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# The Systems Model Approach to Urban Policy Planning

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**ABSTRACT**

With the expanded scope of planning and awareness of the complexity of urban systems, computer systems models can be invaluable vehicles for learning and the advancement of theory. They do not, however, represent simple means to leapfrog gaps in theory and the political process to arrive at instant solutions. Two contrasting actual modeling efforts are described to illustrate how models can be used and sometimes misused.

## Introduction

In recent years, systems analysts, engineers, operations researchers, and other quantitatively oriented specialists have increasingly turned their attention to social problems. It was inevitable that much of the resulting effort would focus on cities as the locus of the most critical problems in American society. It also seems to have been inevitable that the manifold complexities of urban problems would lead to attempts to apply the so-called "systems model" approach and, more specifically, the technique of computer simulation models.

The observation that urban problems were embedded within an interlocking flow system thus making it perilous, if not impossible, to study a single aspect and formulate strategy decisions in isolation, was not a new discovery of the systems analyst. Urban planners were already well aware of the need for a more integrated approach but they have been limited in terms of time, resources, tools, and techniques, and, not least of all, theoretical foundations. The computer model-builder could provide tools (primarily the





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computer) and techniques (mathematical, statistical, and computational aspects of model-building) as the basis for a new approach. He could not leapfrog the gaps of theory in urban dynamics and planning but he could provide a new vehicle, the computerized systems model, to examine more fully the implications of a given theory or view of how things should and do work. This approach has not, and should not be expected to provide instant answers. It can, however, be a powerful aid in the search for both better theory and better decision-making.

Ira Lowry summarized the situation in 1965[1] in a statement we would continue to subscribe to today:

> "The growing enthusiasm for the use of computer models as aids to urban planning . . . derives less from the proven adequacy of such models than from the increasing sophistication of professional planners and a consequent awareness of the inadequacy of traditional techniques."

In this paper, we propose to review the nature of the planning problem, the recent systems model approach, and indicate some directions for future progress.

## The Role of Planning

City planning in both colonial America and in the early part of the twentieth century was concerned almost entirely with the physical layout and appearance of cities. Master plans were drawn up primarily by architects and engineers and consisted of specifications and discussion of:

1. street patterns
2. transit and transportation
3. parks and recreation
4. civic appearance, and
5. zoning

In the 1920's, every plan ended with a statement to the effect that the master plan should be kept up to date. Plans of that era were characterized more as "holding operations against change"[2] rather than as strategies to achieve positive change.

In the period starting immediately after the American revolution until the 1900's, planning was for all practical purposes non-existent. The demise of planning in that major period of American development was attributed to four major factors:[3]

1. The anti-urban bias of colonial American intellectuals (notably Thomas Jefferson, among others).

2. Economic competition between cities in capturing the trade of tributary areas instead of cooperating in mutual interest in political, economic, social, and planning problems.
3. The decline of municipal governmental powers after independence.
4. The rise of land speculation in an expansive laissez faire economy.

These factors are of more than historic interest. The attitudes and effects produced by them are still with us today.

A significant change took place in the 1930's when professional planners placed new emphasis on social issues and economics in addition to the traditional concerns of the architectural and engineering approaches. These wider concerns have continued and grown as priorities of modern planners. This is clearly evidenced in the recently published Plan for New York City. In addition to the conventional topics of mass transit, highways, aviation, and the port, the Plan discussed such topics as job development, manpower training, welfare, health, education, crime, and the governmental structure required to execute the Plan. Under a heading of "Critical Issues," the Plan discussed the Federal role in welfare activities, medical payment systems, taxicab rates and services, educational programs for dropouts, city programs for narcotics addicts, and other social problems–quite a departure from mere street and park designs.

Another aspect of the Plan for New York City, however, illustrates the limitations in the current state of the planning art. The Plan does not represent itself as a set of answers to all the main questions and even states that all problems have not been solved. At the same time it takes a clear position on one of the most controversial aspects of planning: central city concentration. The Plan states that "Concentration is the genius of the City, its reason for being, the source of its vitality and its excitement. We believe the center (mid-Manhattan) should be strengthened, not weakened, and we are not afraid of the bogey of high density. We hope to see several hundred thousand more office workers in the business districts in the next ten years and we think the increase desirable and helpful."

