SEVEN MODELS OF URBAN DEVELOPMENT: A STRUCTURAL COMPARISON

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Attempts to develop quantitative models of the spatial aspects of urban development for use as planning tools hardly antedate 1960. Since then, there have been innumerable prospectuses, many serious enterprises, and at least a few substantial accomplishments.

The model-builders—a group that overlaps but does not coincide with the planning profession—claim that their brain-children have present or potential value as planning aids. One of the frustrations of the planner as client is that he does not usually find it easy to judge these claims or to choose among the many alternatives now available for his consideration.

In this essay, I shall try to show how a number of these models relate to each other and to a generally accepted theory of the market for urban land. The undertaking involves some risk of misrepresentation, since only two of the specific models I shall discuss are adequately and finally documented. It also involves some risk of misunderstanding; my analysis by no means exhausts the grounds on which these models may be compared, but focuses on the significance of the variables included and the coherence of the model's formal structure.

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* The RAND Corporation. Since this Conference was convened to review the state of the art of modeling urban development, I have taken the liberty of commenting quite directly on a number of existing models Because documentation of these models is characteristically incomplete and fugitive and the models themselves are in a more or less continuous state of revision, it is quite possible that my information is neither complete nor up-to-date. I have indicated my documentary sources in each case and have tried to avoid reliance on information from other documents in my files which are marked "Not for Publication."

Although I am quite prepared to encounter dissent from my critique of these models, I will be grateful for clarifications or corrections on matters of fact. And no doubt the editor of these proceedings will welcome, as I will, written rebuttals from any who dissent from my interpretations Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of The RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors.

Briefly, I shall argue that an adequate system of interdependence is spelled out by the theory of the market for urban land, the formal structure of which is elaborate but easily grasped. Most model-builders leave out substantial portions of this system in order to reduce the number of variables and relationships to be manipulated. I do not imply that anyone is cheating. The art of model-building is above all the art of simplifying complicated problems. But in choosing a model for a particular purpose, the planner will do well to understand what is left out as well as what is left in.

The following section of this essay presents a theory of the urban land market in paradigm. A paradigm is itself a kind of model. I choose this mode of presentation because it is both adequate to my needs and more readily accessible to readers short on mathematical training. The paradigm provides me with heuristic definitions of a number of important variables and relationships among variables, and it is illustrated with two charts whose features are easily retained for later reference.

In the next section, seven specific models are reviewed in some detail. Each was chosen to illustrate a particular strategy of simplification. In no case is this a "pure" strategy; I speak more frequently of greater or less emphasis on a particular set of relationships than of omission or inclusion. And I must confess being troubled from time to time by a sort of optical illusion in which the foreground relationships of the model reverse values with the background relationships. On the whole, however, I am satisfied with my perspective and hope that I make it convincing to the reader.

In dealing with these models, my attention is confined to their formal structures; I am not concerned with the quality of the data assembled nor the integrity of calibration methods nor the adequacy of such tests as may have been made. My interest in specific variables ends with their conceptual definitions; for my purposes, one "accessibility" measure is as good as another.

Nor have I exhausted the possible dimensions of formal structure. Britton Harris recently drew up a list of six such dimensions,[1] describable either by categorical alternatives or by polar extremes: (a) descriptive versus analytic, (b) holistic versus partial, (c) macro versus micro, (d) static versus dynmic, (e) deterministic versus probabilistic, and (f) simultaneous versus sequential. Although most of these are represented in my selection of examples and are discussed insofar as they relate to my central purpose, my comparisons among models are not systematic on these six dimensions. I have a different axe to grind.

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[1] In a paper prepared for The Committee on Urban Economics of Resources for the Future, Inc., Conference on *Urban Economics Analytical and Policy Issues*, Washington, D.C. January 26-28, 1967. See also Ira S. Lowry, "A Short Course in Model Design," *Journal of the American Institute of Planners*, XXXI (May 1965) pp. 158-166.

THE MARKET FOR URBAN LAND

Urban spatial organization is the outcome of a process which allocates activities to sites. In our society, the process is mainly one of transactions between owners of real estate and those who wish to rent or purchase space for their homes and businesses. These transactions are freely entered contracts, neither party having a legal obligation to accept the other's offer. These elements suffice to define a "market" in the economist's dictionary.

To be sure, there are exceptions to the general rule of the market. Governments exercise the power of eminent domain, although an independent judiciary controls the terms of forced contracts with at least formal obeisance to the standards of the market place. Transactions which are internal to an organization—between agencies of government, divisions of a corporation, or members of a family—are sheltered from the market. Nearly all urban governments impose negative constraints on land use and also levy real estate taxes, both of which may influence a potential buyer's interest in a particular site but do not constrain his freedom of contract.

With exceptions as noted, the market process of transactions between willing buyers and willing sellers determines the spatial organization of urban activities in a very immediate sense. Since models of urban development must reflect the institutional arrangements of our society if they are to reproduce the results, a closer look at the market process will serve as point of departure for the analysis of alternative models The salient features of the process can be vividly shown by paradigm.

Consider a city whose territory is divided into many parcels of land, each of which I shall describe as a site. Most of these sites have structural improvements designed for some particular use. Each site has an owner who is free to sell or lease his property. His potential clients, whether households, business enterprises, quasi-public corporations, or governmental agencies, will be called establishments.

Since I wish to describe a market process over time, I will define a unit of time, the transaction period. At the beginning of each transaction period, every establishment in the city reappraises the advantages of its present site as compared to other sites. Indeed, each establishment explicitly considers the merits of every site in the city and decides what dollar price it would be willing to pay for each. At the designated prices, then, the establishment would be indifferent among locations.

This set of demand prices can be displayed in matrix form, as in Figure 1 The shaded cells in each row of the matrix indicate the initial location of each establishment; note that the establishment sets a price on that site as well as on all others.

Assume also that this matrix is published, available for inspection by the owner of each site. He scans the appropriate column of demand prices to identify the tenant who would be willing to pay the highest price for the use of

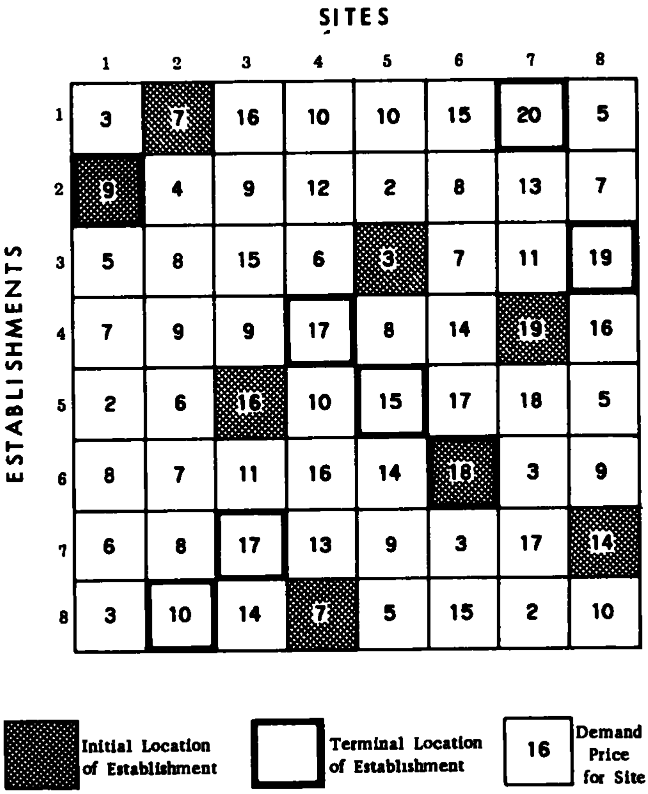

Figure 1. The urban land market: demand prices for sites and locations of establishments.

that property during the coming transaction period. Naturally he deals with the highest "bidder," who may be the present tenant, the owner himself, or some third party. Some sites change hands and some establishments move to new locations, thus modifying the distribution of establishments in space. In Figure 1, the location of each establishment at the end of the transaction period is indicated by a heavy border on the appropriate cell.

This paradigm, which could easily be elaborated to deal with unequal numbers of establishments and sites, illustrates in its essentials the economist's interpretation of the market for urban land. Competition among potential occupants determines the market price of land and each site goes to the highest bidder. Under the simplifying assumptions of the paradigm, there is an unequivocal market-clearing solution so long as no one establishment offers the highest prices for two or more sites. In the latter event, the solution depends on bilateral bargaining between the several site-owners and this particular establishment, with the next-highest demand price for each site providing a floor to each site-owner's bargaining position.

Of course, the paradigm assumes a higher level of calculation and communication than exists in real markets. Few establishments ever make a thorough investigation of the full range of alternative possibilities, and none does so frequently. Except for occasional auctions, real estate negotiations are conducted by offer and counter-offer; an establishment's "demand price" is always a closely guarded secret, and the floor to an owner's bargaining position is unstable unless he knows these prices. Real estate leases do not conveniently expire simultaneously; thus only a portion of all establishments and of all sites are on the market at any one time.

It requires at least a small act of faith to assert, despite these known market imperfections, that the actual allocation of urban sites to establishments is approximately that suggested by the market-clearing solution of the paradigm. But this theory offers a general and reasonably coherent account of the process by which urban land is allocated, and it has no serious intellectual competition—at least among analysts whose background is the discipline of economics.

The existence of a market-clearing solution does not depend on any particular assumption about the sources or pattern of demand prices except as noted above. Whatever method establishments use to decide on demand prices for individual sites, we need know only that they reach conclusions—*i.e.*, that we have definite demand prices to enter into the matrix. But we are not interested in the market process *per se;* we are interested in the spatial distribution of activities within the city, a distribution that changes over time. This interest leads us to ask why different establishments will offer different prices for a given site, and why the same establishment will offer different prices for different sites. We want to know what regularities can be found in the matrix of demand prices, and how these regularities reflect in the market-clearing solution.

The abundant evidence of spatial patterns in our cities suggests a certain consistency over time and space in the evaluation of sites by establishments of a given type. Demand prices are not random numbers In fact, we can with considerable confidence formalize the evaluation function by which they are determined:

$$P^{hi} = f\,(X^h{}_1, X^h{}_2, \ldots; Y^i{}_1, Y^i{}_2, \ldots; Z^{hi}, h = 1,2, \ldots, n)$$

Where h is a particular establishment and i is a particular site, the price P that establishment h will offer for site i depends on a number of characteristics of the establishment $(X^h{}_1, X^h{}_2, \ldots)$, on a number of characteristics of the site $(Y^i{}_1, Y^i{}_2, \ldots)$, and on the location of the site with respect to the locations of other establishments $(Z^{hi}, h = 1,2, \ldots, n)$.

The formal statement is easy, but it is far from easy to identify and measure the relevant X's, Y's, and Z's. If we are dealing with households, for example, both reflection and observation suggest that income, number and ages of household members, and ethnic background are among the relevant X's. As for site characteristics, one would expect the size and shape and topography of the lot, the nature of its structural improvements, and the availability of utilities to be among the important Y's; we might also include microclimate and view, noise pollution, and even historical values attached to the site or the neighborhood. Prominent among the relevant Z's will be the most recurrent travel-destinations of household members—places of work, schools, shopping facilities, and the homes of friends.

These examples suggest both the number of possibly relevant variables and some of the difficulties of classification and measurement. There still remain the difficulties of determining a concrete form for the function which relates these variables to P^{hi}, and of specifying the numerical parameters of the function. These problems are not peculiar to the theory of demand for urban land. Economists have had scant success in giving empirical content to consumer preference functions in any context.

