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12. Revised by

Oscar Pereira Dias Jr.

9. Authorship *Damaceno Dal Bianco*
Odwaldo Bueno Netto Jr.
Maria Suelena Santiago Barros
Celso de Renna e Souza

Responsible author

13. Authorized by

Nelson de Jesus Parada
Director

14. Abstract/Notes

A systemic urban growth model for cities with developing country characteristics is presented. The model is divided in two sections: the first addresses the question of household location under uncertainty (with demand and supply sub-models) and the second, the location of commercial and service activities, considering accessibility and the potential market created by the resident population. The model and methodology were applied to São José dos Campos, São Paulo State, Brazil, as part of a method to plan telephone network expansion. The computer Monte Carlo technique was used to simulate the model's operation.

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MODELLING URBAN SPATIAL STRUCTURE IN DEVELOPING COUNTRIES

Damaceno Dal Bianco
EMBRAER - Empresa Brasileira de Aeronáutica S.A.
12200 - São José dos Campos, SP - Brazil

Odwaldo Bueno Netto Jr.
IPT - Instituto de Pesquisas Tecnológicas
05508 - Cidade Universitária, SP - Brazil

Maria Suelena Santiago Barros
Celso de Renna e Souza
INPE - Instituto de Pesquisas Espaciais
CNPq - Conselho Nacional de Desenvolvimento Científico e Tecnológico
12200 - São José dos Campos, SP - Brazil

I. INTRODUCTION

In city planning, the city is nowadays viewed as a complex system. The use of models to express relations between elements of such systems through mathematical equations has been earning increased respect, insofar as the results have been shown to be consistent with observed reality.

Models formulated abroad bring with them certain implicit assumptions about the structure of urban space, which are only valid in the context of the prevailing socio-economic conditions within the industrialized countries for which they were conceived. It is thus hardly feasible to take such models out of context by transposing them to urban areas of developing countries.

Some characteristics of developing countries fail to fit into models from developed countries. They include low percapita income, irregular and deficient distribution of urban infrastructure, extremely high demographic growth rates, and "favelas" (shanty towns).

The concept of homogeneous zone (HZ) has been used extensively in the present study. Sectorization of the urban area into HZ's provides objective and suitable city planning criteria, reducing as well the variance of socio-economic and demographic variables; through an analysis of the urban texture in aerial photos, it is possible to identify homogeneous physical spaces, called "homogeneous zones", to which correspond socially and culturally consistent human groupings[3].

Using urban sectorization methodology based on the concept of HZ, a method was developed by the authors for planning the structure of urban space in such a way as to take into account the characteristics of Brazilian cities. The computer Monte Carlo technique was used to simulate the model's operation.

II. SYSTEMIC FORMULATION OF URBAN GROWTH

There are two sections to this systemic formulation of the urban growth process. The first addresses the question of household location under uncertainty (demand and supply).

A.1. Residential Location Demand Model

This model utilizes income, building standards (in the sense of building quality), and urbanization level of the neighborhood as the decision-making variables.

A "household" is defined as a group of people living in the same dwelling and earning a given total income (Y).

The house construction standard (H) is defined as a measure of the physical features of the house. The urbanization level (L) is defined as a measure of the physical and social features of a neighborhood in a given HZ.

The household utility function, U, is represented by $U = U(X, H, L)$, where X is a set of itens not associated with the building itself, such as cars, educational level of the group constituents, etc. The household is subject to a budget limitation, as follows:

$$Y - \theta X - CH - R_j = 0, \quad j = 1,\ldots,J \tag{1}$$

where θ is the "price" of the aggregate X, C is the construction cost, and R_j is the cost associated with locating the household in ZH_j, corresponding to transportation costs and price differentials for land plots. Maximizing the utility function for the household and addressing the analysis to each homogeneous zone ZH_j, we have:

$$MAX\ U_j = U(X, H, L_j); \quad j = 1,\ldots,J \tag{2}$$

Within any given city, prices of nonresidential goods to not vary from one HZ to another in a way which is related to their location. This assumption means that the cross elasticity between residential and non-residential features is equal to zero or virtually zero. The equation (1), then, can be broken down into utility of residential (V) and nonresidential (W) features:

$$U_j = V(L_j, H) + W(X) \quad , \qquad (3)$$

In order to be able to compare the utility of the various HZ's, it is convenient to express the utility of each zone in terms of/urban quality (L_j; H), and of an extra term corresponding to the difference between the transportation costs and price differential for the plot in HZ_j, and those for a household which chooses HZ_b. Thus, we have:

$$U_j = V(L_j, H) + W(X_b) + K(R_b - R_j); \qquad (4)$$

K = constant

The household will choose HZ_j if:

$$V(L_g, H) - V(L_j, H) - K(R_g - R_j) > 0, \text{for } g \neq j \quad g = 1,\ldots,J \qquad (5)$$

subject to the limitations of the households income, expressed by equation (1).

