Regional Development and Land-Use Models

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INTRODUCTION

In the brief history of IIASA's involvement in urban research, first in the Urban project and now in the Human Settlements research area, emphasis has been placed on mathematical models of urban growth and public policy in a national settlement system (see Figure 1). Commonly, in this kind of research, each city or settlement is treated as a point in a network of urban centers linked by transportation and communication facilities or by some organizational connection. Certain useful kinds of behavioral and policy theorems can be derived from elementary models based on such an abstract conceptualization.

There are, however, a whole class of urban growth processes that operate either in the immediate vicinity of an urban center or in that small subset of the national settlement system representing neighboring cities and towns. The urban network approach

Figure 1. Urban and regional research at IIASA.
used at the national level is not satisfactory at the regional level. Instead of treating cities as abstract points in space, one must put emphasis on the continuity of space. Regional land-use models are preferable because of their specific emphasis on land areas and spatial patterns of land use.

It is toward an examination of these regional growth processes, their controllability and their optimality that the present research has recently been started. The purpose of this short-term project is to undertake a review of the use of mathematical models in analyzing such growth issues. This research is serving to outline some potential research issues to which the Human Settlements and Services area might contribute, within the Integrated Regional Development (IRD) program. In addition to this in-house purpose, the research will contribute to IIASA's clearinghouse role by reviewing recent major advances in these topics.

TOPICS AND LINKAGES

The purpose of this research is to analyze the processes underlying the spatial pattern of regional development. Two topics of research have been identified (see Figure 2). The

![Figure 2. Main research questions in RDLUM.](image-url)
first is concerned with the problem of designing a spatial arrangement of land uses which, in some sense, "optimizes" regional development from society's point of view. In previous research, the design problem has virtually always been treated abstractly. There has been no attention paid to the questions of how this development is to be managed or how it is to be integrated within the market sector of society, where this exists. The design problem has been to determine where facilities or land uses should be placed, and how much of them there should be to optimize some objective function.

The abstract nature of this design problem makes it applicable to many kinds of societies, both East and West. However, every society operates within a particular institutional structure and its own division between central planning and decentralized or market decision-making. Given that some notion of an "optimal" spatial pattern of regional development can be found, most governments are faced with either of the following problems: they are not able to manage the proposed development, or the market sector behaves so as to thwart the optimal plan. To counter these problems, the government typically has to find policy tools and strategies to shift the regional development process toward the optimal solution. This constitutes a second topic of research, one that has been virtually ignored in previous research.

This research has many potential linkages with other areas and programs at IIASA (see Figure 3). The outputs of this work can be incorporated into the IRD program. The inputs could come

Figure 3. Potential research linkages with RDLUM at IIASA.
from several sources. The Resources and Environment (Ecology) area could, for instance, contribute to an integration of land-use design and air quality management models. The System and Decision Sciences area could contribute toward the research on optimization models. Finally, the current activities of the Management and Technology area could be integrated directly into the development management topic.

To give some detail and flavor to this discussion, let us consider briefly the work that has been done on optimal land-use design models at IIASA.

OPTIMAL LAND-USE DESIGN MODELS

In research to date, progress in the development of optimal land-use design models has been evaluated. In particular, the ways that design problems have been cast previously as mathematical programming models have been studied (see Figure 4). This involves looking at how the instrument variables in such models are designated, what kinds of constraints are allowed for, and how the objective function is formulated.

As an example, Dickey and Najafi* have described an application of their TOPAZ design model to the New Valley Planning District of Virginia in the USA, an area of approximately 120,000 hectares. This region was subdivided into 40 zones. The 200 instrument variables in the TOPAZ model are the assignments of aggregate new development (over the next 20 years) in five different categories of land use (including residential, commercial, industrial, public, and park land uses) among each of the 40 zones. The objective function of the TOPAZ model to be minimized is the sum of the establishment costs (including land purchase and preparation, facility provision, and building construction) for each land use allocated to each site, and the capitalized value of the anticipated resulting transportation flows among zones. In the model, there are constraints which assert that, for each of the 40 zones, the amount of land allocated to each use does not exceed the amount of developable land in that zone. In addition, there are five other constraints. Each asserts that, for a given land-use type, there is a minimum total amount of land which must be allocated among the 40 zones. Although this is only one specific case, the TOPAZ model has several features in common with virtually all other design models: a gross-scale representation of the region as a finite set of homogeneous zones, an orientation toward development cost minimization, a fixed-planning horizon for new development, and

### Mathematical Programming Approach: A Typical Land-Use Design Model

**Minimize:**

\[ Z = f(x_{i1}, x_{i2}, \ldots, x_{in}, x_{j1}, \ldots, x_{jm}) \]

**subject to:**

\[ \sum_{i=1}^{m} x_{ij} \leq S_j \quad j = 1, 2, \ldots, n \]

\[ \sum_{j=1}^{n} x_{ij} \geq D_i \quad i = 1, 2, \ldots, m \]

\[ S_i(x_{i1}, x_{i2}, \ldots, x_{in}, x_{j1}, \ldots, x_{jm}) \geq c_i \quad i = 1, 2, \ldots, k \]

\[ x_{ij} \geq 0; \]

**where:**

- \( n \) = zones,
- \( m \) = land uses,
- \( k \) = design standard constraints,
- \( Z \) = discounted stream of development costs,
- \( S_j \) = supply of developable land in zone \( j \),
- \( D_i \) = aggregate land requirement of use \( i \),
- \( x_{ij} \) = real assignment of land use \( i \) to zone \( j \).

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**Figure 4.** Research approach to optimal land-use patterns.

Constraints ensuring that no zone's capacity for development is exceeded and no land use's aggregate demand for space goes unmet.

In the brief research to date, several major methodological issues have been raised concerning the theoretical foundations of such models and the transition from a theoretical to an applied planning tool. These issues should form the basis of a next stage of research. They include the following questions. To what extent can the objective function of such models be expanded to include criteria other than cost minimization? To what degree can uncertainty about future social conditions be...
incorporated to yield a more "robust" or resilient optimum? Can the concept of a fixed planning horizon be replaced by a more dynamic and open-ended design model? Finally, how can the interdependencies among land uses, as for example, those created by air pollution, be incorporated in these models? A main conclusion of the research at IIASA at this stage is that we are a substantial way off from realistic empirical applications of these models. However, research on the above questions can move us considerably closer to that goal.

CONCLUSIONS

The emphasis in this research is on the processes that affect the development of human settlements at the regional level, the extent to which such processes are controllable, and the extent to which an optimal spatial pattern of development can be delineated. Our approach is to use mathematical models to look at these issues. Thus, commitment to a theoretical framework, with a concurrent emphasis on the ultimate empirical applicability of the research, is in keeping with IIASA's potential role in integrated regional development.