One group of variables in the evaluation function represents the characteristics of the site under consideration. Not all these characteristics are fixed. Raw land may be graded, utilities may be laid on, buildings may be erected, remodeled, or demolished. These actions are taken by site-owners, sometimes to meet their own needs as occupants, often with a view to selling or leasing the site. Corresponding to the evaluation function by means of which establishments appraise sites, we can usefully postulate an investment function by means of which owners appraise the merits of site-improvements At any point in time, the characteristics of a site are given; the owner must decide what improvements, if any, would be likely to raise his revenue by more than his outlay. Such an investment function might be written as follows:

$$E^i_j = g(C^i_j, P_j)$$

In this notation, i is a specific site and j is a specific bundle of site characteristics, some combination of the Y's which we encountered in the evaluation function. E^i_j is the expected gain from converting site i to condition j. C^i_j is the expected cost of imposing the jth bundle of site characteristics on site i, a cost which may well vary with the present condition of the site. P_j is the current market price of sites in condition j. The owner will choose an investment program which maximizes E^i_j; to do so, he must compare P_j and C^i_j for each alternative j.

As in the case of the evaluation function, it is easier to formulate the investment function in such general terms than it is to give it empirical content. Though the number of conceivable combinations of site characteristics which might be imposed on a particular site is infinite, only a cursory knowledge of the market will enable the owner to narrow the alternatives to a manageable set. For a given alternative, costs are readily approximated. The going price for that alternative is easily ascertained if it is currently offered on the market at sites in the geographical vicinity of *i;* the pioneer developer faces greater uncertainty.

The dynamics of the land market thus extend beyond the transaction period of my paradigm. Each period's market-clearing solution is examined by landowners for clues to profitable investments in site-improvements. As improvements are installed on particular sites, establishments reevaluate these sites. The matrix of demand prices is thus altered, and a new market-clearing solution is in the making. The site-owner's expectations of profit from the site improvements he has made may or may not be realized. Typically, too many developers respond to favorable market signals in one period, glutting the market with a particular type of improvement in the next period. Competition among landlords drives prices for this type of site improvement downward in the market-clearing solution.

The passage of time also brings changes in the number and types of establishments seeking locations. Existing establishments also change in their characteristics. households change in size, manufacturers acquire new production methods, retailers shift product lines. So long as some establishments are moving, the pattern of accessibility and contiguity changes for other establishments. These various changes in the argument of the evaluation function would cumulate over time to cause significant shifts in the demand-price matrix even though site characteristics were fixed.

There are also forces which stabilize the market. All other things equal, the existing location of an establishment is usually preferred to alternatives; for in adapting its activities to the characteristics of the site and vice versa, an establishment makes an investment which is seldom recoverable on the market. The search for alternative sites is tedious, transaction costs are high, and a move itself can be expensive. Consequently, few establishments are likely to move during any short period of time.

CLASSIFYING MODELS OF URBAN DEVELOPMENT

From what I have said so far about the theory of the urban land market and the underlying evaluation and investment functions, it must be obvious that, while these provide a useful abstract framework for analysis, the theory could not readily be applied directly to a concrete case—the empirical problems would be overwhelming. Consequently, we resort to models of urban spatial organization. In this context, a model is the operational simplification of a theory which is necessary to fit our limited resources for empirical work. Not all models are explicitly derived from a more general theory; but if they work (and if the theory is correct), it should still be possible to interpret even an *ad hoc* model in terms of this theory.

One simplification which is characteristic of every model I have seen is aggregation. If one were to compile a matrix of the kind shown in Figure 1, it would have thousands of rows and thousands of columns. Since these are models of urban spatial organization, the reasonable horizontal aggregation is

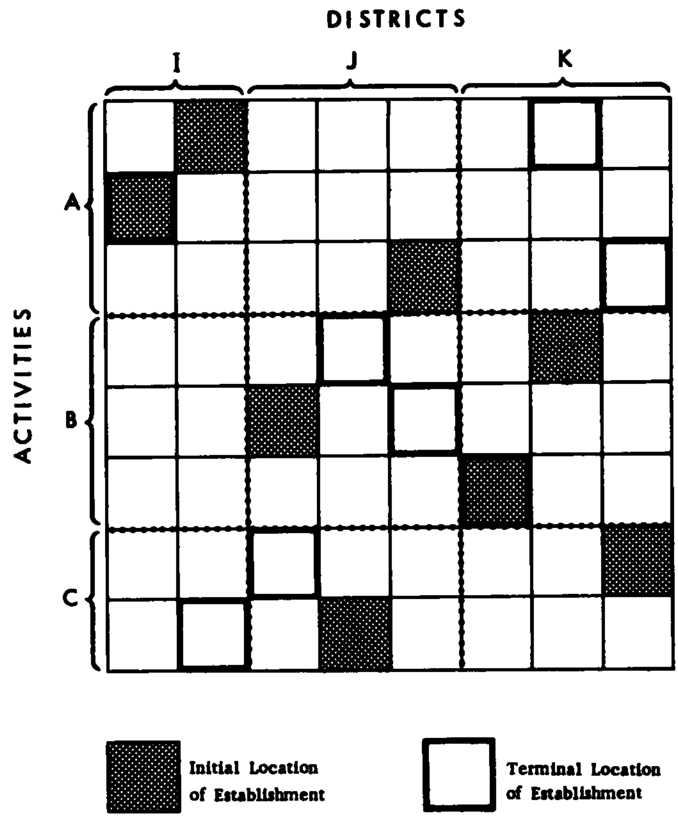

Figure 2. Changes in location and land use during a transaction period.

to group contiguous sites into larger areas which I shall call districts. The best way to group establishments is not so clear, but the usual practice distinguishes households, business enterprises, and government agencies, perhaps with subgroups among these broad categories of activities.[2] The sites and establishments of Figure 1 have been thus grouped to create Figure 2.

My illustration would have been better if I had used a larger matrix to begin with; but even the reduced 3 × 3 matrix of Figure 2 will allow me to make my principal points if the reader will tolerate a rather casual treatment

[2]When more than one characteristic of a site or establishment is relevant to analysis, grouping is a delicate art. If sites are grouped merely on the basis of contiguity, the district is likely to be heterogeneous in terms of other site-characteristics. If establishments are grouped in terms of one trait important to the planner-client (*e g*, trip-generation characteristics), the group may be heterogeneous in other important respects.

of discontinuities. Notice that I have not carried over the prices which were registered in the cells of Figure 1, but have retained the symbols which indicate both the old occupancy of each site and its new occupancy.

I want especially to direct the reader's attention to the significance of the rows and columns of the reduced matrix. Since each column represents a district, the initial distribution of land uses (*i.e.*, by type of user) in each district is indicated by the vertical pattern of shaded cells. Since each row represents an activity, the shaded cells of the row display the initial distribution of establishments belonging to this activity among the several districts. Vertically, the matrix displays land-use patterns; horizontally, it displays location patterns.

The heavily banded cells also form vertical and horizontal distributions, representing land use and location patterns, respectively, at the end of the transaction period. Moreover, we may compare initial and terminal distributions to derive additional patterns. vertically, these are patterns of land use succession; horizontally, they are patterns of migration.

The various patterns interlock, in the sense that each individual pattern implies others. Given an initial distribution of establishments among districts, a pattern of land use is implied. Given also a list of migratory movements, a new distribution of establishments among districts is implied, also a new pattern of land use and a certain pattern of land use succession. Whichever of these patterns we choose to manipulate, the others change by implication.

One clear difference among models of urban development, however, is just this choice. Some models focus on land use patterns, some on location patterns, a few on land use succession or on migration. The choice is important because it provides a focus for the ingenuity of the model-builder. He strives for coherence in one pattern and neglects or subordinates the coherence of others. By this means, he radically reduces the number of relationships which enter into the determination of a solution to the model. Depending on the use to which the model will be put, such an incomplete solution may be adequate; but it is nonetheless incomplete.

In the following pages, I will present concrete examples of these modeling strategies and explore their implications. I will also present three examples which do not fit any of the four classifications given above, one is a hybrid of two strategies, and two approach the complete system of market interdependence, but with significant variations in emphasis. For the reader's convenience, the seven examples are listed below.

1. Land Use: The CATS Model
2. Land Use Succession The UNC Model
3. Location: The EMPIRIC Model
4. Migration: The POLIMETRIC Model
5. Hybrid: The Pittsburgh Model
6. Market Demand The Penn Jersey Model
7. Market Supply: The San Francisco Model

Land Use: The CATS Model

The method used by the Chicago Area Transportation Study for forecasting 1980 land uses in that study area will serve as an example of a land use model. Of the models discussed in this essay, it is the earliest. It has a less formal structure than its successors, and *ad hoc* judgments are introduced at many points in the forecasting process. It is also unique among those to be discussed in that it was seriously used in conjuction with a transportation plan.[3]

The model is built around a strong system of land use accounting for small territorial subdivisions[4] of the study area. For each such district in turn, the future inventory of land uses is extrapolated from the initial inventory according to rules (modified by judgment) specific to the kind of use. Six land uses are recognized: residential, commercial, manufacturing, transportation, public buildings, public open space, and streets. Vacant land is classified as residential, commercial, or industrial, according to its status under local zoning ordinances. Unusable land is also accounted for.

The initial land use pattern of each district is modified in six steps.

1. Specific parcels of land in some districts are designated for conversion to public open space and transportation uses (*e.g.*, a new airport). The designations are based primarily on existing plans of public agencies for such development.

2. Commercially zoned vacant land in some districts is designated for shopping centers and heavy commercial uses. These designations are based on announced private plans and staff judgments

3. Residentially zoned vacant land is designated for residential use. The amount so designated in each district depends on the location of the district and its residential holding capacity at existing or slightly modified net densities. The percentage of a district's holding capacity to be filled by 1980 is defined as a function of distance from the Central Business District, with sectoral and local modifications based on staff judgments.

4. For residentially oriented uses, per capita norms are applied to the estimated 1980 population of each district as determined in the third step. Thus space for streets, local commercial facilities, public buildings, and recreation is set aside in each district.

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[3] My sources are John R Hamburg and Robert H. Sharkey, *Land Use Forecast*, Document No. 32, 610 (Chicago Area Transportation Study: Chicago, 1961); and Chicago Area Transportation Study, *Final Report*, Vol. II (Chicago, 1960), pp. 16-33.

[4] These are "traffic zones" in the original. I will call them "districts" to avoid confusion with "land-use zones" determined by municipal ordinances.

5. Industrially zoned vacant land is designated for manufacturing use. The amount so designated in each district depends on the location of the district and its manufacturing holding capacity. Trends in net employment density in manufacturing establishments, both over time and by distance from the CBD, serve as the basis for 1980 forecasts of such employment density for each district; this projected density, in conjunction with the amount of industrially zoned space, determines the district's holding capacity The percentage of this capacity to be filled by 1980 is defined as a function of distance from the CBD, with sector and local modifications based on staff judgments

6. Since net activity density and acreage in each use have been explicitly predicted for each district, the implied population and employment totals for the district can be calculated. These are summarized for the study area as a whole and compared to independent projections of the area's population and employment. The land use forecast (acreage occupied) is then systematically modified so as to reconcile the implied activity totals with the independent projections.

In terms of Figure 2, this is clearly a column model. The inventory of land uses is projected for each district separately; the forecast is based on that district's initial inventory, its zoning map, and its location. After each column has been filled out, the resulting tableau of land uses is indeed modified by scaling the entries along each row so that they add to a control total. But the model avoids systematic comparisons of districts with respect to their merits as locations for establishments belonging to a given activity group; such comparisons are either highly generalized (distance from CBD) or else embedded in undocumented staff judgments (locations of shopping centers).