This clear position is apparently based not on a lack of concern with "quality of life" issues but on accepting a hypothesis about the effects of concentration on people as well as the "vitality" of the City. The hypothesis has not been tested. It is disputed by other planners and the effects on other aspects of urban development have not been fully explored in the context of an urban systems concept.

To us, this characterizes not so much a fault of one group of planners, but the dilemma faced by all planners who feel a sense of urgency for decisive action while faced with uncertainty and the limitations of even the most sophisticated of proposed new systems modeling techniques. Modern planners are more aware of the need to broaden their concerns, examine the interactions between people, institutions, and policies, combat the constraining attitudes and political structures of yesterday, and take bolder approaches to urban problems. At the same time they are more aware of how little we really know about urban systems.

Professor Britton Harris[4] describes all of the specific activities of planners as falling into three more general types of actions: invention, evaluation, and prediction. Computer systems models can currently be of little direct help in the first, and of somewhat more help in the latter two concerns. In any case, with the broader approach of the modern planner to what he now perceives as a multidimensional complex of interrelated problems, computers and systems models are likely to play a growing and perhaps indispensable role.

## The Role of Models

As we have already noted, the primary role of computerized models for urban problems is to provide a means to represent the variety of interactions that must be dealt with. As one observer has put it, planners are now prisoners of the discovery that in the city everything affects everything else.

The computer implemented model does not in itself represent any new knowledge or wisdom independent of that provided by the model builder. The model builder, in turn, has no special insight or knowledge in the problem area that is not extracted from the planning specialists themselves or equally available to both planner and model builder. The planner may, in fact, find it convenient in some circumstances to be his own model builder.

The unique role of the model builder is to express general relationships between the building blocks representing real world factors within the model in a form which enables the computer to manipulate them. The model builder is essentially a translator of knowledge or assumptions from one form into another. The form of the model, however, has more rigorous requirements than just new syntactical rules and new symbols. The model builder must, or should, spend considerable attention on maintaining internal consistency throughout the formulation of the model.

The resulting model then represents already known or assumed general relationships in a consistently linked and computable form given required specific data. What we have when the computer model is completed is old information but represented in a form that provides a new potential: the potential for computing new deductions. The mechanism that enables us to realize the potential is the computer.

The computer operates on the rules expressed by the model using the data provided by performing repetitive calculations and data manipulations at high speed and with essentially absolute mechanical accuracy. Resulting output consists of records of values (levels) for the variables of interest labeled as to their time and/or place of occurrence.

If new general patterns and relationships emerge as a result of examining this output, their validity is dependent on the validity of the model itself. The computer model is merely a deductive device, albeit a powerful one, and can never provide an ultimate proof of anything independently from coordinated real-world testing.

Often "sensitivity testing" is recommended as a more accessible substitute for actual performance tests. Sensitivity tests generally consist of varying the value of a single parameter (or alternatively the input value of a single variable, or even the functional form in which a variable enters a relationship) in successive runs of the model. Differences in resulting outcomes are then examined to determine if wide differences in parametric (or other) values produce significantly different outcomes and to determine the proportional effects on the outcomes. Such testing is used to conclude which parameters and variables are superfluous or relatively unimportant in seeking more refined measurements of their real rates or levels, and which may represent key or high leverage points at which to influence the behavior of the system and produce desired outcomes.

Although such sensitivity testing is relatively easy to perform and applies to a wide variety of models, it is not a test of model validity or accuracy. The only thing it directly tests is the resiliency of the model design itself. It can only test real-world sensitivity if we accept the model as a valid behavioral stand-in for the real world. To use sensitivity tests as arguments for accepting a model would therefore be circular and logically invalid.

Another immediate means of testing a model is to let it run to simulate a known past event or series of events and determine if it does so accurately. This method, also, is usually circular to some degree in that the model is generally constructed by incorporating observations of past patterns. Even when the model faithfully produces past outcomes which were not consciously "built in," we have the usual Catch-22 of all forecasting, that is, we cannot be certain that future events will be reflected by the model with similar accuracy.

