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Empirical Analysis of Allocation

On the State of the Art in Urban Development Modeling

By Walter Buhr*

This review paper will consider urban development modeling as a branch of empirical allocation analysis based on the concept of markets. In this context essential methodic approaches of recent research will be discussed. A critical investigation of selected central aspects of urban simulation modeling will focus on the analysis of markets, the incorporation of material infrastructure and the description of location decisions as dual complements of corresponding allocation problems. Finally, attention will turn to the future prospects of urban development modeling.

I. Introduction: The Problem Areas to be Discussed

Most urban development models, as far as they are empirically applied and practically relevant, basically embody land use and transportation models. Their dynamic character is generally guaranteed by a recursive model structure which refers to successive time periods of analysis. The main objectives in constructing land use and transportation models are the empirical investigation and the projection of urban development. Today these models can form a sound background for urban planning and decision-making.[1].

Since this research field has in the recent past undergone broad and rapid development under the interdisciplinary influences of economics, regional science, quantitative geography and psychology, civil engineering and applied mathematics, the following evaluation will be limited to some selected aspects characterizing models in current use and present theoretical thinking.[2] In particular we shall stress that urban development model-

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1 Cf. *Pack* (1978), *Foot* (1982), *Albers* et al. (1983), *Young / Mason* (1983), *Friedrichs* (1985).

2 A number of references on the older review literature may be found in *Buhr / Pauck* (1981).

ing, by reason of its objectives and approaches, essentially constitutes a branch of the economic theory of allocation.[3] In section II we shall discuss the relationship of the models to the concept of markets. Then we shall present essential methodic approaches of recent urban modeling. Since the theoretical quality and the empirical applicability of the model subsections determine the efficiency of model construction and use, we shall turn to an investigation of selected problems of modeling in section III. These problems concern the analysis of markets, the incorporation of material infrastructure and the description of location decisions. In the concluding part, section IV, attention will be directed to future prospects of urban development modeling.

II. Modeling Urban Development as a Branch of Empirical Allocation Analysis

1. The Reference of Urban Development Models to the Regional Market System

In the present context the relationship between the allocation and the location of economic variables may be described as follows. For particular periods in time a general theory of allocation attempts to explain the spatial assignment of factors of production to satisfy consumers' demands for goods and services distributed in space, regarding society's economic objectives. With respect to a city (or a region), the solution of the urban (regional) allocation problem generates the intraurban (intraregional) factor, goods and communication flows and trip patterns and thus the changes in the corresponding factor stocks. Over time, looking at individual economic units, the spatio-temporal allocation problem reduces to the long-run location problem of these units. Location decisions lead to new patterns of sizes and location of non-residential buildings, facilities and housing in the city. Basically, the distinction between allocation and location is independent of the definition of the variables as stocks or flows.

In market economies, leaving aside government activities, allocation problems (in the flow version) are solved by markets. Although for a long time there were only occasional references in the literature on land use and transportation models to the central role of markets in the urban growth process, it has become increasingly clear in the recent past that the idea of markets has always implicitly underlain urban development modeling.[4]

[3] The term "welfare economics" as an alternative to the term "theory of allocation" will not be used here, since, at least for an economist, it has specific connotations which may not be relevant in the present context.

[4] See *Buhr / Pauck* (1981).

Abstaining here from a detailed description of market-relevant demographic and economic stocks and flows, the relationships between urban markets used as the most commonly applied model structure may be sketched in the following way. The city level of research is represented by analytical procedures standing for the urban labor market to generate above all the city aggregate of employment[5] (as market result), often preceded by the derivation of the aggregate of urban population[6] (on the supply side of the labor market). Since most land use and transportation models concentrate on the intraurban distribution of total urban population and employment to city zones, the (inter-)regional level of considering urban variables occupies a prominent place in the construction of the urban development models, especially regarding the empirical validity of the disaggregated model results.[7] At the intraurban level, the zonal land markets and/or housing markets, markets for non-residential buildings and transport markets come into the foreground. A peculiarity of the derived market results is that they are almost exclusively represented by quantity variables. There are only few urban development models in which prices are determined by market demand and market supply in order to be used as determinants of other model variables.[8] As exceptions we may refer, for example, to the generation of dual variables as prices or price elements in the application of mathematical programs[9] or to the determination of traffic conditions such as speeds on the zonal transport markets which can be related to price-like indicators such as travel times or transport costs.[10]

The intraurban location of factor stocks and the results of the urban markets indicated above determine firstly interzonal commuting flows, secondly zonal accessibilities under the influence of daily trip patterns and thirdly, in view of given accessibilities, migration of households and relocation of firms which entail zonal land use conversions.

We can summarize these considerations in the statement that urban development modeling may be regarded, in a wide sense, as applied general equilibrium analysis. This view is suggested by regional economic theory. For instance, *Gat* (1974) has shown that the theoretical approach explaining the household's dual choice of where to live (demand for housing) and where to work (supply of labor) in the city can be incorporated into a general equilibrium model of a competitive economy. But the general market equilibrium "... has proved somewhat elusive in simulation, since most

[5] Cf. *Prastacos / Brady* (1985).

[6] Cf. *Frey* (1983), *Akkerman* (1985), and *Bierens / Hoever* (1985).

[7] On the problems of combining national and regional models cf. *Köppel* (1979), *Courbis* (1982), and *Bolton* (1985).

[8] Cf. *Buhr* (1978), *Anas* (1982).

[9] Cf. *Ingram* et al. (1972).