In its dynamic as well as its static aspects, land use accounting is much more rigorous than establishment accounting. Thus, there is a fairly explicit account of land use succession within each district, but no account whatever of the origins of new tenants of each district or of the destinations of those who leave.

In summary, the CATS model suppresses most horizontal relationships even at the level of aggregation implied by the reduced matrix of Figure 2. Its implications for the full matrix of Figure 1 are unguessable We cannot say what structure of demand prices is consistent with the solution of the CATS model, nor can we infer much about the evaluation and investment functions which presumably motivate the establishments and land developers of Chicago. I do not offer these observations as objections to the CATS modeling strategy, merely as matters worthy of note. The reader would do well to withhold judgment until we have examined alternatives.

Land Use Succession· The UNC Model

The model of residential growth developed at the Center for Urban and Regional Studies, University of North Carolina, can best be described as a model of land use succession.[5] It is designed to predict the incidence of conversion of rural or vacant land to residential use as the population of the study area increases.

The study area is divided by a rectangular grid into cells of about 23 acres each. The cells in turn are divided into "ninths" of about 2.5 acres, the unit of land development. All previously developed ninths are removed from the inventory, and certain ninths are exogenously scheduled for nonresidential development during the forecasting interval. The remainder are available for conversion to residential use at densities which are determined from zoning laws or master plans.

The UNC program assigns to each cell an "attractiveness" score which is a linear combination of initial assessed value, accessibility to work areas, availability of public sewerage, accessibility to nearest major street, and accessibility to nearest elementary school. For each unit of undeveloped land within the cell, the probability of conversion to residential use during the ensuing forecasting period is proportional to that cell's attractiveness score, and discrete units of development are assigned to cells by random sampling (without replacement) from the resulting probability distribution. The sampling process continues until enough ninths have been developed to accommodate the given increment of urban population.

The manipulation of land uses within each cell is quite rigorously controlled in this model. Net residential densities of each ninth are predetermined, and there is no point in the assignment algorithm at which it is possible to "overdevelop" a cell or to carry inconsistent land use accounts for the cell. Moreover, land use succession is quite explicitly represented by conversion of specific ninths from rural (agricultural or vacant) to residential use.

Oddly, and despite some suggestive language in the text of the reports, the UNC group's extensive research into the behavior of land developers is not reflected in the formal structure of the model. The entrepreneur is certainly not explicitly represented, and one looks in vain for such phenomena as speculative overbuilding or withholding of choice land from the market. "Development" occurs only when households are assigned to a site. Land use succession is governed by demand, not by entrepreneurial decision.

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[5] The evolution of the model to date is described in a series of monographs by F. Stuart Chapin, Jr, Shirley F. Weiss, and Thomas G. Donnelly, under the imprint of the Institute for Research in Social Science, University of North Carolina, Chapel Hill. The principal titles are *Factors Influencing Land Development* (1962), *A Probabilistic Model for Residential Growth* (1964), and *Some Input Refinements for a Residential Model* (1965) See also F Stuart Chapin, Jr., "A Model for Simulating Residential Development," *Journal of the American Institute of Planners*, XXXI (May 1965), pp 120-125.

Although the entrepreneur is invisible, there is an explicit pool of households to be located, and each ninth of a cell is assigned an attractiveness score which is clearly intended to reflect its relative merits as a residential location. But it is not at all clear why the chances of development for each ninth are proportional to its attractiveness. If there are no constraining prices, one would expect the most attractive ninths to be developed first, and the least attractive ones to be developed last. If there are price constraints on residential choice, one would expect the prices to be collinear with attractiveness.

In fact, there is considerable resemblance between the UNC attractiveness scores and the demand prices of my market paradigm. On that interpretation, the UNC scoring procedure is equivalent to filling out a single row of demand prices on behalf of a homogeneous group of households. But the market solution would not be a proportional distribution; indeed, it could not be determined at all without comparing demand prices offered for each ninth by competing user-groups. Since nonresidential urban users have been preassigned to specific sites independently of the ensuing residential development, the only competing users left, presumably, are agricultural. The most likely alternative demand price is the site-owner's (speculative) reservation price.

Whatever the ambiguities of this process, the UNC model does use an explicit evaluation function. Since it applies to a single group of residential establishments, the function's argument does not include establishment characteristics (X's), only site and accessibility characteristics (Y's and Z's). The most recent extension of the model,[6] however, does distinguish nine classes of households on grounds which are not clearly stated; each group apparently uses the same evaluation function, but is permitted to locate within only a subset of the stock of available ninths. These subsets are characterized by particular ranges of zoned density and initial assessed values. In terms of my market paradigm, the revised program fills out nine rows of demand prices, but only one non-zero entry per column is permitted. The remainder of the program operates as described above. Thus, the nine household groups are prevented from confronting each other in the market place.

Like the CATS model, the UNC model abstains from direct comment on the origins or destinations of movers. The implication of the algorithm seems to be that no one moves within the study area, and no one leaves the study area: "The study presently concentrates on the growth areas and new residential development, leaving the handling of decrease areas and renewal processes. . . to be dealt with in later extensions of this research."[7]

Location: The EMPIRIC *Model*

An interesting example of a model with a strong emphasis on locational patterns to the exclusion of other perspectives in the EMPIRIC, devised for the

[6] *Some Input Refinements for a Residential Model*, pp. 14-20.

[7] *A Probabilistic Model for Residential Growth*, p 3.

Boston Regional Planning Project by Traffic Research Corporation.[8] The model is designed to reallocate population and employment among the region's territorial subdivisions as the regional totals change over time and as local changes occur in the quality of public services and transportation networks. The territorial subdivisions are irregular in size and shape and many times larger than the 23-acre cells of the UNC model.

In the reports cited, the model distinguishes two classes of population (blue collar, white collar) and three classes of employment (retail and wholesale, manufacturing, all other). The model is formulated as a set of simultaneous linear equations for each district, one equation for each population or employment variable. However, these equations do not directly estimate the number of households or employees to be assigned to each district at the target date. The dependent variable in each case is the change, during the forecasting interval, in the district's share of the regional total for that activity. After the model has been solved, these changes-in-shares are added into the shares held by each district at the beginning of the forecasting interval, and the revised shares determine the distribution of independently forecast totals for each activity group.

The determinants of each district's change-in-share of a given activity appear on the right-hand sides of the equations described above. They include concurrent change-in-share variables for each other activity and also variables which represent various site and accessibility characteristics of the district (existing activity distributions, quality of water service, quality of sewage disposal service, automobile and transit accessibilities). These forecasts are thus simultaneous in population and employment variables, each change-in-share influencing the others.[9]

Land use accounting plays a very minor role in this model. Apparently at some stage in the forecasting cycle, forecasts of activity-volumes are converted

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[8] My account is based on Donald M. Hill, "A Growth Allocation Model for the Boston Region," *Journal of the American Institute of Planners,* XXXI (May 1965), pp. 111-120; and Donald M. Hill, Daniel Brand, and Willard B. Hansen, "Prototype Development of a Statistical Land Use Prediction Model for the Greater Boston Region," *Highway Research Record* 114 (1965), pp. 51-70. There have been subsequent revisions of the model, not yet documented in quotable form. These pertain mostly to further disaggregation of both activities and territorial units; so far as I know, they do not affect the structural features to be discussed here.

[9] The method used for simultaneously estimating the parameters of all equations should yield regression coefficients that are true partial derivatives. However, the logic of these equations is puzzling. Since each district's population and employment variables are expressed as changes in shares, the fitted parameters fix relationships among these changes in *shares* without regard for the magnitude or even the sign of changes in the total regional volumes of the relevant activities. The fitted equations tell nothing about the relationships among changes in volumes for the activities within a district.

to forecasts of land use volumes, and measures of activity density and holding capacity have been included in various versions of the estimating equations. Since these variables appear in linear combination with others, they cannot absolutely constrain the solution of the equations so as to prevent "overdevelopment" of a district. Since the dependent variable of each equation is in any case a change-in-share of an unspecified regional total, the land-use implications of this model's forecast of activity distributions do not in any significant way constrain the forecasts. In terms of my paradigm, EMPIRIC is *par excellence* a row model: the columns are left to fend for themselves.

Although EMPIRIC's equations solve for changes in the spatial distribution of the elements of each activity group, only net changes are explicit. The model does not comment on the pattern of interdistrict flows necessary to produce these net changes. In view of the casual land use accounting, the model is also silent on the question of land use succession within each district.

There is a formal resemblance between the solution values of the EMPIRIC equations and the demand prices of my paradigm a "score" is calculated for each activity in each district by means of a formula which greatly resembles my concept of an evaluation function. Conceivably, these scores might be interpreted as *changes* in demand prices which are subsequently added into the initial demand prices (base-year shares). But in any case, scores for different activities in the same district are never compared. As with the UNC model, comparisons are horizontal rather than vertical, serving to allocate the establishments of a given activity among districts. I have already indicated the difficulty of finding a market interpretation for this method of allocation.

Migration: The POLIMETRIC *Model*

Studies of metropolitan development usually give some attention to the scant data on intrametropolitan shifts in the location of residential population and employment. They are rarely able, without special surveys, to identify the origins and destinations of actual movers. Because of the expense and technical difficulty of such surveys, the migration strategy for modeling metropolitan development has received relatively little attention.

The best example of such a model is POLIMETRIC, devised by Traffic Research Corporation for application to the Boston Region, but soon abandoned in favor of the EMPIRIC model described above. However, POLIMETRIC was simplified, calibrated, and used by the Delaware Valley Regional Planning Commission for projections of residential location (RESLOC) and manufacturing employment location (LINTA) within the Philadelphia Region as part of the Commission's transportation planning process.[10]

[10] My source of POLIMETRIC is a public but fugitive document: Richard S. Bolan, Willard B. Hansen, Neal A. Irwin, and Karl H. Dieter, "Planning Applications of a Simulation Model," a paper prepared for the New England Section, Regional Science Association, Fall Meeting (Boston College, October 1963). The name POLIMETRIC is not used therein, but the model is so known to the trade.

POLIMETRIC is formulated as a simultaneous set of nonlinear differential equations, one for each activity in each district. In each such equation, the dependent variable is the rate of change over time in the level or volume of the specified activity. This rate of change consists of a growth component, an inmigration component, and an outmigration component. An activity is assumed to grow at the same rate in all districts, the rate being determined by independent forecasts for the region as a whole; redistribution occurs only through interdistrict migration The inmigration component is the sum of all movement from other districts of the region. The outmigration component is the sum of all movement to other districts of the region [11]

The heart of the model, then, would seem to be the estimation, for each activity, of a square matrix of migratory movements between each pair of districts. In fact, this matrix is suppressed. The operational form of the model expresses the dependent variable of each equation (*i.e.*, the rate of change in activity-volume in a specific district) as a function of the regional growth rate for the activity, the current volume of the activity in each district, the effective area of each district, the difference in desirability of the subject district and each other district, and the general mobility of the activity.[12] These are the relationships actually to be calibrated; the migration variable is simply a theoretical convenience from which the model-builder derives an appropriate functional form for the operational equations.

Land use accounting is suppressed in this model. The only land use variable which enters the system of equations is effective area, which may vary by district but would be fixed over time. Development densities are unspecified. However, the authors do suggest a supplementary monitoring routine which "has at its disposal a table of [district] holding capacities" for each activity, and uses these entries to forestall overdevelopment of any district.