We have no alternative but to accept computer model results to the extent that they are used for current decision-making as, at best, accurate reflections of our going-in assumptions. That is, the only immediate validity tests that can be made are partial, and the only complete tests that can be made are tests of internal consistency and not validity.

This situation may be very unsatisfying to those who are asked to undertake the high costs and arduous effort required to build models of complex urban systems. We feel, however, that there is ample justification for such model building and that rejection on the grounds that instantly proven answers cannot be provided, is an unreasonable criterion for any human endeavor. The ultimate payoff from systems models may be more evolutionary than revolutionary in that they may be indispensable in the step by step building of better understanding.

Later we will enumerate some suggestions for using models more effectively in learning about and planning for urban systems.

## Two Specific Models—The Pittsburgh Simulation Model and Forrester's Urban Dynamics Simulation

We have chosen to discuss these particular models for two reasons: (1) they are each broad in their scope of urban factors included, and (2) they represent very different approaches not only in terms of detailed data content and functions, but in terms of modeling philosophy. On the first count, they qualify as being relevant to examining the use of models in treating urban problems in a systems context and on the second, they serve to illustrate divergent approaches to model building which may assist us in formulating effective future efforts.

### THE PITTSBURGH MODEL

The Pittsburgh Model has been referred to as an urban renewal (or community renewal program) simulation, but it is sufficiently broad in scope to be categorized as a general model of urban development and growth designed to test and predict long range effects of urban plans and policies. It was first reported in 1965[6] and consisted of several sub-models which were the work of a number of analysts. In its treatment of residential and residence serving facilities and their allocation, the basic assumptions embody the prior work of Ira S. Lowry.[5] Lowry, using actual data for Pittsburgh, had developed a set of allocation rules that could be applied to relate places of residence to places of work and locations of retail stores. The allocation rules were empirically derived by fitting curves to the data consisting of origin and destination counts. The allocation rules are consistent, according to Lowry, with micro-economic and behavioral analyses and would follow from averaging some simple decision rules over a total population. In actual use, the rules were used in a form which best fitted the data, and their justification is empirical rather than theoretical.

Lowry incorporated these allocation rules within a model which also included as given conditions the total population, location of externally conditioned industrial, commercial, and administrative employment activities, and legal and physical constraints on land use. Structurally, the model consisted of a number of equations in an equal number of unknowns plus a set of constraints. These were solved by an iterative sequence of rapidly converging successive approximations.

The solution, then, represented an instantly arrived at equilibrium condition rather than a simulation over time. The equilibrium condition is, of course, of interest as an indication of the direction of future outcomes resulting from current conditions. However, equilibrium itself may never be reached in the real world and planners must also be concerned with intermediate conditions over a time sequence, timing itself, and the dynamics of the development process.

This aspect of Lowry's original model represents one of two major modifications made in the Pittsburgh model. The Pittsburgh model does not solve directly for an equilibrium condition but deals incrementally over time with the location and relocation of housing and businesses. The other major change in Lowry's model incorporated in the Pittsburgh model was the treatment of industrial and commercial basic activities as endogenous factors rather than externally determined conditions.

The complete Pittsburgh model is driven by essentially three sub-models:

1. a population-employment projection model,
2. a "basic" employment (nonresidentially oriented services but basically site-oriented commercial and industrial enterprises) allocation model, and
3. an allocation model for residential housing and residential service related employment.

Each of these sub-models is, in effect, a major simulation model. Their respective outputs are connected to one another so that the entire system simulates the complete process of urban development.

In the first model, employment is projected by several categories for the region, county, and city. These projections are joined with estimates of labor force participation and travel to work patterns and exploded into estimates of city population and employment. Independent estimates of population by age, sex, and race are used to check these estimates and make proportional adjustments if necessary.

The second model allocates the previously projected basic employment related activities according to transportation access, land use policies, assessment patterns, and other locational criteria. If some basic activities can find no suitable sites during the time period, this implies that employment has left the city.