[10] Cf. *Beckmann* et al. (1956).

models deal with one or another sector of the urban scene, and not with the interactions of sectors through these mechanisms. However, planning and policy need to consider the larger systems which are involved in a general equilibrium, because a failure to do so entails the possibility of unintended and adverse consequences."[11] Finally, to return to the economic theory of allocation as the starting point of our brief exposition, we support the proposal by *Sharpe* and *Karlqvist* (1980) that existing urban development models should be classified as special cases of a more general model which combines community and individual welfare objectives in a weighted fashion.[12]

2. Essential Methodic Approaches of Urban Development Modeling in Recent Research

In order to provide a more solid basis for the estimation of transport demand, urban transport models were linked to urban land use models.[13] While, for a long time, the transport models used in practice showed only relatively minor deviations from the classical sequential package of trip generation models, trip distribution models, modal split models, and trip assignment models on the demand side and the traditional approach of capacity estimation on the supply side,[14] a substantial number of rather diverse land use models have originated from the contribution by *Lowry* (1964). Despite their diversity many of these models are basically of the *Lowry*-type, meaning that they have the following characteristics:[15] (a) they distinguish between basic (export-oriented) and nonbasic (population serving) employment, the latter being derived from the former by a multiplier-like relationship; (b) they determine from the given intraurban distribution of basic employment the spatial distribution of city population, this information being required for the calculation of the distribution of nonbasic employment; adding now basic and nonbasic employment, the initially projected urban population distribution can be adjusted etc. – this process of iteration must be continued until the results for the model variables converge to their final values. The nonlinear and – more especially – the linear representation of the *Lowry* model has been discussed by *Batty* (1983). A comprehensive investigation of the implications and possibilities of the model is given in *Webber* (1984).

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[11] *Harris* (1985 a), 547. For an exploration of the use of supercomputers in the application of land use and transportation models see *Harris* (1985 b).

[12] See also *Brotchie* (1978). With reference to mathematical programming cf. *Diedrich* (1970).

[13] Cf. *Allen / Boyce* (1974).

[14] Cf. *Pauck* (1983).

[15] Cf. *Goldner* (1971).

A lesser influence on the art of model building than has arisen from the *Lowry* model has been exerted by *Forrester's* (1969) contribution on urban dynamics. In a specific way the dynamic structure of this model depends on modified difference equations. The reason for the slighter impact of this contribution on modeling is rooted in several deficiencies such as unsoundness of model construction and absence of empirically valid hypotheses. For instance, the endogenous dynamics of the system are determined by a much smaller number of stock variables than indicated so that the majority of the equations may be discarded.[16] However, what none the less still does make this approach attractive is the renewed concern with spatial dynamics and the fact that these deficiencies may be overcome by, to give some examples, regionally disaggregating the model, introducing accepted concepts of economic theory and relating the model to real-world data.[17]

A fundamental step in the direction of achieving greater reliability of model results and in particular towards guaranteeing consistency in the projection of spatial allocation, was taken by *Wilson* (1967), (1970), (1974) who improved the theory of the gravity model by formulating differently constrained entropy-maximizing models.[18] In gravity models interaction between spatially concentrated economic units is assumed to vary with their number and distance apart. Later the entropy approach was generalized, for example, by the introduction of the minimum information principle by *Snickars* and *Weibull* (1977). Alternative models of spatial interaction were derived from deterministic and random utility theory.[19]

The integration of the entropy models into the existing body of theory, on the one hand, concentrated on the discussion of the relationships to mathematical programming.[20] On the other hand, *Anas* (1975), (1983) and *Williams* (1977) showed that the doubly constrained entropy model is compatible with a multinomial logit model of joint origin-destination trip choice, consistent with stochastic utility maximization. Thus behavioral demand modeling which follows *McFadden* (1974) and entropy-maximizing modeling in the sense of *Wilson* can be seen as two equivalent views of the same problem. Recently, the roots of the entropy concept in information theory have again been under discussion.[21] Apart from incorporating entropy models into the existing framework of analysis, the question was

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[16] Cf. *Schönebeck* (1975), *Beumer* et al. (1978).

[17] Cf. *Chinitz* et al. (1973), *Bertuglia* et al. (1980).

[18] *Faber / Proops* (1985) may serve as an introduction to the notion of entropy as used in economics. A general formulation of the doubly constrained model is given by *Ledent* (1985). On estimation problems see *Haining* (1978), *Sen / Sööt* (1981), *Fotheringham* (1983), *Willekens* (1983), *Sen* (1985).

[19] An overview is given in *Kemming* (1980). For a thorough critical evaluation cf. *Bröcker* (1984).

[20] Cf. *Evans* (1973), *Wilson / Senior* (1974), *Nijkamp / Paelinck* (1974).

[21] Cf. *Wilson* (1970), *Haken* (1978, Ch. 3), *Fisk* (1985), *Erlander* (1985).

raised of how to enlarge and modify these models to gain new scientific insight. To give examples, entropy-maximizing interaction models have been developed to deal with demand for activities sensitive to accessibility and congestion or to determine spatial consumption patterns when imbalances between demand and supply occur.[22] Other efforts have been dedicated to the evaluation of the role of alternative attractiveness functions in the determination of equilibrium solutions to spatial interaction models.[23]

The development of future research will be oriented around two ever more strongly emerging lines of urban analysis: on the one hand, from the viewpoint of more effectively integrating models in application, the suggestion of microsimulation using the Monte Carlo technique and, on the other hand, from the viewpoint of forming regional and urban economic theory, the introduction of explicitly solvable dynamic models.