The formal structure of the model has an elegant symmetry and simultaneity which is partially eroded by its confrontation with normally intractable

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For the Philadelphia application, see David R Seidman, "A Decision-Oriented Model of Urban Growth," paper presented to the Fourth Annual Conference of the International Federation of Operations Research Societies (Boston, 29 August —2 September 1966), and "A Linear Interaction Model for Manufacturing Location," mimeographed document (Delaware Valley Regional Planning Commission, January 1964).

[11] This definitional relationship is repeatedly presented in my sources as a mixed differential-difference equation; the rate of growth of the subject activity is written *(dR/dt)*, while its components are defined as magnitudes per unit period of time —in effect, first differences of activity-variables As it turns out, this curious identity is not used in the calculations

[12] "Effective area" is undefined in my source, but it seems to mean all usable space, whether or not occupied "Desirability" is defined as a weighted sum of the intensity (gross density) of each activity in the district plus a measure of the district's accessibility to other districts The "mobility" term is not a variable, but a constant fitted for each activity.

data in the Philadelphia application. Like EMPIRIC, this is emphatically a row model, but it deals at least implicitly with interdistrict movements of the elements of each activity, while EMPIRIC is concerned with net shifts only. These interdistrict movements are premised on direct comparisons of the "desirability" of alternative locations for each activity. Although the desirability scores have a substantive resemblance to both the attractiveness scores of the UNC model and the demand prices of my paradigm, the authors deny any motivational hypotheses [13]

The net effect of the algorithm is to shift establishments from districts of below-average desirability to districts of above-average desirability; each activity has its own standards of desirability, and scores for different activities within a given district are never compared. If there is a market interpretation of this model, it is (as the authors cheerfully concede) buried in the parameters rather than in the formal structure.

A Hybrid: The Pittsburgh Model

My own contribution to the inventory of urban models was developed in the course of a study of the Pittsburgh region, and is calibrated to data drawn from that study.[14] Although it could be described without great injustice as a location model, it has a stronger system of land use accounts than the preceding two examples, and the land use implications of each activity-distribution serve as constraints on the distribution itself.

The model allocates three classes of retail employment and one of residential population among mile-square tracts of the urban region. The resulting pattern is claimed to be uniquely consistent with a given spatial distribution of basic employment. It is thus an equilibrium model with no time dimension.[15]

The model is formulated as a series of distributional algorithms, one for each activity In the algorithm for residential distribution, each tract is assigned a score which reflects its accessibility to places of employment. A pool of households (whose number is consistent with total employment in the study area) is distributed among tracts in proportion to these scores. A maximum-density constraint, derived from the land use accounting system, limits the number of households which can be assigned to a specific tract, given the residential space available.

[13] "There are no assertions with respect to maximization of profit, seeking of low-cost locations, or other motivational hypotheses The model is quite analogous to traditional population analysis which asks not why births and deaths occur but simply observes that they do and seeks to determine if there are any statistical regularities to form a basis for prediction " (*Ibid.*, p 17.)

[14] Ira S Lowry, *A Model of Metropolis*, RM-4035-RC, The RAND Corporation, Santa Monica, 1964

[15] A time-phased version of the model was developed by CONSAD Research Corporation. See John P Crecine, "A Time-Oriented Metropolitan Model for Spatial Location," CRP Technical Bulletin No. 6, Department of City Planning: Pittsburgh, 1964.

Retail employment is grouped into three activities, the number of employees in each being determined by productivity norms and the size of the regional market (number of households). The three groups correspond roughly with conventional hierarchical clusters—neighborhood, local, and metropolitan—which are functionally distinguished by the increasing territorial "range" of their markets.

For each retail activity, in turn, tracts are individually scored for their accessibility to consumer markets, *i.e.*, to residential population and employment centers. The appropriate total of retail employment is then distributed among the tracts in proportion to these accessibility scores, with the proviso that the number of employees assigned to any one tract must be either zero or greater than a specified minimum.

The novel feature of the algorithm is an iterative process for achieving consistency between the spatial distributions of retail employment and residential population, each distribution entering (along with the distribution of basic employment) into the accessibility calculation for the others. The atemporal structure of the model naturally suppresses all questions of land use succession or internal migration of establishments.

Throughout the iterative sequence, the model carries a running account of land uses in each tract, beginning with fixed amounts assigned to exogenously located basic employment and fixed amounts of unusable land. Retail uses have next priority; each class of retail trade absorbs land at a fixed rate per employee so long as additional space is available; thereafter, retail densities automatically rise to accommodate the assigned number of employees.

For most tracts, however, the assigned complement of retail trade absorbs only a small fraction of the available land. The remainder is then classified as residential. In effect, households are the residual claimants of space in each tract. Residential density is a free variable which reflects rather than controls the household assignment up to the point at which the maximum-density constraint is violated.

The text of the report goes to some trouble to develop a market interpretation of the distributional algorithms without explicitly invoking land prices. In the case of retail trade, however, the effect of the algorithm is really to deny the relevance of land prices to retail location. Assuming that the accessibility scores indicate the relative volumes of business that can be done in each tract, the assignment of retail employment to tracts simply equalizes the volume of business per employee for all tracts; the assignment of retail land equalizes the volume of business per unit of space except in those few tracts where the assigned employment could not be accommodated at standard densities.

The case for a market interpretation of the method of residential distribution is somewhat better. Residential densities are not predetermined in the Pittsburgh model as they are in the CATS and UNC models The accessibility score of a tract determines the number of households to be assigned there, and the average size of a residential parcel in the tract is jointly determined by this assignment and by the amount of residential space available after higher-priority uses have been accommodated. Residential density thus varies directly with the accessibility of a tract to places of employment; among tracts with equal accessibility scores, residential density varies inversely with the amount of space available.

These two results are generated by the model, not imposed upon it. The first result is clearly consistent with a market allocation of land given the assumption that accessible space commands a premium to which households adapt by living at higher densities. The second result is ambiguous; it would be clearly consistent with a market allocation only if accessibility fields did not overlap.

A striking feature of this model is its concentration on spatial relationships among different activities, to the exclusion of most other variables which seem pertinent to the market process. Households have no dimension except number; retail activities are only slightly more differentiated. Available space is described only by quantity and location; its historical development, as reflected in lot size or existing structures, is ignored. Virtually the entire machinery of the model is given over to the calculation of accessibility measures. The solution of the model is explicitly a locational equilibrium, constrained only by the availability of space.

Market Demand: The Penn Jersey Model

The builders of the models so far discussed were of course aware of the existence of a market for urban land, but their stratagems are designed to avoid its explicit representation. We now turn to a model which undertakes this representation, although only for the market in residential land. I have characterized it as a demand model because it limits the functions of landowners to choosing among prospective tenants, entrepreneurial behavior is suppressed.

The Penn Jersey model was originally formulated as a forecasting device for the Penn Jersey Transportation Study. Although the model was eventually abandoned by that Study in favor of other approaches, its development resumed at the Institute for Environmental Studies, University of Pennsylvania, under the guidance of its steward at Penn Jersey.[16]

In its first incarnation, the model was intended to link with other models dealing with non-residential land and activities The operations of the various

[16] My direct sources are John Herbert and Benjamin J. Stevens, "A Model for the Distribution of Residential Activities in Urban Areas," *Journal of Regional Science*, II (Fall 1960), pp 21-36; Britton Harris, *Linear Programming and the Projection of Land Uses*, P J Paper #20 (Pennsylvania Department of Highways: Harrisburg, no date), Britton Harris, Josef Nathanson, and Louis Rosenberg, *Research on an Equilibrium Model of Metropolitan Housing and Locational Change*, and Britton Harris, *Basic Assumptions for a Simulation of the Urban Residential Housing and Land Market* (Institute for Environmental Studies, University of Pennsylvania: Philadelphia, both dated 1966).

models were to be sequenced so as to provide comprehensive forecasts of activity distributions and land uses within the region under study, distributions which were sensitive not only to changes in regional aggregates but also to changes in the transportation network. In the model's current development, its transportation features have been retained, but distributions of non-residential activities are treated as independent parameters of residential distribution. The solution of the model is an atemporal equilibrium allocation of households to residential sites.

The data requirements of this model far exceed those of any of the models so far discussed. It calls for an inventory of households cross-classified by incomes, patterns of consumption preferences, and patterns of daily movement; and an inventory of all residential sites in the region, grouped into districts such that sites within a given district are homogeneous with respect to size of lot, type and quality of structure, and neighborhood amenities. For each district, accessibility to alternative destination-sets (the sets reflecting alternative patterns of daily movement) must be calculated.

These data are entered as arguments of an evaluation function similar in form to that previously presented in this essay. Although the grouping of households and sites implies some repetition of entries, in principle the Penn Jersey model calculates the complete matrix of demand prices suggested by my paradigm (Fig. 1). The model then seeks the market-clearing solution which is interpreted as the "equilibrium" assignment of households to residential sites.

The solution is found by a linear program which assigns households to sites so as to maximize aggregate "rent-paying ability" of the region's population. This quantity was originally defined for an individual household as the household's budget allocation for jointly consumed housing and transportation minus the cost of obtaining these items in a given district if sites were free; in other words, it is the budget residual available for land rent. For a given pattern of daily travel, it is assumed that travel costs will vary with residential location. The cost of a dwelling unit which meets the household's standards would vary with the character of existing structures in a given area. Obviously this cost would be least when the appropriate housing is already in place, but, in principle, an existing structure could be remodeled or replaced. Thus the investment calculation attributed in my paradigm to land-owners is here represented explicitly, but attributed to households evaluating sites.

In the current version of the model, this investment calculation has been suppressed. "Rent-paying ability" is replaced by "bid rent," a budget residual covering the entire residential package of site and structure (but not the cost of transportation), and households are not permitted to tamper with the given inventory of dwelling units. This modification was in part a response to certain mechanical difficulties in the linear program which threatened the integrity of the solution. Linear programming, an algorithm designed for continuous variables, does not readily cope with an assignment problem involving groups of households and groups of residential sites.[17]

An assignment of households to residential sites which maximizes bid rents is mathematically equivalent to the process by which the market-clearing solution was found in my paradigm; the reader can readily test this equivalence in the example offered by Fig. 1. Discussions of the Penn Jersey model have been much plagued by interpretations of this algorithm as an "optimizing" procedure. Depending on the reader's taste in welfare theory, the market-clearing solution may be endowed with social values, but surely these values do not derive from the algebra by which the solution is identified.

Designing a linear program appropriate to this assignment problem has proved difficult Only recently have the architects of the model come to grips with an even more intractable problem, that of formulating and calibrating an evaluation function. This function is necessary to generate the matrix of demand prices; the linear program comes into play only after the matrix is available.

For the linear program, grouping households and sites is a means of reducing the assignment problem to dimensions manageable by present-day computer storage. For calibrating the evaluation function, grouping is essential to the statistical identification of preference structures, while selection of appropriate grouping criteria presupposes considerable *a priori* knowledge of these structures. It is not easy to break into this circle. The statistical identification of preference structures is the focus of current research on the Penn Jersey model.

With respect to that portion of the urban land market involving households and residential space, the Penn Jersey model closely approximates my land-market paradigm. (Indeed, that paradigm's construction was considerably aided by Herbert and Stevens' conceptualization of the assignment problem.) Within these limits, both row and column controls govern the allocation of a given pool of households to a given stock of sites. Because the solution is an atemporal equilibrium, it cannot comment on either the patterns of population movement or the incidence of land-use succession en route to equilibrium.

