. cit.

The use of models and modeling techniques forces planners and other decision makers to make explicit the problems in the field of planning and the concepts of planning itself. It is an advantage of the models that they necessitate the translation of vague ideas and goals into precise and quantifiable statements, and to make clear the relationships between these goals and the present urban situation. There is a place in the planning operation for growth allocation models, even in their present state of development, pointing out the most likely pattern of growth based on past trends. The model provides a way to organize the data from the area receiving attention, and to demonstrate, in a relative way, the probable effects of different policy decisions on the future land use pattern. But the greatest benefit from computer models would appear to come from their actual construction. The model acts as an objective device around which different persons representing different social theories and priorities can work towards the development of one goal system for their city.

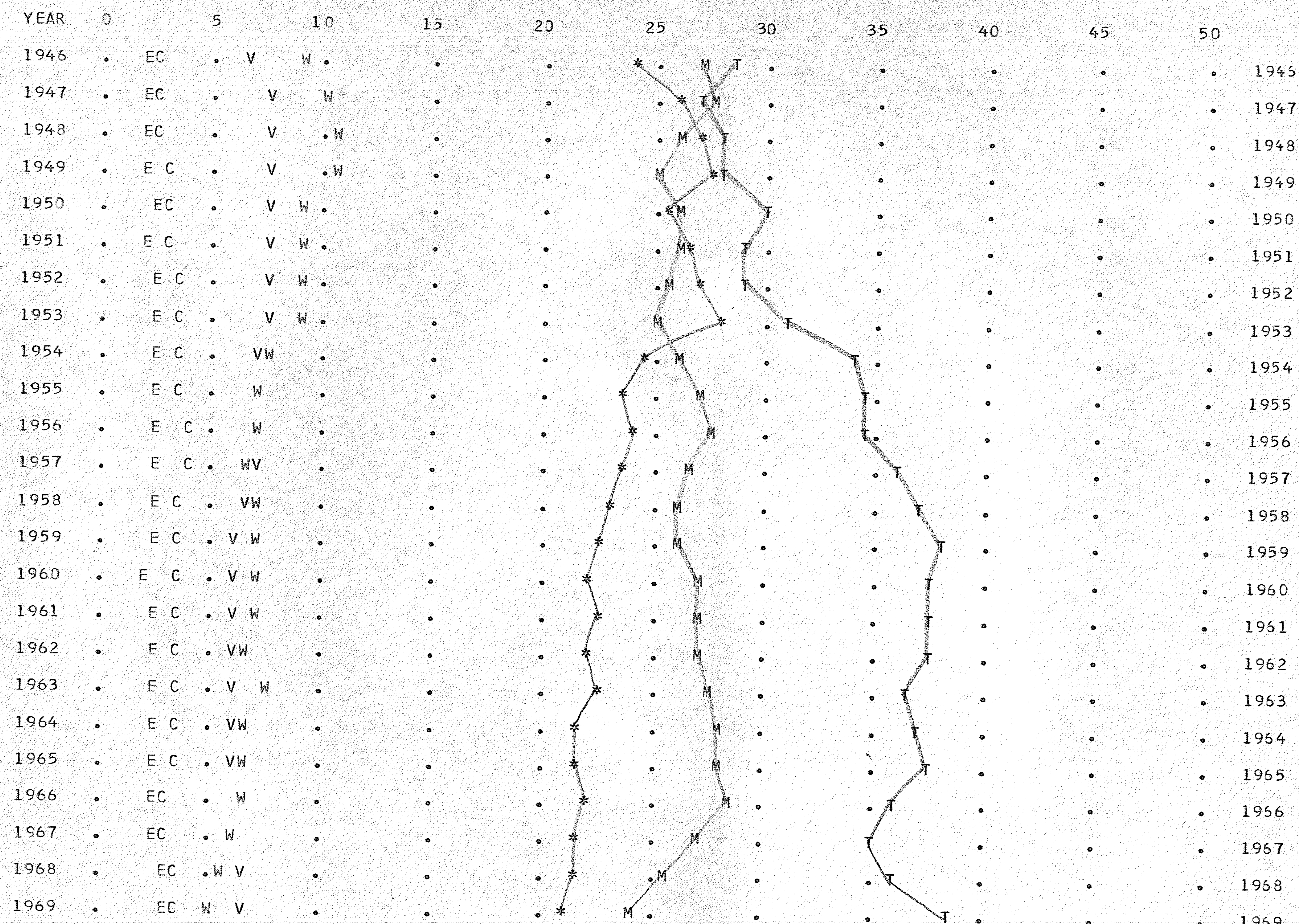
Computer models are definitely not the be-all and end-all which eliminates the need for planners, but rather they are a means of organizing theories and data about urban areas; a means to test hypotheses; and a base on which to build a better understanding of the process of urban growth.