The third model uses rules determining the location of residences based on employment locations, availability constraints, race, occupation, and economic characteristics. Residential locations in turn affect nonbasic residence-serving employment locations which in turn affects further residence locations, and so on.

Throughout, comparison with independent projections are made and used to proportionally calibrate the model. Parameters for the model were derived from a massive amount of computerized analysis of actual data from special surveys, U.S. Census and City records.

The output of the complete model consists of a large number of forecast levels of several dimensions including population by type, employment by SIC, land use by type, a number of social indices, housing by type, economic measures, blight indices, and other measures, all by census tract. In addition, revenues, expenditures and other project oriented data is produced for the total city. Various interpretive and evaluative schemes can therefore be applied to the model's output.

An important and immediate payoff of the Pittsburgh model was thought to be the understanding gained by the planners and analysts who participated in the model building process itself. Further, it is a general tool that can be used by a number of investigators for a multiplicity of purposes.

Rather than offering any immediate and startling "breakthrough" type of revelation, the Pittsburgh model served as both a learning device and a vehicle for well-designed experimentation by planners.

Not the least of what was learned was a healthy respect for the difficulty of the subject and the need for better models before any final conclusions can be reached. W. A. Steger, a consultant on the development of the Pittsburgh model, has laudably maintained an attitude of objectivity and humility despite the massive effort represented by the Pittsburgh model. Steger commented: [6]

> "There is obviously much room for improvement in the processes which have been involved in the construction of this model. There are many directions in which the collection, management, and preservation of data could be improved. These in turn are related to an improved understanding of the way in which locational decisions are made, of the impacts of public policy, and many other aspects of urban life. It seems likely that much model building will have to move in the direction of a more thorough microanalytic treatment of individual locational behavior. Closer attention will be paid in the future to the validation of models."

Considering the importance of the subject, it seems an easy prediction that closer attention will be paid to the validation of urban models. The prediction, however, turns out not to apply to the more recent and more widely publicized work of J. W. Forrester in simulating an urban system. We will turn now to a general description of Forrester's efforts.

## "URBAN DYNAMICS"

Forrester's simulation model and results are fully discussed in his book, "Urban Dynamics."[7] Forrester's own general criterion for the scope of an urban model is that it should include those processes necessary to the creation and correction of urban decay. He states that the model "... should show how an area develops from empty land and eventually fills that land with decaying housing and declining industry to produce economic stagnation." The model should then be useful in helping to discover those policy changes that can enable a city to recover from its stagnation phase.

Forrester concludes, or more accurately, starts with the conclusion that urban development is not causally dependent on the larger environment outside the city itself and that the city can control and determine its own economic and social condition. This is a somewhat different assumption than the one embodied in the Pittsburgh model which at least considers "basic" employment in terms of a region before considering its internal effects on the city and its population.

Forrester considers the fundamental urban processes to depend on housing, population, and industry which are the three major components of his model. These, he states, are more fundamental than city government, social culture, or fiscal policy. He likens the aging of a city to that of a person, i.e., it is basically an internal process that can only be hastened or retarded from the outside but is not fundamentally caused by externals. Much general discussion is devoted to this point as the rationale for formulating the model as a closed boundary internal feedback system. By this definition, Forrester does not preclude a flow of people and things from and to the city, but he can omit any cause-effect linkages between the city and what he calls its "limitless environment." If this conception were taken as a convenient mode of simplifying a "first approximation" model, that would be one thing, but Forrester seems to assert it as an article of faith.

That, however, is only the beginning of the "Urban Gospel" according to Forrester. It is impossible to consider, let alone evaluate, his Urban Dynamics without matching your own subjective view of the world with Forrester's. This is unfortunate because reality may not coincide with anyone's personal concepts. While it is generally true that no scientific work is totally objective, an analyst will usually aim for at least an objective test of his hypotheses against real world data. Forrester derives his theory, his model, and even his parameters from naught but his personal view of the world. This kind of uninhibited model building may be a way to fall upon some aspect of truth, but how would one know it and what directions could be provided for either planners or other analysts in the absence of a shred of empirical evidence?