Market Supply The San Francisco Model

My final example is the model developed for the San Francisco Community Renewal Program by Arthur D. Little, Inc.[18] It is intended as a tool for ana-

[17] The issues are too complex for exposition here, but compare Herbert and Stevens, *op. cit*, with Harris, "Basic Assumptions ," especially on the use of "subsidies" as a variable in the original model

[18] My sources are Arthur D Little, Inc, *Model of the San Francisco Housing Market*, San Francisco Community Renewal Program, Technical Paper No. 8 (January 1966); and Ira M Robinson, Harry B. Wolfe, and Robert L Barringer, "A Simulation Model for Renewal Programming," *Journal of the American Institute of Planners*, XXXI (May 1965), pp 126-134.

lyzing the impacts of various public programs—zoning projects, public housing, rent subsidies, mortgage guarantees, etc —on the housing stock of the city and its utilization. Given a time-phased program of public actions, the model provides biennial forecasts of construction and demolition, of changes in the physical condition of the standing stock, and of rent-levels and occupancy rates for its various components.

These components are numerous Dwelling units are cross-classified by type of structure, tenure, number of rooms, physical condition, and type of neighborhood—more than 1100 combinatorial possibilities, although not all are actually represented in the inventory at a given time. The characterization of the resident population is equally elaborate. Households are cross-classified by size, stage in family cycle, color, and income, for a total of 114 types. An independent population forecast is required to provide this detailed inventory to the model at two-year intervals

At the beginning of each biennial forecasting cycle, the model is instructed to match this population with the stock of housing inherited from the preceding period. Normally, the attempt will be unsuccessful, in the sense that not all households can be assigned to suitable housing and not all housing units will find tenants. These discrepancies are noted as market signals which cause landlords to alter the physical condition of their properties, raise or lower rents, build new units, or demolish old ones. These events reflect as changes in the housing inventory reported for the end of the forecasting period.

For each household group, the model-builders provide a list of 50 housing types in order of preference by that group. It is not altogether clear what "preference" means in this context, but the list reflects, in a complicated way, the relative frequency with which each housing type was occupied in 1960 by the specified group.[19] From similar empirical sources, a range of rent-budgets is calculated for each household group, representing the maximum and minimum (!) prices that members of that group would be willing to pay for housing of any kind.

[19] Robinson, *et al*, say, "The preference list is in order of priority so that the first space type (including location) represents the first choice of living space for a household type The space types listed will in general be those for which the people in a particular kind of household would normally search and make their needs felt through real estate agents " ("A Simulation Model . ," p. 130). Construction of the preference list from 1960 Census data is explained in Technical Report No 8, pp. 28-29, but the account is garbled, I think, by misplacement of two paragraphs on p. 28

Both sources imply that the household's budget and the market price of each type of housing, as well as the physical qualities of the housing unit and its neighborhood, enter directly into the preference ordering. If so, the list is improperly used in the model, for it is there treated as though it reflected "pure" preferences for housing qualities, unconstrained by budgets or prices.

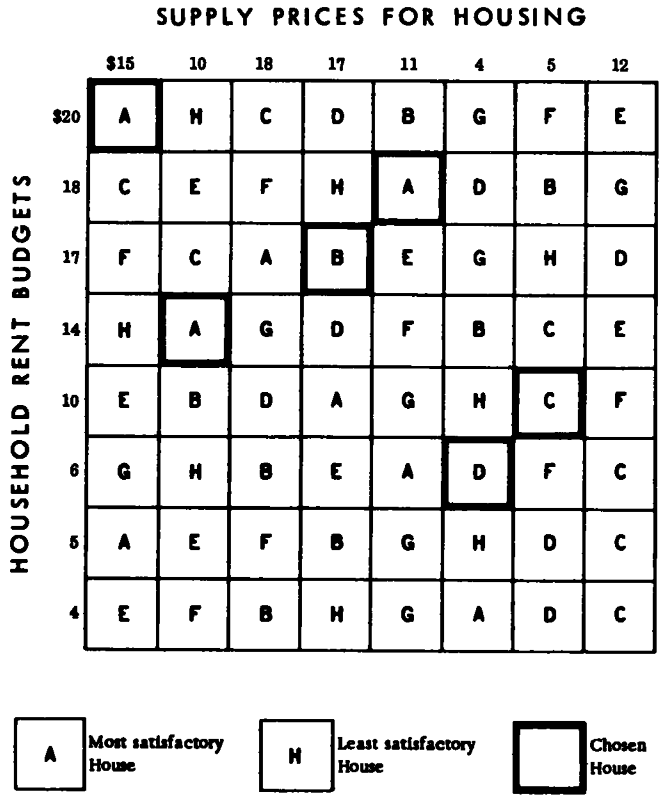

Figure 3. A model of the housing market: household budgets, housing preferences, and supply prices.

The assignment process, somewhat simplified, can be illustrated in a way that clarifies its relationship to my paradigm of the land market. In Fig. 3, each column of the matrix represents a single dwelling unit, and each row a single household. The numbers across the top margin are the prices at which the owners of each dwelling offer their property on the market. The numbers down the left margin are the amounts budgeted by each household for rent. Note that the households are arranged in descending order of prosperity, as indicated by the sizes of their rent budgets.

Households differ in their opinions of the available alternatives. The preferences of each are shown by letters of the alphabet, with A as the most satisfactory alternative, and H as the least satisfactory. In this model, the household selects the dwelling, rather than the landlord selecting the tenant. The most prosperous household has first choice; among those dwellings that are within its budget, it chooses the one which ranks highest on its preference list. With that alternative eliminated, the second household makes its choice, and so on. The results of these choices are indicated by heavy outlines on the appropriate cells of the matrix.

This procedure does not ordinarily result in a market-clearing solution. In the illustrated case, the $18 house and the $12 house found no takers, while the $5 family and the $4 family found no homes within their budgets. In the San Francisco model, these discrepancies set off a chain of events which move landlords and home-seekers toward a market-clearing solution. After examining the market to see what changes could be made either in their properties or in their asking-prices to gain tenants, the owners of the $18 and $12 houses calculate which of several alternatives would be most profitable.

The model-builders have provided a number of rules for landlord responses in particular situations. In general, these rules reflect the sort of calculation suggested by the investment function previously proposed. Structural modifications and rent-changes are recorded in the housing inventory along with physical deterioration due to the passage of time. The "solution" of the model is the state of the inventory and the pattern of rents after these events have been recorded.

Of course, the actual simulation proceeds at a somewhat higher level of aggregation than the illustration suggests; the rows are household groups, and the columns are housing categories. Within each housing category, the unit of account is the "fract," a two-acre parcel [20] containing the appropriate number of units for housing of a given type, and located in a particular district of the city. Households, however, do not choose locations in the geographical sense; they choose a housing category, and the particular fract to which they are assigned is a matter of chance.

Indeed, a notable feature of this model is its neglect of accessibility, a variable which is prominent in every other model we have reviewed. Neighborhood accessibility could easily be added to the characterization of the housing types, and this was apparently contemplated at one stage of model development. But it would seriously complicate the already ambiguous scheme for ranking housing preferences, and, in the compact city for which the model was developed, accessibility differentials are not large.

Within their limited scope, the model's land-use accounts are rigorous. The amount of space available for residential uses and the initial details of these uses are given; the remainder of the city's land is apparently excluded from the accounting system Within the residential sector, land-use changes are faithfully recorded for each two-acre fract in each district, so that both its current status and history of change are available to the user of the model.

Establishment accounting is more casual. The number and types of households in the market during each forecasting cycle are externally specified, without identifying previous place of residence. Not all households need to be

[20] The fract is merely a unit of account Its location within a district about the size of a Census Tract is unspecified, and the dwelling units it contains need not be contiguous in space

located by the model and the disposition of those who fail to find a suitable home within their budget is left vague. Their function is fulfilled when they have registered their unsatisfied preferences; landlords may or may not respond to accommodate them, depending on the profitability of doing so.

CONCLUSIONS

The foregoing section of this essay at least establishes that a variety of modeling strategies are available to anyone seeking to represent or forecast the process of urban development. But surely there are more profound lessons to be learned from these comparisons.

I have deliberately avoided the question probably of most immediate interest to my readers: How well does each model work? I have avoided this question because I don't know the answers in each case and have little hope of finding them. The authors of the San Francisco model say bluntly, "The accuracy of the Model ['s forecasts] cannot be determined with presently available data." This statement would apply with little qualification to the other six models reviewed.[21]

In lieu of this question, I offer another which might help to evaluate a particular model: How well should it work considering those aspects of the market process which are ignored or subordinated in the model's structure? Suppose the model were provided with accurate data and the parameters were fitted by exemplary statistical procedures: Does it capture enough of the structure of the market to reproduce market results? Do the relationships which form the structure of the model appear to be consistent with market theory, even if crude in detail? If some pertinent factors are not explicitly present as variables, can we believe that they are implicitly represented by fitted parameters which are fixed over time? Is the accounting system sufficiently rigorous to guarantee internal consistency of the model's solution? If these questions cannot be answered affirmatively, we have grounds for skepticism as to the soundness of the modeling strategy.

The reader is of course entitled to object that the theory of the market, as presented, is itself open to question. I would agree in principle, although I would ask for a bill of particulars. At the same time, I would point out that the authors of every model in my collection pay at least casual obeisance to this theory. Their strategic simplifications seem to derive not from the conviction that the theory is wrong, but from the more reasonable premise that its literal translation into a tool for forecasting or program analysis requires data which are not practically obtainable.

The force of this point is illustrated by the two models which can be fairly said to try this translation. Seven years after its engagement, the Penn Jersey model is still not married to data. The San Francisco model is on its honey-

[21] See Lowry, "A Short Course . . ," pp. 164-165, for an account of the inherent difficulties in testing these models

moon, and I wish it *bon voyage.* In idle moments I have tried to imagine the expression on the face of the staff demographer when he was asked to contribute, for each biennium of an 18-year forecasting interval, a prediction of the numbers of households in each of 114 socio-economic categories

One's evaluation of a modeling strategy cannot, however, be dissociated from the purpose for which the model is built. If land-use forecasting at a level of detail adequate for transportation planning is the sole objective, and if the transportation plan does not contemplate any radical change in either the general ease of movement within the urban area or the relative ease of movement in its various parts, one could do much worse than use the CATS model. But this model does little to enlarge understanding of the spatial organization of the city, nor does it help us evaluate alternatives of land use which might be achieved through public policy.

At the other end of the spectrum stands the San Francisco model—of dubious value for literal forecasting, but immensely educational in other ways, especially as a means of experimenting with public policies whose consequences cannot easily be imagined outside some detailed context of implementation. In contrast to the CATS model, the San Francisco model has the potentiality of enriching the user's understanding of his problems with every repeated run under slightly changed assumptions.

The sequence in which the seven examples are presented is not strictly linear in transition between these polar extremes, but the general drift is clear. As the ease with which a model can be used for forecasting diminishes, its educational potential increases. This judgment must be qualified by an assessment in each case of the care with which the data are handled. Such an assessment is not provided in this essay because it is not particularly relevant to the usefulness of a model outside the hands of its present custodians.

COMMENTS

Brian Barber, *Metropolitan Area Planning Council, Boston*

I would like to say that I welcome Jack Lowry's type of paper because we in public agencies are interested in seeing to what extent the work we are doing conforms to theory. It is not a principal concern; we consider it more of a restraint. I know that in the EMPIRIC model, with which we have been working, there are economic and social principles which guided development and calibration of the model. For example, we think that we can see something like social climbing in the patterns of population distribution by income groups; and I would like to compare a sociologist's simplified theoretical construct and the findings of our model.