The household will thus be located in the HZ which maximizes the satisfaction of its needs, with a rational allocation of its income. This representative behavior is subjected to a random component (ξ), which describes the idiosyncracies of an individual household, in order to achieve a better fit with the urban supply of houses, which have the desired construction features in a neighborhood with the desired urbanization level. Therefore,

$$U_j = F_n(L_j, H) + \zeta \quad , \qquad (6)$$

where F indicates the representative behavior of the household's set whose income bracket is n.

The parameters of equation (6) are obtained by stratified sampling of households, by HZ, of the city under survey. The demand model will be, then, a joint probability function for house construction standards and urbanization level in the neighborhood, for each income bracket. The households' income distribution profile is projected along the planning horizon and is used in combination with demographic projection, to obtain the number of new households which are to be located in any period within each income bracket, by simulation. The existing households are relocated through the probability distribution function as the fraction of households of each income bracket that have moved in recent years. The projection of demand for urban plots, at each neighborhood urbanization level, is obtained subjected to the constraints of supply of such locational facilities. The demand and supply of construction space interact and achieve equilibrium through a progressive saturation of the absorption capacity of each HZ, given by the supply model for residential location.

A.2. Residential Location Supply Model

The supply of residential locations is based on a model proposed by Clark[1]. In this model, the distribution of household density on urban land (d_x) at a distance (x) from the District Commercial Center (DCC) tends to be negatively exponential from the DCC outwards, though care must be taken to exclude areas with institutional use and areas which are unsuited to urbanization. Its mathematical expression is:

$$d_x = d_0 \, e^{-b_x} \quad , \qquad (7)$$

where d_0 = the density of households in the DCC and b is a parameter. The urban space can be divided into radial sectors, to each of which corresponds a main development axis. This allows the model to be applied by taking into account the specific contingencies of topography and the historical trends of land use. A progressive saturation of the areas at each urbanization level is achieved, until all households to be located have been exhausted.

B. Nonresidential Activities Location

This second section addresses the location of commercial and service activities, considering accessibility and the potential market created by the resident population.

The location of establishments is a function of their potential market (M), and thus depends on the degree to which they are accessible to consumers. The size of the establishment, represented by the number of employees (E), is a further factor in determining its locational behavior.

The attractiveness of a commercial establishment, and by extension its profitability, is therefore a function of these two factors: accessibility and size.

Modelling the process of choosing location and operating size is approached to the viewpoint of decision under uncertain conditions, and the structure of the model, therefore, is as follows:

$$G_{p,E} = G(M_p, E) + \xi \quad , \qquad (8)$$

where $G_{p,E}$ = the profitability of the location in the commercial zone p, with E employees.

The potential market of a commercial zone, M_p, will be given by the total sum of markets (M_j) in the homogeneous zones ZH_j, located in the same urban sector affected by an accessibility function (A).

$$M_p = \sum_{j=1}^{J} (M_j \cdot A_p) \quad , \tag{9}$$

The accessibility function (A_p), as considered in this paper, is of the gravitational type. The potential market (M_p) determines the number of establishments (N_p) by means of a function of the Cobb-Douglas type:

$$N_{p,e} = \alpha M_p^{\beta} E^{\mu} + \xi \quad , \tag{10}$$

where α, β, μ are parameters which can be determined by using sampled data.

Industrial plants are located exogenously, in compliance with local regulations governing land use.

III. OPERATION OF THE MODELS

This above methodology was applied to São José dos Campos, State of São Paulo, Brazil, as a constituent part of a method aimed to plan telephone networks[2], but can easily be applied to planning of a wide range of infrastructure and urban services.

The models were calibrated using data obtained from a sample survey conducted in 1978 from Municipal Land Use data files, and Business data files.

They were validated using data obtained from aerophotogrammetric mosaics of the city in question for 1962, 1972 and 1977. This validation comprised an application of the model for the year 1962 and reconstruction of the city in successive iterations up until 1978.

Initially, the location demand of a household is obtained through sequential rank-ordered sampling for two levels of decision-making, given the household's income, which is exogeneously determined. Housing level and urbanization level are defined by their probability distribution functions.

The next step was to simulate, using the same technique, the choice of an axis of the town and an HZ on this axis.

Such an HZ must be able to absorb the households defined in the supply model. This process is repeated until all the units to be located are exhausted, for the simulation period considered.

For each iteration of nonresidential location, the potential market for each HZ is calculated in terms of the households already located.

The accessibility function which best represents the town is calculated on the basis of the geometry of road networks and population data. The next step is to simulate the location of business and service establishments. In mixed-use zones (commercial and residential), no notice is taken of variations in residential density due to the location of commerce and services, and commercial zones are excluded from the supply model as areas available for residential location.

The short processing time required for each simulation run using these models makes it feasible to perform the necessary number of runs in order to obtain results within the desired reliability and precision. Finally, it should be stressed that, while there is no inherent limitation to the models with respect to the size of the city to be modelled, care must be taken with particularities of each city and developing country.

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