In economics, the inability of aggregate models to adequately predict the consequences of government policy for different groups of people led to the formulation of micro-analytic models, especially by *Orcutt* (1957), (1960) and *Orcutt* et al. (1961), (1976). This change in conceptual approach was reproduced in urban development modeling, since many urban models, for instance those of the *Lowry*-type, were also constructed on a relatively aggregate scale. The microsimulation methodology, considering the given data problems, may be briefly described with regard to a demographic submodel.[24] The initial population at a certain point in time is to be classified according to individuals and households, each of them having an associated set of attributes that relate to diverse characteristics. To synthesize a population from the scarce (micro and macro) data available involves the building up of a list of attributes for the individuals and the households by means of conditional probability distributions derived from Monte Carlo sampling procedures. The advancement of the disaggregated population from one point in time to another can formally be expressed as a set of difference equations. For their solution, Monte Carlo simulation methods may again be used to select from all those individuals and households eligible for a certain transition process (for example, death or house purchase) the subsets that undergo this transition in a given time period. This demographic submodel can be integrated into a labor and housing system, considering algorithms to match demand and supply in the markets[25] and being closed by aggregated

[22] Cf. *Leonardi* (1981 a), *Roy / Brotchie* (1984).

[23] Cf. *Clarke* (1985).

[24] *Clarke* et al. (1980) and *Clarke* (1981) may serve as introductions to microsimulation; the demographic submodel outlined is derived from the latter. On the application of microsimulation in population projection see also *Nakamura / Nakamura* (1978).

[25] A possible allocation model is discussed in *Snickars / Weibull* (1977) and *Clarke* et al. (1979).

relationships. Housing is indeed one area where the benefits of microsimulation have proved particularly appropriate, leaving aside other possible applications such as in the analysis of local authority infrastructure provision.[26] *Wegener* (1981 a), (1985 a) used microsimulation to study stochastic household behavior in the clearing process of the Dortmund region housing market. In the present context another important area of research is transportation. As representative here for recent work appears *Kreibich's* contribution (1979) simulating modal split and trip distribution as an interconnected decision process at the individual level.

With reference to dynamic urban modeling we may essentially observe four distinct lines of research that now begin to merge, thus appering to be interlocked under various aspects which cannot be pursued here. Firstly, there is a transfer of the basic concepts of economic theory, in general, and of positive and normative economic growth theory, in particular, to urban model construction.[27]

Secondly, starting from a critique of traditional growth approaches, the development of growth models capable of explaining simultaneously the rapidity of change and the persistence of spatial patterns in an area according to the principles of self-organizing systems has been promoted by the physical sciences (Brussels school led by *Ilya Prigogine*) and by biology (Paris school led by *Henri Atlan*). While the Paris school's starting point of research may be linked to a city such as Los Angeles that has experienced a very high turnover of households and dwellings accompanied by a remarkable invariance of its landscape structures during the last forty-five years,[28] the Brussels school set out to model the evolution (growth or decline[29]) of a system of central places by using some basic differential equations.[30] This interurban approach representing systems of cities was supplemented by an urban model taking account of the location activities within cities.[31] The Brussels group has also explicitly addressed the role of transportation in the process of spatial and economic self-structuring.[32]

Thirdly, stimulating impulses have come forth from mathematical catastrophe theory[33] which, using techniques of differential topology, is con-

[26] Cf. *Clarke* et al. (1981).

[27] Cf., for example, *von Böventer / Hampe* (1978), *Miyao* (1984), *Dendrinos / Mullaly* (1983).

[28] Cf. *Marchand* (1984).

[29] On the problems of modeling urban decline see *Wegener* (1982). In a more general context cf. *Buhr / Friedrich* (1981).

[30] Cf. *Allen / Sanglier* (1981).

[31] For a critical evaluation of the two models see *Wilson* (1981), 156 - 171.

[32] Cf. *Kahn* et al. (1981).

[33] Catastrophe theory is a special case of bifurcation theory which comprises a more general set of methods relating to the solution properties of differential and difference equations.

cerned with sudden and discrete changes in system state variables resulting from a slow, smooth and small change in one or more parameters (for example, very rapid enlargement of a city over a short period or sudden exchange of dominance roles between rival cities).[34] So far the application of catastrophe theory to urban simulation modeling has mainly concentrated on theoretically exploring its relevance in different branches of urban analysis.[35] There are only few empirical applications of catastrophe theory, one exception being *Casetti*'s (1982) discussion of a problem of economic growth. Thus the critical evaluation of catastrophe theory by one of its major proponents is still valid: "... its practical usefulness is still very much dubious, as the theory did never predict any new experimental result of very marked importance."[36]

Fourthly, the question of whether an equilibrium will ever be achieved also refers us to the application of dynamic theory. This approach, starting from disequilibria, for example, between demand and supply in markets, was used by *Harris* and *Wilson* (1978) to explore a number of economicly relevant mechanisms for modeling equilibrium values of attractiveness terms in production-constrained spatial interaction models. Their main achievement was the generation of equilibrium solutions for the location of retail facilities.[37] To understand better the complexities of the equation systems involved, it is necessary to undertake such numerical experiments as have been carried out by *Beaumont* et al. (1981), *Clarke* and *Wilson* (1983).

Our present inability to model the spatial evolution of urban systems originates from the current non-existence of a unified dynamic theory of spatial decision behavior of the main actors (households, firms, government entities) in the cities. Only such a theory could explain spatial processes such as urban growth and decline, concentration and deconcentration within cities, and agglomeration and deglomeration in space.