Public agencies have a production-oriented point of view; deadlines are very important to us For this reason, conformance to theory is a secondary consideration University groups have another point of view. I think each should be encouraged provided that each group is aware of, and sensitive to, the requirements and work of the other. I think that the development of many models in various public agencies (even *ad hoc* temporary ones) is a very healthy circumstance. I would like to see this trend continue until something like an authoritative approach and technique emerges.

In the short run, most agencies will probably be limited to only one model. In this case there will be a tendency to choose the kind of model that will permit the agency the most options. While they will be interested in questions of theory and reliability, agencies will be more interested in the kinds of different jobs the model can do. Agencies are interested in using models to predict, to simulate, to conduct *ceteris paribus* tests, and they want to introduce as many realistic types of constraints in their tests as possible. Therefore, I would predict a tendency for agencies to choose a model which employs many variables in spite of the serious data measurement errors and their consequences which Bill Alonso covered in his paper. This problem would be a secondary consideration, in terms of the questions that agencies are expected to answer. Even if you have low reliability in your models, you might take the chance that you could come up with the right answer.

There are various kinds of payoffs for public agencies in modeling that I think one can measure, at least in a qualitative way. One of these is propaganda value. I foresee a situation in which a model would serve as a staff-unifying device. Land use forecasts are basic to many of the studies that planning agencies do. A common set of forecasts prepared with a model all parties had agreed to, would be one way of unifying staff work. I do think that the dominance (in a technical sense) within an agency of a particular type of model might be a disadvantage. I particularly see this happening if we tend toward design models. Basically, the problem is that simplification is required for modeling, while all factors have to be considered for planning studies and proposals. We have found that the model we are presently using influenced greatly the kind of planning work that we are able to do. We have acquired quite a bit of information about the policy variables that we are able to manipulate and to test systematically. We have been accused by our lay policy groups of dealing with too narrow a scope of problems, but because of time and money constraints, we have to gear everything to the capabilities of this model.

It is also possible with a land use model to do plan evaluation work on the question of ordinal ranking of plan alternatives. If wide enough forecast differences in the alternatives can be found, and the plan alternatives can be ranked ordinally by plan performance measures, perhaps a greater range of errors can be accommodated. Plan evaluation criteria and their use in developing and using land use models should be mentioned. This is an issue which has been raised in almost every session. I think that the development of urban systems modeling has proceeded much faster than the whole field of goal formulation and quantification, selection of objectives, and plan evaluation measures. This has been rather unfortunate because this question of goals introduces additional criteria which can be of use in designing a model. Perhaps the area of modeling urban systems is more interesting than the problem of establishing planning goals. I do not quite see why, but I would strongly urge that the problem of goals be explored intensely and that it receive at least equal priority in the short term with such other research areas as design models, applied models, and so forth.

On the other hand, urban systems models can contribute to the plan evaluation process. We have done this to some extent with the EMPIRIC model, We think we are able to judge some features of the plan alternatives objectively. I think the decision-makers are more confident about these outputs than the staff is. When the decision-makers see results such as property loss or employment loss, they translate the results into terms of benefits and costs from their own internal calculations. Staff people seem to feel that they need to have some more formal procedures to do this.

More specifically, I would like to comment on Lowry's remark about density being a free variable in what he calls row models. I am curious about what the term "free" might imply. In the EMPIRIC model (a row model) we have kept these column totals in mind, although as he points out it is done via monitoring routines. The densities we used are not completely free in the sense that we just let them fall where they may. We use preconceived, planned densities or forecast densities that are derived either from a plan or from existing patterns. I am very much in favor of using planned densities that are external to the model. I think they provide a real bridge between the traditional urban land use designers and the model builders. We use the planned densities, and after we have done our accounting we find that we do not have to adjust density significantly in order to keep zones from filling up or from losing too much.

Finally, I would like to comment on what was said about the idea of using market clearing procedures in a land use model. Having a model not directly developed from and dependent on market clearing theory makes it more amenable to the kinds of possible adjustments and manipulations required by non-market clearing public actions, *e.g.*, urban renewal. We had to do this very extensively because there is a large urban renewal program under way in Boston. It was very useful to be able to put these predetermined renewal decisions directly into the whole forecasting procedure without upsetting the basic logic and elegance of the model.

One further note. We are in the position now of having had some operational experience with the EMPIRIC model. It has gotten on the critical path in the transportation study, and we have used it to do some production forecasting. This puts us in the position of being able to make some good, management-type estimates of future use of the model. For example, I have just been working out a work program for a future study employing the model. It is a 15-month work program in which I have been able to make some reasonable estimates of time and manpower requirements for use of the model. A

PERT schedule to which I think we may be able to hold has been developed. We are by no means at the point of being able to look at land use forecasting as a routine job, but it is likely that in a few years it will be routine.

ALAN BLACK, *Tri-State Transportation Commission*

First of all, I am going to address myself to Jack Lowry's theory of the urban land market. He asked for specific objections to it, and I am going to state the ones that I have. Some of the difficulties, although not all of them, perhaps come from the particular numbers that he put in the illustration that he gives in his paper. I would argue that in such a matrix many of the cells would have either zeroes or negative values. There would be many cases in which an establishment would not move to a new site, even if it were given that site free. There is a considerable moving cost involved which generally tends to encourage the firm to stay where it is, and Lowry does acknowledge this at the end of his discussion. I would say that for each of the alternative sites the moving cost should be subtracted from the demand price.

I question some of the demand price argument of this paradigm. I do not think that a firm wants to pay demand price. The firm wants to pay as little as it possibly can for a site, and if it decides that it wants a particular site, it will offer only slightly more than its competition in bidding. For example, establishment No. 3 has a demand price of 19 for site 8, but this establishment would not actually pay 19 for this site. I say it would pay 17, because the next highest bid is 16. The demand price essentially indicates a break-even point for each establishment—the point at which it makes no profit or the profit is at some fixed level.

I would argue that each firm wants to maximize its own profits, and thus will try to attain the lowest possible site price. Each firm would select that site which maximizes the difference between its demand price and the price it actually has to pay for the site. Just how this would work out in a matrix, I cannot really say, but it would be more complicated than what is given here. In general, the matrix demand price is only indirectly related to the way in which sites are allocated. Perhaps all the models are based on this urban land theory, but I do not think it is a very good representation of how the land market works.

I guess I am an anti-taxonomist, because my reaction to this paper was that I did not see a great deal of value to this classification of models. The particular model Lowry describes with which I am most familiar is the CATS model. From his description I had a little trouble recognizing it. He says that this is clearly a column model in which there is a calibration of row totals. My own particular interpretation of it is that it is a row model in which there is a careful accounting of the column totals. I am not sure who is right, but this kind of argument is not very productive.

The one classification that would interest me would be the old "plan versus prediction" dichotomy, because in my current work I am interested in developing a land use plan rather than a projection. Lowry really did not go into this, and I could not tell which one of these models would be useful in making up a plan in which you could plug in some kind of planning decisions, although the San Francisco model does have building codes and zoning requirements in it.

DAVID R. SEIDMAN, *Delaware Valley Regional Planning Commission*

I have one point of information concerning Lowry's paper. We have constructed the RESLOC model which is a transformation of POLIMETRIC which takes the original simultaneous differential equations apart. It makes an exponential function into a piecewise linear function which represents migration from less desirable to more desirable districts, but not vice versa; the desirabilities are a linear combination of variables weighted by parameters. Thus we have had some experience with that kind of migration model.

Now I would like to state the several conclusions I have reached in constructing an operational forecasting model. These are stated as rules proposed as part of a set of standard operating procedures for anyone setting about the construction of an operational land use model. These were distilled out of five years of effort in the construction of the Activities Allocation Model at the Delaware Valley Regional Planning Commission. The rules are stated succinctly for the sake of brevity; because of this they may imply a greater conviction than is intended for them. Several of these statements are in fact still controversial, such as those in items 12, 13, 15, and 16. One purpose for asserting these as well as the less controversial items is to generate greater discussion. There has been an unfortunate tendency to ignore such tactics in favor of discussing the grander strategies of modeling theory—unfortunate because these tiresome tactical details can lose in the field the battle won in the war room.

As employed in the following paragraphs, a research model is one whose prime purpose is to provide a better understanding of the urban system and the process of location and land use; an operational model is one whose prime purpose is to provide conditional predictions for planning purposes.

Administrative Strategy

1. Research models should be "off line" completely. The time has come to call research *research*. In the earlier days of model-building, the only possible way to obtain funds for such modeling efforts was in the name of a planning process. Now, however, more funds are being made available for research and these should be used instead.

2. The operational models being developed should have reliable back-up procedures available for them if there is any doubt about their being fully operational in the required time. Furthermore, the management must be willing to go to these back-up procedures as soon as the schedule is threatened. Mod-

els have gained a very bad reputation with decision-makers in the planning field because they have deflected the agencies from their main purpose, which is not to build models but to provide plans and implement programs.

Data Reduction and Data Manipulation

3. Since approximately 80 percent of the work on the Activities Allocation Model was concerned with the data, it is crucial that an agency have a good data manipulation system available before it starts a similar modeling effort. There are several alternative types of systems to choose from for this capability. Large agencies might want to use an elaborate and highly integrated system such as the one developed by the System Development Corporation. The small or medium-sized agencies might not want such an elaborate system but might instead prefer a modular approach like that used at DVRPC. This modular approach provides a series of subroutines which can be used independently or linked together. In either case, the time has gone when we can afford to spend much time writing individual small programs to specify each of the routine data manipulations required in such abundance in modeling efforts.

4. Any data manipulation system must have available to it a set of standardized data files on which it can operate. These data files will generally be in a matrix format, in which the rows stand for areal units, such as census tracts, and the columns stand for variables, such as population by age, race, and sex. Such standardized files will generally be constructed for areal systems at a higher level of aggregation than that at which the data were collected.

5. The *basic* data files, constructed on the individual areal systems originally used for each file, cannot generally be placed into the standardized data file format; there are usually some peculiarities in each data collection and reduction which require a unique format for each basic file. A separate set of so-called extractor programs is therefore required to produce standardized data format tapes from these basic data files.

6. A set of flow charts should be drawn to indicate how each of the variables required in the models is to be constructed from the variables in the existing basic and standardized data files. These flow charts can then be used to construct a PERT diagram with which to plan and schedule this major block of work.

Areal and Classification Systems

7. An early decision must be made about the areal systems to be used in the calibration of models and in projections into the future. This is necessary before the input tapes to these processes can be prepared. As few areal systems as possible should be involved, but more than one system may be required, as will be shown later. In any case, it is important that the areal systems be compatible with one another, with major secondary data sources, and

with areal systems used in other models or in analyses dependent upon the model's output.

8. In addition to being compatible, the areal systems used in calibration and projection should cover approximately the same area. It is statistically unsound, for example, to calibrate on the urbanized area of a region and then, using these calibration parameters, project on an area twice as large.

9. Areal units in calibration should be chosen small enough so that the parameters will be stable; in a projection they should be chosen large enough so that the output does not have large spurious variations between contiguous districts. These joint criteria can conflict seriously if regression methods are employed. Different areal systems might be used without serious difficulty. However, the parameters might not be sufficiently constant over different levels of areal aggregation. If this is the case the projection output should be aggregated to a higher areal level, and then disaggregated according to some proportioning scheme.

