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Modeling the population and industry distribution impacts of urban land use policies in Beijing

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ABSTRACT

Capable tools are desired for urban spatial policies planning in China to safeguard its sustainable development strategy. This study develops an activity-based Land Use/Transport Interaction (LUTI) model to forecast the urban activity impacts of the land-use policies. Essentially, its endogenized and interactive features in residential and employment distribution modeling mark it out from the traditional Lowry models. The LUTI model proposed consists of four models, i.e., a transport sub-model, a residential location model, an employment location model and a real estate rent model. It is then applied to the Beijing metropolitan area to characterize the urban activity evolution trend under the land use policies of recent years. The results show that with the increasing number of floorspace developed on the outskirts, more residents and employers are relocating there and sub-centers are formed to divide the service of central Beijing. This trend is consistent with the objective of government planning to develop more sub-centers around central Beijing by decentralizing industries to guide residential population growth patterns. The model provides a capable planning tool for urban spatial policy makers and demonstrates its first success in Beijing scenario.

1. Introduction

The present study addresses the issue of urban development from the perspective of the spatial evaluation of urban activities. China has been undergoing a period of rapid and large-scale urban development (Gu and Pang, 2009; Liu et al., 2012). This ongoing process has resulted in increasing adverse effects for environmental and social systems. As a result, urban sustainable development has become one of the most widely discussed issues in urban studies in China. A new type of urbanization strategy in China is now being implemented, intended to bring more people into cities. In this context, urban planners are seeking scientific urban spatial polices for sustainable development. As such, modeling the impacts of urban spatial policies is of great significance for China's decision-makers to develop sustainable development policies.

There is a long tradition of modeling urban growth and development processes in geographic and urban studies. Urban spatial development has historically been focusing on key dynamics or driving forces, key factors, characteristics, effects and trends (Zeng et al., 2015; Haregeweyn et al., 2012; Liu et al., 2012; Liu et al., 2011; Verburg et al., 2009). In China, the most commonly used methods for modeling urban spatial development are Cellular Automata (CA) based models for urban land-use change analysis. The CA-based models mainly concentrate on urban morphology (Deep and Saklani, 2014; Long et al., 2013; Wang et al., 2013; Lagarias, 2012). The corresponding data mainly used is survey land-use data, satellite remote sensing data (Wang et al., 2013; Powers et al., 2015; Jing and Jianzhong, 2011) and physical land use statistics.

However, the rules of interaction between urban activities through transport systems have been studied to a lesser degree, though there are intensive interactions between transport activities and land use planning decisions (Reisi et al., 2016). Besides, there is significant potential and need for enhanced modeling research on changes in the spatial distribution of urban activities in China, where social and economic activities are the essence of a city's development. China's economic reforms have empowered the growth-oriented local governments. Urban land has become a central concern of governmental officials for local economic growth and even rent seeking (Gao et al., 2014; Wei, 2012; Ding and Lichtenberg, 2011). While the urban development and specialization is influenced by state priorities for certain types of development (Zhang, 2000; Liao and Wei, 2014), as a result, the government, not simply the marketplace, has a responsibility for land use change. In this context, a model to forecast urban development trends in terms of the spatial pattern of urban activities is required.

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A city comprises a diverse range of activities, and the evaluation of how these activities spatially interact with each other through transport is an important piece of understanding urban development. As a result of this interaction between activities and transport, the concentration and spatial distribution of activities changes continuously with the urban development. The urban land use/transport interaction model (LUTI) has proven to be an important and effective tool to model the interaction process (Geurs and Wee, 2004; Pierlugi et al., 2013).

Lowry gravity land use model (Wang, 2014; Garin, 1966; Lowry, 1964) as an equilibrium model was one of the first LUTI models. The model estimates and allocates the regional retail employment, residential population and land use to sub-areas within a bounded region through the interactions between the land-use and transport systems driven by gravity formulation. However in practice the drawing boundary between basic and non-basic sectors is not straight forward, especially for large cities such as Beijing. Additionally, the model assumes the basic sectors' locations are exogenous while the decisions on the selections are always influenced by the local residents and sectors. The alternative category in LUTI models is economic models, essentially based on the theory of consumers' behaviour and firm in utility or profit maximization (Wilson, 1998). Contrary to the gravity-based models, utility-based economic models capture the complex choice behavior dynamics involved in land-use and transport decisions at the individual level and address the locational characteristics (Acheampong and Silva, 2015; McFadden, 1978). Complexity theory and general systems theory based on agent-based approaches to model cities as complex adaptive systems have also been introduced into the field of LUTI modelling (Batty, 2007).