Since the 1970's increasing efforts have been dedicated to reconsideration and integration of the existing urban development models, many of a partial nature, to take account of the interdependencies of individual submodels. *Wegener* (1984) confronts "unified" models[38] using one algorithm or system of equations to model all subsystems and "composite" models[39] combining specialized and thus different submodels in each model subsystem. In view

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[34] Cf. *Thom* (1975), *Isard* (1977), *Wilson* (1981).

[35] Cf. *Wilson / Clarke* (1979), *Wilson* (1980), (1981), *Dendrinos* (1980), *Kaashoeck / Vorst* (1984).

[36] *Thom* (1977), 32.

[37] This research has its roots in *Coelho / Wilson* (1976). A more recent contribution to the location issue is *Roy / Johansson* (1984).

[38] Examples are *Gordon / Ledent* (1980), *Leonardi* (1981 a), *Madden / Batey* (1983).

[39] First approaches to composite modeling still restricted in scope, have been formulated, for instance, by *Kain* et al. (1977), *Mackett* (1980), *Nakamura* et al. (1983).

of the complex urban allocation-location processes as described above, only composite models will be capable of adequately fulfilling the often far-reaching aims of urban development modeling. Unified models are no serious alternative, as far as their potential is concerned. Difficulties of theoretical analysis and data shortage make the alliance of pluralistic methodic approaches indispensable.[40] In this context, *Buhr* and *Pauck* (1981) have outlined an analytical framework for future research and urban policy formation. Their main objective has been to prepare for integration of the analytical instruments included in the models into a comprehensive system by means of critical comparison and evaluation, thus creating a box of tools out of which alternative combinations of instruments can be selected to solve specific problems of city planning. This approach was inspired by *Isard's* (1960), Ch. 12, suggestion for synthesizing different methods of regional analysis.

III. A Critical Evaluation of Urban Development Models: Selected Problems of Modeling

1. Analysis of Markets

Since a detailed evaluation of the analytical instruments of the models would be beyond the scope of this paper, the following critical considerations will focus in a more general way on three outstanding fields of urban modeling in which further research will be needed in the future: markets, material infrastructure, and location decisions.

The most substantial contribution of urban development modeling to economics has been in the field of empirical investigation of multi-market systems. Comprehensive urban market analysis today forms the core of transportation research and leads to the most convincing results in housing research. However, it must be borne in mind that market modeling covers a broad spectrum of approaches ranging from elaborate analysis to rudimentary description. The more or less implicit or deficient description of market processes partly originates from the incomplete account of the market-relevant stocks and flows in the models. Often the demand side of a market is not dealt with separately from the supply side, since the empirical data are only available on the market results (for example, on employment in the case of the labor market). Or, the market results have been derived from only one of the two market sides (for example, employment calculated from labor supply by applying a labor force participation rate to population). Weak market representation is a particularly serious shortcoming in the case of the urban labor market, because additional urban employment in many

[40] This position is shared by *Harris* (1985 a), 563 - 564.

cases is one of the essential aggregate variables distributed among the city zones by the allocating transportation and land use models.

Considering the two sides of the urban markets under analytical aspects, we find that the supply side of the land market and the supply side of the transport market,[41] especially with reference to roads, have been subject to only limited empirical analysis. As far as the supply of developed and directly developable land, unused for construction, in total or for different purposes is concerned, this is simply determined as a residual, by summation or by another variable (mainly demand for land). No urban development model takes account of the supply of land as a function of any other variable included in the model. That little analytical attention has been devoted to empirical study of the causal factors of transport supply[42] – beyond the measurement of selected variables of capacity functions as either speed-flow or travel time-flow relationships[43] – may be taken to be a result of the fact that the government sector has been widely neglected in model construction.

Consequently, in view of given urban road service supplies the major emphasis in studying the city transport markets lies on analysis of the demand side of urban transportation.[44] If the assignment of a variable or constant demand for transport services to the routes of the urban transport network fulfills certain optimality conditions, then the market equilibrium for the entire transport system is reached. In the case of a given transport demand, the solution of this problem, formulated in terms of traffic flows to be optimized for road users, may be derived from an adequately formulated cost minimum problem of mathematical programming. As is known, this equilibrium solution regularly diverges from a system-optimum efficiency solution which minimizes total costs of the transport system.[45] Since these market approaches replacing increasingly the classical sequential combination of transport models often run into difficulties of practical application due to their great number of variables and constraints and to the nonlinearity of the objective functions (in the case of user-optimized flows), in many instances the urban development models incorporate only heuristic iterative procedures to generate user-optimized traffic flows. These capacity restraint methods of network assignment assume a given transport demand, which, in accordance with the criterion of minimum time paths, is to be

[41] The basic framework for analyzing the supply of transportation services has been described by several authors, among them *Morlok* (1976), (1980), *Florian / Gaudry* (1980), (1983), *Manheim* (1980). An overview is given in *Kanafani* (1983). See also *Pauck* (1983).

[42] On recent research cf. *Turnquist* (1985).

[43] Cf. *Branston* (1976).

[44] Cf. *Horowitz* (1985) and *Goodwin / Williams* (1985).