10. Spurious effects of the areal systems on the modeling outputs should be avoided by means including the following: All variables should be either intensive or extensive. An extensive variable is a number, like population; an intensive variable is generally a ratio of two extensive variables, like population density. Cutting a homogeneous district in half will cut an extensive variable in half and leave an intensive variable unchanged. For this reason they should not be mixed in a model unless they are suitably transformed by the model itself.

Suitable weighting factors should be used in regression analyses to assure that large districts do not have a disproportionate influence. To observe this hazard, consider two districts having equal proportionate errors in a residential location model, with one district holding twice the population of the other. Then in the regression analysis, the first district will get four times the weight of the second district because the residual errors are squared.

11. As with areal systems, care must be taken that classification systems used to define the model's variables are compatible with one another, with the classification systems of data sources, and with the systems of other models and analyses dependent on the model's output.

Model Structure

12. If regression models are used for projection, a strenuous effort should be made to solve for their required parameters individually rather than simultaneously. Outside data should be used wherever possible as a means to obtain parameters through nonregression means. For example, in constructing a model of retail location one might solve for the parameter specifying the attenuation of influence with distance by using trip data, rather than by solving for this parameter using only the values of the dependent and independent variables within the model. Additionally, wherever possible, more than one time period should be used in determining the regression parameters.

13. Partly because of the above considerations, a good case can be made that sequential models are preferable to simultaneous models; that is, it is preferable to construct a model which determines the location of the activities sequentially rather than to construct a model which locates all activities in one simultaneous equation solution. The argument again is that too many parameters have to be solved for at once in the simultaneous equation model, thus causing greater parameter instability. Furthermore, sequential models allow greater flexibility in tailoring the structure of the model to fit the behavior of the activities and the availability of data. This runs counter to William Alonso's argument in his paper presented to this Conference against constructing a long sequence of models. He has demonstrated that such a structure can have an explosive effect on prediction errors. Nevertheless, considerations of parameter stability and specification error must be balanced against the errors caused by such chainings of models.

Form of the Model Variables

14. In agreement with Alonso's considerations, independent variables should be chosen for which there are good data, and which can be forecasted accurately themselves, either by exogenous means or by derivation from the dependent variables of the previous recursive step. (Here we are assuming that a recursive projection process is involved in which a series of projection steps are used to get to the target year, such as the five-year increments we use to project 1985 from 1960; this is generally accepted now as the preferable way to project most locational behavior.) An accurately measured proxy variable is generally better than a badly measured "basic" variable. Similarly, basing the projection of a dependent variable upon an independent variable which is itself difficult to project is, of course, to be avoided. For example, basing the projection of the incidence of blight on the vacancy rate is a poor idea because the vacancy rate is harder to predict than blight.

15. For the reasons stated above "state" variables are generally preferable to "change" variables as independent variables. In this context, a state variable is one which describes the state of existence at a point in time, and a change variable is one which describes the amount of change occurring between two points in time. Since state variables tend to be much more stable than change variables, they have less tendency to promote explosive feedbacks in recursive projections.

16. Although the independent variables should be as uncorrelated as possible in a regression analysis, component analysis does not appear to be a very useful means of providing uncorrelated variables to the regression analysis. (Component analysis is a special case of factor analysis; in either, one obtains a linear combination of independent variables which are uncorrelated with one another.) The trouble with component analysis is that the projection phase requires translating the parameters obtained for the components back to the original independent variables. In this process a great deal of the parameter

variance is generally reintroduced, unless the number of components is so small as to provide little predictive power.

17. In operational models the dependent variables should be aggregated across categories as much as possible. A key difference between research and operational models is this preferability of aggregation. Dependent variables should generally be disaggregated only for the following reasons: (a) because it is necessary to provide the output required for evaluation or by other models; (b) because the mix of categories within a dependent variable is going to change drastically in the future and the behavior of the different portions of this mix is sufficiently different to require being taken into account; and (c) because the model calibrates better disaggregated than aggregated. With regard to (c), we can easily test whether in a given model heterogeneity sufficiently outweighs statistical randomness to justify disaggregation on the grounds of goodness of fit.

Supervisory Program

18. Because of the large number of operations involved in a recursive projection process, it will generally prove necessary to construct a supervisory program which executes the submodels and transforms the outputs of each submodel into the inputs to subsequent models.

19. A series of feasibility checks and corrections should be incorporated into this supervisory program. Included in these checks might be maximum growth and decline rates and checks for negative population, employment and land. Since regression models are especially apt to produce some extreme values, they should not generally be allowed to project unchecked. The feasibility checks should, however, influence only a minority of the values projected; otherwise, they will become in essence a significant model themselves.

DISCUSSION

DONALD HILL

Jack Lowry as usual has been painfully honest, and I have enjoyed it. I think this type of appraisal is very much in place. I think the more honest we can be about the kind of work we are doing, and the objectives we hope to achieve the better. I am very sympathetic with the numerous comments made about the particular developments we have contributed to the field, but there are two points I would like to clarify in regards to the development of the EMPIRIC model.

The first is that the original purpose of the model was to produce an unconstrained forecast as part of a total plan evaluation package. The only real constraint was that the sum of activities projected for the region should equal some overall control; so the sum across all sites or districts should equal some regional total. But within this general context it was our intention, and continues to be our intention, to have some sort of iterative adjustment procedure for achieving this so-called vertical or site balance. This is somewhat analogous to negative feedback where on the first round of forecasts the intention would be to reassign the overloads or overflows and thereby alter some of the original specifications of the sites, for example, their control densities. Now, to the best of my knowledge, this iterative feedback process has only been used very slightly, although perhaps in the later evaluation work it will be used more extensively. It is more or less a trial-and-error process; but I think it gives the opportunity to the planner to perhaps become better educated in the model, to learn how to use it. So this vertical control . . the vertical land use accounting can be taken into account, and probably will be.

The second point I would like to make, and it is a further comment to Dave Seidman, is that we do have an example where there was a dual model development—the POLIMETRIC. We had high ideals and expectations for POLIMETRIC. If it had not been for a number of reasons, I think it would be a truly operational model today. I do hope that sometime in the future we will be able to encourage sponsors to come forward and continue this type of research.

At the same time, there was a backup model developed. This was the EMPIRIC model. And as time went on and our data requirements became painfully obvious, and as budget restraints and timetables also became painfully obvious, it was necessary to fall back on the backup procedures, and still come up with a technique which the planning agency could use. But at the same time we feel that we did not sacrifice our ideals or objectives; we still had this research done on POLIMETRIC, and we did try to encourage other agencies to make use of it. We were very pleased that Penn-Jersey did pick it up. However, we do feel that they did oversimplify it. They very neatly destroyed the differential equation construction of the model, and they dropped the simultaneous interaction between the activities. This was done for a very good reason—data limitations, but I think Dave Seidman would agree that this is a property he would like to keep in that model, but because of necessary constraints, it was necessary to go the other way. Now, what this implied, both the data limitation and the differential equation construct, was very great computational expense to reformat and expand the data base in order to fit the general theory of the model. It became, again, very painfully obvious that it could not be made an operational tool within the constraints of the data at hand.

IRA ROBINSON

I want to make a few comments about the San Francisco model to clarify Jack Lowry's paper. Before I do this I should say that his allusion to the honeymoon is a very good one. It has been about two years since the honeymoon started, and as far as I know, the honeymoon is continuing. The marriage has not become very mature, and it seems to me that this is very unfortunate; what would be very good, perhaps, is a completely new marriage. What I am really saying is that from what I understand from a distance, and I have been away from this for almost two years, no one is really doing any serious work in refinement along the lines that Lowry himself implied, or on some of the refinements that we would like to have seen done. And this is one of those sad things. The model just may die, or become something of only historical interest.

The first point of clarification has to do with Lowry's reference to the establishment accounting being most casual. The fact is that the number and distribution of households are obtained in a computer printout after each period. However, we do not follow out the movements of the household, and for the purpose of model, the only reason we were concerned about the distribution was to compute space pressures and rent pressures. But in fact, we can obtain, and do obtain, and can keep track of if we wish to, the number and distribution of households.

Another point is the illusion to the rent budgets and maximum/minimum prices. What we did was for each household type we computed a rent paying distribution, and generally this conformed to a normal distribution. In other words, based on rents paid in 1960 we had a range of both a maximum and a minimum.

Finally, it is correct, as Lowry mentioned, that unlike the Herbert-Stevens model we do not use accessibility as an explicit variable. However, location is a factor. Remember all neighborhoods are grouped into fourteen location categories; location is based on topography, predominant dwelling type, and median rents; and households are bidding for not only a housing type but also for a particular location within the city. But accessibility clearly was not a variable for the reasons that Lowry points out. We decided early in the game, and I am sure that everybody would agree, that in San Francisco it really is not an important consideration.

JACK LOWRY

To respond to those three points, the first one had to do with the rigor of establishment accounting, and my point there was that not all households need to be located by the model and the disposition of those who fail to find a suitable home within their budget is left vague. You may have a printout, but it does not necessarily explain what to do with all the people you started with. Presumably they must have left the city or something.

The second point was on minimum prices. I recognize that what you did was find a distribution of actual rents paid, but when you connect that with an interpretation, *i.e.*, that this range represents the prices that members of the particular group in question would be willing to pay for housing of any kind, I think it is appropriate to raise a question.

The third point was on location classes. Perhaps this is simply a difference in vocabulary, but I do not think of location as meaning topography, or class, or type of structure, or things like that. I think of it as referring to points in space, and as we agree, points in space are not part of the definition of your housing types.

JOHN HAMBURG

Over the past ten years there has been a curious kind of switch. I can remember talking about the work we did in Chicago, and telling the people that while it was not a model it seemed to be a very useful and instructive way of organizing a tremendous amount of data in a way that you could handle and learn something from. Jack Lowry now tells me that, in fact, we did have a model, but you cannot learn anything from it. In the sense that it is not an experimental design which you can run again and again and learn from, I would agree. Moreover, the very thought of going through that process again for any purpose, I think would drive me to a mad-house. But I am not going to admit that we did not learn something from such a macroscopic view of the city. I still recommend many of the points in it.

Regarding this question of a horizontal versus a vertical model—and which is which—I am not sure I agree that this is a column model. But knowing the source from which you drew these conclusions, if there is ambiguity, I provided it to you in giving you the original document. So I cannot complain except to say that the things which had been described as staff judgment were, indeed, staff judgment just as were the gradient extrapolations into the future and the densities. A great deal of judgment went into the model. I would insist that a good many of these staff judgments were based on a fairly careful analysis of data and a variety of statistical formats, as well as just looking at maps and geographic distributions of data. I cannot argue that they were objective. In fact, I am flattered to think that this whole series of calculations has been characterized as a model. But I do think it is more than either simply a vertical or horizontal approach.

DANIEL BRAND

My comments will be addressed mostly to the research strategy which Dave Seidman enumerated. I think that Seidman has done a great service and set an example for a lot of us in that he has enumerated a set of procedures which he feels, on the basis of his own experience, should be followed in developing models of the sort that we are talking about. However, I think he has essentially recoiled from some of his own bad experiences to state perhaps too firmly that we should be avoiding certain procedures in the future. There are certain parallels which we have had to his experience, and there are areas where our experiences rather radically diverge. And so, let me discuss two or three of the elements in his research strategy, and then perhaps add another one of our own.