Though with the merits of these, few studies in China focus on the LUTI model and there are still no successful applications of LUTI to support decision making to the best of our knowledge. The development of the state-of-the-art LUTI model has a long history and is considered to be activity related (Pierlugi et al., 2013; Brandi et al., 2014) though an activity-based LUTI model is never put into practice. Under this background, based on both Lowry gravity type of models and economic type of models, we develop an employment and household activity-based LUTI model, taking the Beijing metropolitan area as a study case to model urban activity impacts of land-use policies.

The paper proceeds as follows: Section 2 provides a brief review of the literature of the LUTI model and describes the new model in detail. This is followed in Section 3 by an application of the model to evaluate the impacts of land-use policies in Beijing. Section 4 describes the main results, outcomes and further research.

2. The model development and case study

2.1. Overview the LUTI model and rationale

LUTI models combine theory, data and algorithms to provide an abstract representation of the interaction between the two main components of urban areas: the transport and land use subsystems (Torrens, 2000). The term 'land-use' in LUTI models does not refer to the physical use of land by buildings or transport infrastructure, instead, it tends to refer to the social and economic activities which use space, in particular, where people live and work. In many cases, the space is measured in terms of the quantities of floor space rather than land (Simmonds and Feldman, 2011). A LUTI model is essentially a land-use model linked to a transport model in such a way that each one influences the other. The land-use (represented by population and employment etc. activities) forecast by the land-use model is used by the transport model to generate the demands for transport. Similarly, the travel costs and times forecast by the transport model resulting from the interaction between those demands for transport and the supply of transport are used in the land-use model in calculating accessibilities which, to some extent, influence subsequent land-use changes.

LUTI models have traditionally been used to simulate the possible effects of introducing new policies and projects into existing urban systems and, especially, those related to transport (Zondag et al., 2015; Mohammed, 2014; Foot, 1981). There are quite a few LUTI models that have been developed. The model proposed by Lowry (1964) is a classic LUTI model and was a milestone in the development of LUTI modeling techniques. Later on there were a number of different LUTI models in terms of their objectives and implementation. Wegener (2004), Waddell et al. (2007), Iacono et al. (2008), Timmermans (2003) and Pierlugi et al. (2013) have classified LUTI models found in the literature based on different criteria. Beyond urban planning policy applications, LUTI models are increasingly used in sustainability analysis (Kenji and Masanobu, 2012).

This study develops a LUTI model concentrating on the interaction between residential activities and employment activities to analyze the impacts of urban land use. In contrast to the Lowry model based on the distinction between basic sector and non-basic section, the model is developed by activity.The model assumes that the location/relocation of every activity is based on the ability to maximize their utility/profits, which is affected by real estate rent and accessibility etc., therefore, the change of location utility causes the change of activity distribution. An estate rent model is developed to adjust the rent in an iteration of the modeling.

2.2. Beijing Land Use/Transport Interaction Model

2.2.1. Model description

The activity-based model is named Beijing Land Use/Transport Interaction Model (BJLUTI), with a target of primary use in China's Beijing metropolitan area. However it can be applied to other cities with minor adjustment.

Traditionally in a Lowry model the non-basic sector employment and local population are shaped by the pattern of basic employment, and thus leaving no option but an exogenously-given residential pattern, whereas for Beijing scenario, the residential land uses are tightly planned by the government. Therefore the BJLUTI model adopts an activity-based approach. The BJLUTI model estimates variations in the location of urban activities including household and employment activities to forecast the spatial pattern of urban activities when faced with changes that are associated with the land use system or transport system, such as the introduction of new land use policies or new transport modes. Directly, the residential distribution is determined by residential land uses planned by government, residential location cost and the transport accessibility; the employment distribution is endogenously determined by commercial rent cost and the destination accessibility. Indirectly, the residential distribution and the employment distribution influence each other and evolve at a dynamic equilibrium. The model mainly concentrates on the interaction between residential activities (i.e., housing) and workplace (i.e., employment) in terms of work commuting.

The transport model calculates accessibility by zone based on the transport network and the spatial distribution of urban activities. The land use model calculates the location of activities based on accessibility from the transport model and other factors including land use policies (Fig. 1). The interaction between the sub-models is solved through an equilibrium solution, that is, any change occurring in the territorial system to lead to a new equilibrium solution representing the new state of the system.

2.2.2. BJLUTI model components

The integrated system is made up of four interrelated sub-models: a transport model, a residential location model, an employment location model, and an implicit rent adjusted model. Each sub-model is illustrated in detail below.

2.2.2.1. Transport model. Here the transport model adopts an exponential distance decay function instead of the power function, as