[45] On the state of the art and research opportunities cf. *LeBlanc / Rothengatter* (1982), *Fernandez / Friesz* (1983), *Boyce* (1984 a), *Friesz* (1985), *Sheffi* (1985).

assigned to the routes of the urban road network characterized by the travel time values of capacity functions. The travel times are adjusted according to the assigned link volumes in each iteration. However, during the last decade increasing effort has been invested in supporting algorithmic research pertaining to network equilibrium problems, including congestion changing the behavior of users of the transport system.[46] The results of this research are summarized in *Friesz* (1985), 417 - 419. The outstanding issues among the possible extensions of the deterministic network equilibrium concepts are stochastic network equilibrium and freight network equilibrium, on the one hand, and network design, on the other hand. The network design model aims at the determination of improvement to network link levels, assuming, for example, user-optimum or system-optimum driver behavior. We must also mention recent attempts at modeling dynamic network equilibrium, taking explicit account of the time dependence of network functions.[47] Finally, a discussion of future research opportunities on the issues raised is given in *Supernak* (1983) and *Boyce* (1985).

Remarkable progress has been achieved in simulating the urban housing markets which, in very specific processes,[48] represent the confrontation between the demand for and the supply of built-up lots in the city. The theoretical content of analysis having been substantially increased, market demand and supply have been mostly derived on the basis of micro-economic theory. The present modeling situation is essentially shaped by the following important contributions: Harvard Urban Development Simulation Model (*Kain / Apgar* (1981), (1985)), Urban Institute Housing Market Simulation Model (*de Leeuw / Struyk* (1975), (1981)), Stockholm Region Housing Market Model (*Gustafsson* et al. (1977), (1978)), Dortmund Housing Market Model (*Wegener* (1981 a), (1981 b), (1985 a)), GEWOS Simulation Model of an Urban Housing Market (*Schacht* (1976), *Schacht / Hasenbanck* (1981)), and Ifo-Institute Housing Market Model (*Behring / Goldrian* (1981), (1985)). These and other approaches have in turn stimulated path-breaking theoretical work, in detail[49] and in general[50], that will give rise to new empirical research.

Many of the models mentioned above have gone through several stages of development. For instance, the Harvard model was based on different versions of a model mainly sponsored by the National Bureau of Economic

[46] Apart from general references on dynamic network theory, on congestion also see *Fisk* (1984) and *Nguyen / Dupuis* (1984).

[47] Cf. *Friesz* (1985), 419 - 422; *LeBlanc / Rothengatter* (1983), *Ben-Akiva* (1985).

[48] Cf. *Stahl* (1981), (1985).

[49] For example, on the filtering process in the housing market cf. *Werczberger / Pines* (1979) and *Pines / Werczberger* (1982).

[50] See, for instance, *Snickars* (1978) and *Weibull* (1983).

Research.[51] The earlier NBER-model not only presented a very detailed analysis of the stocks and flows relevant for the housing market, ranging from submodels of available vacancies to filtering and demolition submodels; it also distinguished two well described levels of micro-economic investigation: (a) an investment-theoretical approach which determines the formation of structure capital, and (b) a production-theoretical approach which takes the volume of structure services of each housing bundle to be a function of the maintenance capital and operating inputs of housing. This is another outstanding feature – still present in the Harvard model – in view of the fact that many housing models assume the supply of housing as given. With respect to the simulation of the urban market for dwelling units the NBER-model applied an allocation submodel at different levels implying cross-classification of places of residence and work, and classes of housing and households, to such an extent that a large and unmanageable linear programming problem came into existence. This problem, on the one hand, was disaggregated to provide an operational solution. On the other hand, it was reduced in size introducing ideas from the field of microsimulation.[52] To take another example, the Urban Institute model as a long-term approach centers on an iterative price mechanism guiding demand and supply on the markets of housing services. This mechanism is described in a static submodel which, apart from the simultaneous determination of prices and qualities of housing services, allocates households to housing units at a specific point in time (end of a ten-year projection period). This model, too, has undergone significant changes. For example, it became evident that there was an inconsistency in the supply behavior described by the model so that a modified and more efficient algorithm in the search for the urban housing equilibrium had to be developed.[53]

Since it is impossible to discuss the deficiencies of the housing models in detail here, some major difficulties of modeling will be mentioned in summarized form:[54] selection of the appropriate degree of complexity and disaggregation of the model, determination of time-horizon and equilibrating processes, judgment of the relevance of competing theoretical approaches (for example, maximizing utility or "satisficing"?), estimation of empirically relevant types of economic expectations, lack of knowledge on the formal model properties such as existence, uniqueness and stability of solutions, choice of criteria evaluating the quality of model structures (submodel sequencing) and empirical relationships, development of solution algorithms, absence of sufficient data and lack of insight into housing market processes. Thus, as a representative remark on all models, we may conclude

[51] Cf. *Ingram* et al. (1972) and *Kain* et al. (1977).

[52] Cf. *Harris* (1985 a), 553 - 554.

[53] Cf. *MacRae* (1982) and *Struyk / Turner* (1983).

[54] See also *Schacht* (1981).

with *Kain* and *Apgar*'s (1985), 69, final comment on their Harvard model: "Further analysis of the model's output, more numerous simulations, improvements in calibration, and additional research will be necessary before the model can be considered a reliable tool for the analysis of housing market dynamics or the evaluation of urban policies."

This modeling situation has reinforced those attempts that plead for the application of stochastic models because, under theoretical and empirical aspects, they form an appealing alternative to the deterministic models. Among the representatives of stochastic modeling *Anas* (1982) is outstanding in realizing, on the basis of stochastic choice models, a synthesis of essential results of urban economics (*Alonso*'s (1964) bid rent analysis, *Herbert-Stevens* (1960) model) and of urban development modeling (*Lowry* model, NBER-model, Urban Institute model) with the travel demand models used in transportation planning. *Anas* combines the demand-side and supply-side housing submodels into an equilibrium simulation model that endogenously determines travel and residential choices, equilibrium rents, and vacancies by geographic zone.[55] One of the chief purposes of exploration is the application of the empirically estimated model to transportation policy analysis.