First of all, he feels that *ad hoc* programming should be out. This is a sore point with many, but I should disagree with this based on our experience in Boston We had large amounts of data, and we also have a very elaborate data system. However, we find that there are constantly new demands for data and for new types of analysis. We find that intelligent programmers want to get these data, not using a set of canned programs, but by adapting the canned programs, or when they feel that they can get at it a lot quicker and produce summaries a lot better by constantly changing programs and writing new programs. Frankly, I do not think you are going to keep good programmers if you do not allow them this flexibility.

The second point I would like to dispute is really one of his major points: he is in favor of sequential models rather than simultaneous models. I think there are a lot of advantages to simultaneous models. I think one of the reasons why he is in favor of sequential models is because of problems with stability of parameters, and my feeling is that we just have to do a lot of work with the data, making sure that the data are in very good shape. Then we will not have problems with stability of parameters, particularly if we make efforts to reduce the collinearity of the variables On this point I would suggest that we do run factor analysis, but only use it as a guide to get variables which represent different classes of variables, but not use the factors themselves. In other words, do everything possible to extract variables which represent classes of activities but which do not have collinearity problems.

Finally, I would add one additional element to this strategy. Seidman mentioned that in least squares analysis, you should have zones of similar size. I would also say that you should be forecasting in your model the variables to be used in the final analysis—the variables to be used in plan evaluation, or as input to further models or for steps in the planning process.

DAVE SEIDMAN

On the programming question I did not mean to suggest that specific analyses which come up should not have any programming done for them. I do believe strongly that an extractive program, as we call it, ought to be constructed for every basic data file and a set of extractor programs for the standardized data file, so that you do not have to do *ad hoc* programming to get the basic data you want. Now as far as holding good programmers, I do not think you should have all good programmers. I think you should have one or two, and the rest of them should be the kind of programmers who put together the parameter cards for an extractor program. You get into a similar argument for doing research in agencies—being able to keep their staff—and I am not sure that it is worth it either.

On the sequential problem—and this is partly in response to Don Hill's comment—if your recursive period is fairly small, say five years, I do not think you have to worry nearly as much about interdependence between variables. I acknowledge that calibrating on a ten-year period makes me uncomfortable. I would rather calibrate on a five-year period, or two five-year periods. This question of interdependency can be solved entirely adequately by keeping a moderate period of time for each recursive step without necessitating the relative inflexibility caused by the sequential process. I did not say, by the way, that I am in favor of similar size of zones. I am in favor of taking out the effect of dissimilar sizes of zones by carefully chosen weighting factors. When you get to the question of similar sizes of zones, you get to the question of similar sizes according to what . . . area or population . . . and I regard this as sufficiently intractible that I would not argue for it strongly.

TERRY LATHROP

I think basically what bothers me is an easy sort of establishment of absolutes, and Seidman has, very much in accordance with the way I feel, replied to what Brand said. His assurances that he was not outlawing all *ad hoc* programming or advocating complete divorcement from manipulation of data after the first day of the study, and so on. I think the thing that perhaps bothers me most is something that came up in comments on Chapin's paper where we are facing the question of aggregation or disaggregation on the question of *ad hoc* programming or the question of data manipulation . . . it is very difficult for me to arrive at general principles about these things without a context to the problem. I think that is clearly reflected in everybody's comments after Seidman made his first statement, but I would not want it to go unsaid.

BEN STEVENS

I am not going to comment right away on the so-called Penn-Jersey model to which I thought Lowry gave very fair treatment. He suggests that taxonomy and seeing the labels on the shelf may give him some ideas. There is no question in my mind that this kind of operation tends to make you concentrate on what the problem is in designing land use models in general. And as a matter of fact, carries you a step further, towards a statement (which I do not think exists in the literature) of what the kind of minimum requirements are of a model that is going to the kind of things that we want to do if we can define those things.

We should at least be able to describe the urban area in a way that allows us to make certain kinds of predictions or plans and to evaluate alternative public policies, and be able to simulate the way the urban area behaves in a way that will respond intelligently to alternative plans and policies. I think this kind of presentation of what the elements are that should be in a basic model is extremely useful. I do not think that Lowry pretends that he necessarily has all the elements that need to be there, but he does concentrate on a very important feature—the market solution encompassing the relationship between the activities and their desires to be at various locations and the profits they can make or the satisfactions which they can achieve, and the point of view of the sites and the site-owners and their interest in getting the maximum possible out of the land.

I would like to reiterate what Harris said that from the scientific point of view, the development of a great many models without an underlying theory of how metropolitan areas work is a little bit disturbing. There is some very good theory available. Alonso has written a book about it. There are not in the literature very great extensions of what Bill was saying to take into consideration some of the things that come up in his book. One of these is the question of multiple centers of interest—employment, shopping, and so forth—which have a very significant substantial effect. There are other bits and pieces of theory of the urban area that need to be inserted. But this building of models without really understanding what is going on, I think, has worked to the detriment of some of the model-building activities which end up perhaps solving the immediate problems of the agencies involved, but do not necessarily add to the state of the art. The real difficulty is, of course, that the decision-makers need something that answers their particular problems, and theory building is something that is done on the side. I agree that the theory has to be done to some extent on the side, but the theoretical development has not been good enough to give the people who have to answer the questions of the decision-makers enough to go on. So things are perhaps more *ad hoc* than they really need to be.

I might add that the opportunity to take advantage of the kind of information that has assembled in transportation studies and really develop some generalizations about metropolitan areas as a whole has been very badly underplayed so far. There is now a vast amount of information out of which I am sure with more intensive research we would find that there is a lot more you can generalize about how metropolitan areas work than has so far been either found out or put in the literature. The ability to use the information resulting from existing transportation studies to improve both the projections and the attempts at model-building for future transportation studies is very badly overlooked. I think the kind of thing Lowry is talking about and the way he has organized the material in some of the existing models leads me to the same conclusion. This is a whole area of research on its own which perhaps the transportation studies themselves should not have to support, but which is well worthy supporting

RONALD GRAYBEAL

I would like to comment on three topics. The first is an observation of three out of seven of the modelers whose work is discussed in Jack Lowry's paper reacted in an attempt to clarify what their model attempted to do. Inasmuch as three out of seven of them have had to do this with Jack's paper indicates to me a sufficient reason for much more clarity and communication of our work. Second, whether we are going to use simultaneous equation models or recursive models tends to be a matter of specification; that is, how do we view the world operating and how we view the world operating frequently has to be modified by the kinds of data that are available. These kinds of considerations cause me to take the position that a firm rule here may be inapplicable unless it is qualified by the characteristics of the situation. My third point concerns the applicability of the market model. Alan Black made the statement that it is not a very good representation of the land market, and I hope that he will suggest what is a more appropriate representation of the land use market.

ALAN BLACK

I am not an economist and this is just an intuitive reaction to the theory that Jack Lowry presented. I do not think that he has shown a profit maximization principle. It seems to be perhaps based more on the assumption that a firm wishes to make a certain threshold of profit, but . . . and it is going to be pay-off suffice which will match that exactly. This paradigm seemed to me to take up the viewpoint of the site-owner rather than the establishment. It seems to assume that the site-owner had a lot of information, but that the establishments do not, which I do not think is true. Usually, of course, the site-owner does not have any idea what demand prices are. All he knows is what has been bid for his site, which may be much lower than what a demand price would be. Of course, each establishment could know its own demand price for every site in the region, if you wanted to bother to calculate it. I have a feeling it would be possible to work out a matrix in which each firm would seek to maximize its profits for the choice of the site and the external income and costs that are associated with that site, but I do not know.

JACK LOWRY

Alan Black raised four points about my matrix. First, he was upset not to find any negative numbers in it. It works quite well with negative numbers, just so you have some positive ones, or at least one positive one in each column; and if you have not got positive ones there, I would say you did not have a city. On the question of moving costs, I concede some ambiguity. As a matter of fact, an earlier draft of the paper specifically made a point that the demand prices as entered in that matrix were meant to take into account for each establishment its costs of moving.

Alan Black's third point was that he would expect to find establishments looking for lower priced sites than the ones they currently occupied, and the fourth point has to do with his inability to see profit maximizing behavior in the site assignment process that I have described. I think that these both derive from some confusion on Alan's part about what the demand prices are; and I do not think this confusion arises because I was obscure. In the paper I say, "At the designated prices, then, the establishment would be indifferent among locations." In other words, I am suggesting that we fill out the matrix with prices such that the relative advantages of each location are reflected in the price that the establishment would be willing to pay for it. In this case the establishments are indifferent between locations provided they can get them at the prices listed. And also, the prices listed reflect the profit anticipations of doing business at any one of those locations So that the demand prices are, if you like, profit equalization prices for establishments whose businesses are making a profit, prices which equalize the profit producing potential, in some sense, of each of the alternative sites. Clearly, there is some profit maximizing in the picture because we have at least the site owners picking tenants so as to maximize the return to their land.

I think John Hamburg replied adequately to Alan's comment on my interpretation of the CATS model If it is a row model as Alan claims, this is not reflected in the published documents. I might just add as a footnote to John Hamburg's point that when I say something is a staff judgment, I am not saying that it is bad. I am just saying that it is very difficult to document so that people can reproduce your results.

BILL ALONSO

I want to call attention to one thing that I find personally intriguing and which I think may in the long run be a problem that comes back to haunt us at first, and later on may be productive. This is the distinction between continuous space and regionalized space. Jack Lowry's model, to some extent, deals with regionalized space. In doing this there are some effects that happen. The reason for doing this, in general, I think, is that both because of the way we think and because of computers, we use matrix operations. The matrix is particularly suited to the naming of districts. However, when you have ordered the districts on, say, the top, you use the information because you have a one dimensional ordering system as opposed to two dimensional spatial system, and so you come back to accessibility measures and things like that to try to bring that back in.

There is a second effect which is that by districting you introduce grain into the territory which may not be there from theory. That is, I think that feedback from theory, which probably goes back to central place theory, and the size of districts has not received enough attention When I was working on rent theory I ran into this problem. I did not know the size of the site until I knew the locator. Therefore, I could not identify it The solution that I proposed was to iterate the solution to fix boundaries. What I did was a topological transformation, and this is why the emphasis on the single center, that ordered not just normally, but ordered the users sequentially the users, and therefore named the sites, and then defined the sites by sequentially defining the users and getting the size, and therefore defining the next one. When you shift to the industry scale, be it sectors of the population or occupations, the grain of the decision is more permissive because if you are dealing with large districts and large groups you can cut them and spill a little over into the next one, or you can fill if you have some unused space with some other user.

This is why the shift from the establishment to the industry is an important one when you go to the matrix and not a trivial one.

There still seems to me to be an important distinction in the types of land uses. There are some land uses which may be said to be distributed. I think households are that. That is, you spread them as you spread marmalade or something like that. The thicknesses may vary but they are more or less all over the place. Certain types of shopping and schools are similar. But other uses—industry is very often an instance—are distinct events rather than density functions, and these are much harder and much less tractable by this technique. I would only like to point out again the fundamental importance of the scale implicit in matrix formulations, not just for the capacity of the computer and the aggregation used in the sense that it is spoken of here, but from the point of view of fundamental theory of urban form. If areas are sufficiently big and defined by population rather than space, so that their grain is larger than the grain of certain phenomena, these phenomena disappear as interesting phenomena to be studied. For instance, if the areas are larger than school districts, I disregard school districts because they fall within the areas. Shopping centers may be treated similarly. If I have fine areas I need to worry where the shopping centers are going to go. As the areas get bigger, I do not. There is a lot of thinking to be done. There is a great deal of theory available; and what seem to be difficulties and irritations are, I believe, very often clues as to the sources of insight in the future.