Although the functions and parameters are not validated empirically, the model structure is worthy of interest. Forrester's simulation is composed of nine system levels under his major headings of business, housing, and population. These are as follows:

*Business*

1. New enterprise
2. Mature business
3. Declining industry

*Housing*

4. Premium housing
5. Worker housing
6. Underemployed housing

*Population*

7. Managerial-professional
8. Labor
9. Underemployed

These "levels" represent the variables of interest in describing the state of the city at any point in time. The measure of the variable at the end of each increment in time is the outcome of a dynamic feedback loop. Such a loop in its simplest form is composed of two major elements, a rate and a level. These elements mutually affect one another through two kinds of connections: 1) a controlled positive or negative flow which increases or decreases the level variable, and 2) a feedback of information on the current level, the state of which affects the rate function.

This basic loop concept, rate-flow-level-feedback, is expressed in the more complex context of the nine levels previously described and twenty-two rate functions. This comprises Forrester's model.

The rates are intended to reflect the following:

1. Underemployed Arrivals
2. Underemployed Birth Rate
3. Labor to Underemployed (Downward) Mobility
4. Underemployed to Labor Mobility
5. Underemployed Departures
6. Labor Birth Rate
7. Labor Arrivals
8. Labor Departures
9. Labor to Manager Mobility
10. Managerial-Professional Birth Rate
11. Manager Arrivals
12. Manager Departures
13. Premium Housing Construction
14. Premium Housing Obsolescence
15. Worker Housing Construction
16. Worker Housing Obsolescence

17. Low Cost Housing Program
18. Slum Housing Demolition
19. New Enterprise Construction
20. New Enterprise Decline
21. Mature Business Decline
22. Declining Industry Demolition

It is interesting to note that in Forrester's lexicon "underemployed" means unemployed, unemployable, and unskilled rather than some concept of an individual working below his level of skills or capacity. (It is hard to see how the "unemployable" can be "underemployed.") Forrester also omits and apparently sees no need for a downward mobility rate for Managerial-Professionals, which should be happy news to currently unemployed or underemployed engineers and scientists. In this connection, we mean to suggest that a model's content and even its terminology may reflect the values and biases of its creators.

The 22 rates enumerated above are each further defined as functions of several levels and parameters.

Thus, having created his deus ex machina, it runs, unravels the mysteries of the city, and reveals the word through its "Creator" and "True Prophet," Forrester. The "Word" is to reduce or prevent the increase of "underemployed" housing thereby decreasing the attraction of more underemployed people into the city who will not find jobs and will contribute to the decay process in housing and business conditions. The upward mobility rates and contributing factors will, ultimately, in a decade or two or three or more, serve to decrease the underemployed and the decaying city will move toward recovery.

No suggestion is made that the one or two or three or more decades of temporary inconvenience to the existing poorly housed (but slowly and steadily upwardly mobile) low income people might be mitigated by other ways to attack the problem.

Forrester pleads that government has, before the "Word," been treating symptoms and consequently has been on a predetermined treadmill of failure. Once the cause has been revealed, it can be attacked directly and we are on our way to success. Both causes and solutions, however, are limited to those consistent with Forrester's model which is nothing more than an unsubstantiated theory.

Moreover, in a closed loop system, the state of individual elements are simultaneously cause and effect. We can therefore choose the point at which to try to influence system behavior based on several considerations. These include evaluating system sensitivity, whether or not a parameter is controllable and to what degree and, not least of all, our personal values and evaluation of social benefits or detriments. If the presence of poor housing leads to increasing the number of poor people which in turn increases the spread of poor housing and a decaying business community, and so on in a self-perpetuating negative cycle, we can break into the loop in more than one way. Forrester may choose to decrease housing for the poor while others may choose to concentrate on ways to eliminate or decrease the poverty status of the poor more directly, such as by means of job training programs, rent subsidies, etc.