2. Incorporation of Material Infrastructure

The essential preconditions for the working of the economic process organized by market mechanisms and thus for the efficiency of, most particularly, private production and capital formation may be subsumed under the headings of material, personal, and institutional infrastructure of an economy, taking the supply of land, applied technical knowledge, and human needs as given. With respect to the urban development models, institutional infrastructure explicitly plays a subordinate role via, for instance, certain parameters such as legal minimum standards. Personal infrastructure is referred to by the population variables disaggregated in different forms so that the quantitative aspects of this type of infrastructure are represented in the models. However, this is not true of the qualitative aspects, since educational issues are usually not incorporated in urban modeling.[56] In contrast to these relatively clear positions of institutional and personal infrastructure, the category of material infrastructure (social overhead capital) has been taken into account in various ways which shall be discussed in this section. As is known, material infrastructure includes transportation, education and health facilities, housing, equipment for energy and water provision and facilities for sewage, garbage disposal and air purification.

[55] The most recent application of this line of thought is *Anas / Duann* (1985).

[56] An exception may be found in *Forrester* (1969), 19.

Urban development in reality shows that material infrastructure has not only substantial impact on market results and related variables, but is also determined by them over time. The effects and the determinants of material infrastructure form a dynamic interrelationship which develops in a spiral pattern from the past into the future.[57] Since little attention has been given to systematic representation of the effects of material infrastructure in the construction of urban development models until recently, there is scarcely a hint as to the interdependencies of the effects and determinants of infrastructure, leaving out two broader fields of infrastructural analysis: housing and transportation. On the one hand, given its place of employment, the working population will choose its place of residence with regard to available housing and other given infrastructural location factors such as transportation possibilities (effect of housing production). On the other hand, the demand for housing by the working population will determine the supply of dwelling units (determinant of housing production). The housing models discussed above are basically able to reproduce this dynamic interrelationship of the effects and the determinants of housing production, if they be run recursively.

Regarding these considerations on housing we must observe that the urban provision with transport services is itself a variable in a dynamic context. The interdependency of land use and transportation may be described in the following causal circle: land use → transport demand → transport facilities → trips → transport costs (accessibilities) → land values → land use → transport demand etc. Observe that transport costs are now endogenously determined. Only few urban development models have so far concerned themselves with the investigation of this problem.[58] Most models either assume transport costs as given or pursue separate analyses of land use and transportation: the land use models taking the transport variables as constants and the transport models assuming the land use variables as given. Turning to the exceptions which treat transport costs as variables in a static or time-recursive framework, the central question refers to the existence, uniqueness and stability of the equilibrium of land use and transportation.[59] The first to tackle this problem empirically was *Putman* (1974), (1976) who later substantially extended his investigations, also studying the dynamics of his lagged response system.[60] According to *Putman* (1983), 305 - 314, we find: (a) The effects of transportation on land use act through a complex process involving direct and indirect effects and feedbacks. "... transportation per se does not cause changes in activity location and

[57] Cf. *Buhr* (1981).

[58] A comprehensive overview on twenty models describing the relationships between land use and transportation can be found in *Wegener* (1985b).

[59] A theoretical analysis is *Berechman* (1976), (1980).

[60] Cf. *Putman* (1983), (1984).

land use; rather, it permits such changes by its presence or prohibits such changes by its absence" (p. 309). (b) The link from land use to transportation is travel time, the special phenomenon being congestion; in the longer run the modified characteristics of the transportation network produce, in turn, a new pattern of land use and the system continues to develop in its cyclical way.

Putman's contribution has stimulated at least three empirically important extensions of analysis. Firstly, starting from the issue of congestion, *Boyce* (1978) and *Los* (1978), (1979) presented transport-location equilibrium models based on network equilibrium approaches familiar from transport market analysis.[61] Secondly, *Anas* (1984), (1985) generalized his model mentioned above to incorporate variable transport costs. And thirdly, to demonstrate the role of the transport system in the process of regional deconcentration, *Wegener* (1986) studied the equilibrium results of a fast-adjusting transport model, a medium-response housing market model and a strongly lagged housing construction model.

Generally, there are two reasons for the failure to adequately incorporate material infrastructure with its many facets, including the areas of transportation and housing, into the urban development models. (a) Infrastructure research indicates that relatively far-reaching disaggregation is needed in order to be able to relate material infrastructure to other demographic and economic variables. (b) Due to the complementarity of the facilities resulting from technical relationships and behavioral characteristics of locators, material infrastructure often necessitates a comprehensive view. Only by a disaggregated and at the same time comprehensive approach can the regional allocation function of infrastructure be expected to become evident. However, a stock-taking of infrastructure as implied runs into considerable problems of data collection and handling, since the categories and variables of material infrastructure, as a rule, are no mass phenomena.

Leaving aside studies on housing, the general situation of urban model formation with respect to material infrastructure may be characterized as showing clear overemphasis on transportation issues, in comparison to the analysis of non-transport infrastructure. On the one hand, this transport bias is a direct result of the key institutional role of transport modeling in developing the field of urban simulation, regarding transportation as a primary location factor. On the other hand, the overemphasis on transportation, is an indirect result of the early introduction and overall predominant role of the gravity model in modeling the spatial allocation of economic activities.[62]

[61] Further developments are *Boyce* (1980), (1984 b), *Boyce / Southworth* (1979), *Boyce / Kim* (1984), *Boyce* et al. (1983), *Chon* et al. (1983), *Kim* (1983), *Los / Nguyen* (1983).