APPENDIX A

GRAPHICAL OUTPUT EXAMPLE

The following example demonstrates the use of an IBM 1403 printer as an output-graph device. The printer has 132 print positions, and this limits the accuracy that can be demonstrated. The example shown is the result of calculations made on data read in from cards, and shows the percentage of the Canadian total for cheques cashed accounted for by each of the top six cities and for Western Canada as a whole. The accuracy is to one half of one percent, and the plot character for Toronto, Montreal, Vancouver, Winnipeg, Edmonton and Calgary is the first letter of the city's name. The asterisk (*) is used to represent the total of the four western provinces. The coloured lines have been added to three of the graphs for added clarity. Where two cities are tied for position, only one character is shown, as for Winnipeg and Vancouver in 1955, 1956, 1966 and 1967.

CHEQUES CASHED IN INDIVIDUAL CENTRES AS A PERCENT OF THE CANADIAN TOTAL



APPENDIX B

G.P.S.S. EXAMPLE

The IBM General Purpose Systems Simulator (GPSS) is a program to calculate averages, percentages and performance figures for systems involving probabilistic functions. The small example illustrated is depicting a car-wash facility with cars arriving at different times, and with each car requiring two minutes to move through the washer. The question to be answered is how much of a queue will develop waiting for the car wash as both a maximum and an average figure. The results, based entirely on the arrival function (FN2) indicate that the queue will contain an average of 14.3 cars, with a maximum length of 25, and that it will never be empty.

Although the example is very simple, much more difficult problems, including more than one facility, queue hopping, a range of throughput times and others, could be handled with relative ease.

```
BLCCK
NUMBER   *LCC    OPERATION   A,B,C,D,E,F,G                    COMMENTS
                 SIMULATE
                 RMULT       2335,99,981,9005,1705,57,331,55957
          *  NAME OF PROGRAMMER = KEN WHITWELL
               2 FUNCTION    RN2,D4
          .4   1      .7     2      .9     3      1.0    4
1                GENERATE    1,FN2
2                TABULATE    7
3                QUEUE       5
4                SEIZE       4
5                DEPART      5
6                ADVANCE     2
7                RELEASE     4
8                TERMINATE   1
               7 TABLE       IA,1,1,5
              12 QTABLE      5,0,1,15
                 START       55
                 RESET
                 START       250
                 JOB
```

FACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRAN
4	1.000	250	2.000

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS
5	25	14.301	269		.0

$AVERAGE TIME/TRANS = AVERAGE TIME/TRANS EXCLUDING ZERO ENTRIES

AVERAGE TIME/TRANS	$AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
26.583	26.583	12	19

APPENDIX C

THE KATES, PEAT, MARWICK & CO. STUDY

After the completion of this paper, the final report of Kates, Peat, Marwick & Co.'s work in Winnipeg was published. It comments on the difficulty of establishing an adequate data base for the model, and on the use of questionnaires to collect information. It was felt that although the response to the questionnaire was disappointing, the technique might be refined to be more generally applicable.[1]

The note of optimism on which the company's report ends will be a great encouragement to planners who would further the use of computers in their field:

> ...although there were some rather difficult problems resulting from the unavailability of data, it is felt that the reliability of the Growth Allocation Model developed in this study is sufficient to indicate considerable promise for this type of model as a research and planning tool. With more and better data, there would be virtually no limit to the increased planning insight that could be gained from the development and application of a model within the framework described in this report.[2]

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[1]Kates, Peat, Marwick & Co., Developing a Growth Allocation Procedure for Forecasting Land Use in a Metropolitan Region, (Toronto: 1969), p. 1 - 3.

[2]Ibid., p. 1 - 3.

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