Other investigators, Richard Muth for one,[8] have used real data to search for causality and potential solutions. In addition to formulating his own empirically derived theory, Muth took the trouble to summarize and test eight other theories of slum formation. But he and the other theorists didn't have Forrester's model.

Perhaps Forrester's most positive contribution was to enliven the dialogue and stimulate others to respond with more designed experimentation and analysis before proceeding to the stage of systems modeling.

## Models and Progress

In our brief review of planning, we have noted its progress from the early colonial focus on physically efficient design and esthetics through a limbo period of development without planning, into the early twentieth century pseudo-planning, later recognition of social aspects of the urban environment, and recent recognition of the need to consider multidimensional complex interactions within a systems context. With this latter recognition of the complexities planners must consider came the hope that computerized models could provide an effective tool for better understanding and dealing with the problems.

For the reasons we have discussed regarding the nature and limitations of models, urban planners have for the most part now arrived at a more realistic perspective, as have military strategists, industrial decision makers, and other earlier triers of models of complex systems. If one's perception of real-world phenomena is imperfect or wrong, incorporating it in a computerized total systems decision model can result in coming to conclusions that are even more wrong, harder to argue with, and more difficult to correct than ever before.

As we've seen, a systems model is a means of extending individual assumptions into broader outcomes: it is not a truth machine. Several questions then remain: under what conditions, if ever, should a computerized systems model be used for deciding or helping to decide public policies and plans? Are systems models useful in any way other than in the direct formulation of plans and policies?

In response to the first question, clearly no planner, however altruistic he may be, would or should relinquish his role to a cleverly programmed computer. It is doubtful that he could do so even if he were so inclined. Aside from questions of the mathematical validity of the functions incorporated in any model, planning cannot be separated from questions of social values, human effects, and therefore the political process. The question then is not whether now or in the future we should utilize computer models as opposed to human judgment in deciding basic public policy questions. The question is whether a model can help us to understand how things work and estimate probable outcomes of alternative actions.

We have seen that as a device to estimate outcomes a model is only as good as its built-in assumptions and inputs. This implies that an estimated outcome should not be accepted as probable until and unless the classical scientific methods and criteria have been applied in developing and accepting the building blocks of the model. If these are in question, a model and its outcomes, however elaborate, only represent another opinion.

Few, if any. large-scale models of complex systems could be cost justified within the above criteria. The process of model building, however, can have another valuable payoff when the planners participate in development. The process requires questioning, analyzing, and understanding the problem in new ways, and hopefully results in the planner being better able to form new creative judgments. There is considerable agreement that this experience is of great value to planners, but again, this payoff is difficult to quantify in terms of a project's cost justification.

For the purpose of producing useful outcomes for current decision making, we must conclude that model building and computer implementation techniques have outrun the theoretical foundations on which models should be built. Their current usefulness in this regard is therefore indirect and peripheral to solving today's problems today.

With regard to the second question, however, we see a longer term role for systems modeling as an integral part of the process of building reliable theory. For simple phenomena, simple models suffice as a mechanism for testing and accepting hypotheses. As the store of accepted theory on simpler phenomena grows, our hypotheses, models, and theories must be structured in terms of increasing complexity. Ultimately, the mechanism for addressing questions of urban phenomena must be defined in a systems context. Many such trial formulations will be needed as knowledge increases. In the near term, micro-models, more limited in scope but richer in detail, seem most likely to foster progress and provide sounder bases for structuring later models of larger scope. Future systems models can then be made up of less questionable individual modules.

Although much of this long-term evolutionary model development is likely to take place at universities, private research institutions and in locales other than government planning offices, the involvement of planners and government personnel will remain an important ingredient. Such involvement will help researchers to retain reality and relevance in their work and will help planners to advance with the state of the art and maintain a perspective on their current activities.

The major part of the resources for this long-term continuing development work can only come from government sources. It can be justified as a long-term investment in scientific knowledge of the increasingly complex urban environment which will continue to affect the majority of people in the United States.

If we can restrain the American propensity for seeking rapid cures after a long delayed recognition of a problem's existence, systems model building will serve as a basic means of carrying out longer term but ultimately more rewarding research.

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