[62] *Harris* (1985 a), 548, 550, is obviously of the same opinion.

Apart from the data problems mentioned above, the consideration of non-transport material infrastructure also suffers from the heroic implicit assumption that it has been and will be readily available, thus not constituting a problem in itself. In the given models, this type of infrastructure turns up at best in the form of occasional location factors in regression equations or of attractiveness factors in allocation functions. In the latter case the approaches have either not been calibrated or, if they have been calibrated as, for instance, in entropy models, they usually do not take account of the comprehensive view of infrastructure. To be fair, we must take note of one exception which – with respect to non-transport material infrastructure, too – estimates infrastructural needs by confronting the demand for infrastructure services with the forthcoming supply. The demand is derived on the basis of home-to-infrastructure allocation functions and usage coefficients.[63]

3. Modeling Location Decisions

Spatial allocation and location[64] stand in a dual relationship to each other: one is connected to the other through the medium of time. Location decisions result from the solution of long-term investment problems, concerning individual facilities, in a spatial context (choice of residence and place of production). Their consideration will be indispensable for the introduction of dynamic theory. Simplifying the location issue by eliminating the time dimension and at the same time extending it to include several locators leads to identification of the results of the location problem with those of the allocation problem. This is the general approach characterizing the literature on urban development models, failing to adequately distinguish between allocation and location of economic activities.[65] Therefore, many of the following aspects refer again to the framework of allocation already discussed; however, we shall also report on some exceptions that at least attempt, by the direction chosen, to model location decisions as the outflow of investment analysis.

In the literature[66], urban location problems have been discussed with reference to residential choice, industrial location, location of retail trade, services and public facilities[67], while the interdependencies of location decisions originating from different land uses are neglected in many cases. Two of these objects of analysis shall be looked at here.

[63] Cf. *Popp* (1977), 80 - 85.
[64] Cf. *Stevens* (1985), 673 - 676.
[65] Typical is *Harris* (1985), 552 - 564. See also *Bennett* et al. (1985).
[66] See *Harris* (1985).
[67] Cf. *Leonardi* (1981 b), (1981 c) and *Church / Roberts* (1983).

Leaving aside the housing models mentioned above and a number of specific studies[68] on residential choice, the majority of recently formulated residential location submodels[69] are based in some way on the work-to-home spatial relationship, without[70] or with[71] explicit micro-economic background. A minority of models are optimization models of residential location.[72]

Since industrial location forms the driving force behind the location of other activities, we shall focus on location decision-making of basic industries. Here, modeling encounters a particularly difficult data situation in view of the wide variety of locational requirements existing between and within industries, due to differences in lines of production, size of firm, and available financial resources. Consequently, the existing approaches to the simulation of basic industry locations must be regarded as preliminary attempts only at the solution of these location problems.

Essentially, there are two types of basic employment models.[73] We have one group of models which directly allocate basic employment to city zones in a continuous form. Another group concentrates on the location choice of discrete productive units (mostly expressed in terms of the employment variable). Here, we recognize the attempt to analytically separate units of production standing for the capital factor from related employment representing the labor factor.

Although the continuous function basic employment allocation models[74] are of restricted interest in this context, we must mention them here with reference to empirical aspects. With such a model giving up the distinction between basic and nonbasic employment, *Putman* (1983), 163 - 172, has derived remarkable estimation results. His basic idea may be summarized by two points: (a) the past and/or present location of employment exerts a significant influence on the future location of employment; (b) another important location factor is resident population (consumers, labor force) because of increasing suburbanization of basic employment in the past two decades.

We shall now turn to the discrete facility locating basic employment models. Among the models of gross increases in the number of basic activity

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[68] Cf. *Beckmann* et al. (1983 a), (1983 b), *Clark / Onaka* (1985), *Onaka* (1983), *Rietveld* (1984), *Shefer / Primo* (1985).

[69] For a historical review of residential location models cf. *Putman* (1979).

[70] Cf., for example, *Putman* (1983), *Putman / Kim* (1984), *Kim / Putman* (1984).

[71] Cf., for instance, *Anas* (1973), (1975) and *Bertuglia* et al. (1980), on the one hand, and *McFadden* (1978), on the other hand.

[72] Cf. *Lundqvist / Mattsson* (1983) and *Mattsson* (1984 a), (1984 b).

[73] Cf. *Putman* (1972).

[74] A discussion of these models may be found in *Buhr / Pauck* (1981).

units, the contribution of the New Haven Laboratory is still of outstanding importance.[75] It is exceptional in that it is fully differentiated with regard to the sources of the gross increases: expansion, foundation, and in-migration of firms. Moreover, its model construction allows an intelligently chosen combination of available data and reasonable assumptions on the relevant parameters. Operability and explanatory substance are only detracted from by the fact that this simulation model renounces rigorous restriction to exclusively empirical observations. Certainly, the existence of a broad spectrum of simulation results must be considered as a disadvantage of the New Haven Model. Further reference should be made in the present context to the Bay Area Simulation Study (BASS)[76] including an algorithm of activity settlement in four steps: (1) determination of suitable subregions for each industry sector; (2) formulation of an index indicating the relative supply of each location factor in each subregion; (3) weighted summation of the indices for each industry group, and (4) establishment of an arbitrary sequence of the industry groups, from which a successive allocation of employment units to the city subregions is started. In sum, the spatial distribution of basic employment is performed by successive optimization. Assignments of employment units take place one after the other without correction of earlier allocations in view of later assignments. Little attention is paid to the competition among industries for the given location factors. Since the results of successive optimization depend on the chosen sequence of the variables, this method remains unsatisfactory as long as no justification is given for a particular sequence.

