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Urban dynamics and multiple-objective programming: A case study of Beijing

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Abstract

This study serves as a primary application of the integrated system dynamics and multiple-objective programming (ISDMOP) model for strategic planning of Beijing city, which is here divided into six subsystems as population, resources, energy, economy, environment and ecosystem, with the planning horizon spanning from 2003 to 2020. Comparison between the original system dynamics (ORSD) model based on the existing economic structure of Beijing and the optimized system dynamics (OPSD) model adjusted according to the solutions of the multiple-objective programming (MOP) are conducted. The developing trend of each subsystem is simulated and illuminated, based on which constructive suggestions are provided for urban strategic planning of Beijing. The ISDMOP model is proved effective for investigating urban dynamics and realizing the multiple-objective programming.

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1. Introduction

1.1. Urban strategic planning

Characterized by high level, multiple hierarchy and dynamical structure, cities are typical examples of "complex system" that are combinations of components acting together to perform specific objectives and have many unexpected and little understood characteristics [1,2]. As environmental–economic–social compounds, cities evolve along the life cycle of growth, maturity and stagnation, and behave according to the

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inner changing mix of the factors involved under the support and constraint of the social and biophysical environment. As key nodes in the temporal and spatial network, cities focus many of the concerns underlaying current debates on long-term sustainability [3].

The interactions between the environmental, economic and social variables make it difficult to develop both short-term reactive initiatives and long-term strategic plans. Of all the difficulties, the coordination of economic development with environmental and ecological improvement is regarded as the toughest one. Guide for effective planning requires comprehensive understanding of the inherent inter-linkages and structures impacting urban development and identification of the desirable and undesirable interventions.

Urban strategic planning is a hot paradigm attempting to direct city towards a harmonious development of the inner subsystems. It is a typical planning with multiple-objectives following a need to describe and evaluate the city in diverse dimensions. Early static analysis is found to be difficult to describe the dynamic evolution of urban structures. Multiple-objective programming (MOP) and system dynamics (SD) are thus adopted to regulate the urban structure and the function of the subsystems involved according to the objectives identified by decision maker's needs and desires, and to describe the inner interactions among the subsystems, illuminating the evolving process and predicting the development trend of the whole city.

1.2. Multiple-objective programming

Multiple-objective programming originated from the multiple-objective optimization procedure, which can be traced back to the economic theory proposed by Pareto in 1896. As a valid and useful tool for management and planning, MOP is appropriate for the harmonious urban development, allowing objective decision against former intuitional one, and permitting comprehensive consideration of social preferences, economic demands, and environmental conservations, and has gained over the years popularity in the urban planning field [4–6].

On the other side, defects of MOP have emerged in practical urban applications. Foremost, obtaining the solutions appears to be a tough job when the target system is complex with too many variables. The identifications of the strategic variables are usually based on the experience and understanding of experts. Urban planning involves a great many of parameters, of which some are significant, while the others are not, to the evolvement of the target city. To establish a more objective and effective MOP model and simplify the solving process is the central problem facing MOP. Furthermore, since MOP focuses only on a target year and merely offers the prediction information of the end year of the planning, it fails in simulating and illuminating the evolving trend of the target system during the whole planning horizon.

1.3. System dynamics

System dynamics (SD), once termed of "industry dynamics", dealing with the mathematical modeling and response analyses of systems with a view toward understanding the system dynamic nature and improving the performance, is one of the most outstanding contributions of Forrester. In fact, the scope of "industry dynamics" is too restrictive, concerning much wider applications other than industrial management [7,8]. Since reported in 1960s, SD has been applied to different natural and social fields including global environmental problems [8–10] and national and regional sustainability [11–17].

The original application of SD in urban systems initiated in 1960s', when Forrester's work on "industrial dynamics" converged with the efforts of Professor Jone F. Collins to focus on the troubles of cities. An outstanding work, titled "*urban dynamics*" examining the nature of urban problem, modeling the dynamics of urban decay and revival, has been generated and brought forth the new era of the urban system dynamics [1]. Thence, urban dynamics attracts lots of attentions [6,18,19]. For the complicated urban development and evolution, the urban SD can be an appropriate approach to reflect the driving forces, incorporate individual subsystems into a general framework and analyze their interactions, thereby providing holistic understanding of the environmental concerns as well as the relevant policy responses for urban sustainability.

Complementary to MOP approach in practical urban strategic planning, SD facilitates a comparatively objective identification of the relative sensitive parameters (RSP) and permits the forecasting of the evolving trend of the target system. However, SD is still confronted with the subjectivity when carrying out the strategic planning by scenario analyses, since the alternative proposals for the structure variation and the regulation of