Only the Industrial Impact Model (INIMP) is to be considered with respect to the models of net increases in the number of basic activity units.[77] Omitting reference to a preceding section on employment allocation, INIMP solves the location problem as follows, having excluded all urban zones unsuitable for industrial location: (1) formulation of indices stating location requirements of industries, on the one hand, and zonal location factors, on the other hand; (2) allocation of activity units in accordance with the criterion of maximum correspondence between the requirement indices and location situation indices. The question of firm sizes is settled through the application of a Monte Carlo technique. The basic problems of this model do not substantially diverge from those of the BASS-model.

Finally, we shall review the models of gross or net decreases in the number of basic activity units. Gross decreases have been analyzed in the new Haven Model,[78] analogously to the investigation of the gross increases in the num-

[75] Cf. *Birch* et al. (1974), 290 - 304.
[76] Cf. *Goldberg* (1968).
[77] Cf. *Putman* (1967), 204 - 210.
[78] Cf. *Birch* et al. (1974), 301 - 304.

ber of firm units, but considering here the decline of activities, the death and out-migration of firms. The INIMP-model[79] can be considered representative for the net decrease models; this model here again, although in the opposite direction, features the interplay of its allocation submodel and its location submodel.

The formulation of discrete facility locating basic employment models shows the course to be adopted in future research, although certain details need critical attention. To give another example, contributions such as that of the BASS-model which define the activity units by the employment variable only go half the way. In this respect INIMP, theoretically and empirically the best approach, has been constructed more carefully insofar as it distinguishes between firm units as entities of capital from the complementary amount of labor. But – and this is the most important point of critique – all known models still lack a solid reference to benefit-cost analysis which forms the core of investment analysis for location decisions.

IV. Concluding Remarks: Future Prospects of Urban Development Modeling

The parallel and unconnected advancement of applied urban analysis and theoretical "new urban economics"[80] has obviously come to an end, since urban development modeling work has increasingly shifted from city planning departments and consulting agencies to university research institutions. When discussing the present state of the art in urban modeling, we should observe that the presentation of the models is strongly influenced by the availability of solution methods, calibration procedures and suitable data.[81] We shall not give special mention at this point to any particular topic for future research, because we have raised many issues in this paper and there is ample evidence on this question in the literature.[82] Certain phenomena have not been dealt with above, for instance, urban migration. Related aspects such as land use and energy or environment have also been neglected.[83] However, two research topics will be of general importance: the explicit introduction of the objectives of urban development and the reformulation of modeling in dynamic terms. The incorporation of objective functions corresponds to the allocative nature of urban development models from the theoretical point of view and will facilitate, assisted by the scenario technique[84], the implementation of modeling results in urban planning and policy

[79] Cf. *Putman* (1967), 203 - 204.

[80] Cf. *Richardson* (1977).

[81] Cf. also *Wilson* (1984).

[82] Cf., for example, *Buhr / Pauck* (1981), *Anas* (1982), *Putman* (1983), *Boyce* (1985), *Harris* (1985).

[83] Cf. *Burchell / Listokin* (1982), *Horowitz* (1982), *Ferreira* (1985).

[84] Cf. *Junker / Zickwolff* (1985).

from the practical point of view. Dynamic analysis will permit location problems to be pursued as dual aspects of allocation questions.

The re-enforcement of the role of urban modeling in future city planning will depend to a high degree on the organization of supporting institutions such as (a) the cooperation among cities to create a generally accepted interregional projection model as a basis for modeling urban development; (b) the cooperation between model builders and model users, considering the participation of citizens and politicians in the resolution of urban problems; and (c) the permanent monitoring of modeling success followed by changes in model construction and estimation. As the state of the art in empirical urban modeling presents itself today, urban development models may be used as quantitative tools of learning-by-doing in practical city planning.

Summary

In this review paper, urban development modeling is considered as a branch of empirical allocation analysis relying on the concept of markets. With reference to recent research, the introduction of essential methodic approaches such as techniques of microsimulation and different sources of dynamic theory is discussed. A critical evaluation of selected aspects of urban simulation modeling concentrates on the analysis of markets (transport, housing), the incorporation of material infrastructure (land use-transportation interrelationships), and the consideration of location decisions (residential choice, basic employment location) as dual counterparts of the associated allocation problems. Concluding remarks deal with future prospects of urban development modeling.

Zusammenfassung

Dieser Überblicksaufsatz faßt die Formulierung von Stadtentwicklungsmodellen als ein Teilgebiet der empirischen marktorientierten Allokationsanalyse auf. Mit Bezug zur gegenwärtigen Forschung wird die Einführung wichtiger methodischer Ansätze wie Techniken der Mikrosimulation und Beiträge der dynamischen Theorie diskutiert. Eine kritische Würdigung ausgewählter Aspekte der Modellbildung befaßt sich mit der Untersuchung von Märkten (Verkehr, Wohnungswesen), der Einbeziehung der materiellen Infrastruktur (Zusammenhänge zwischen Bodennutzung und Verkehrswesen) und der Berücksichtigung von Standortentscheidungen (Wohnortwahl, Standortwahl der Basisbeschäftigung) als Dualaspekte der zugehörigen Allokationsprobleme. Die abschließenden Bemerkungen beziehen sich auf die Zukunftsaussichten für die Konstruktion von Stadtentwicklungsmodellen.

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