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Evaluating the effectiveness of urban growth boundaries using human mobility and activity records

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ABSTRACT

We proposed a methodology to evaluate the effectiveness of Beijing's Urban Growth Boundaries (UGBs) using human mobility and activity records (big data). The research applied data from location check-in, transit smart card, taxi trajectory, and residential travel survey. We developed four types of measures to evaluate the effectives of UGBs in confining human activities and travel flows, to examine the conformity of urban activities with the planned population, and to measure the activity connections between UGBs. With the large proportions of intra- and inter-boundary travel flows and an overwhelming majority of check-ins inside the UGBs, the research concluded that Beijing's UGBs were effective in containing human mobility and activity. However, the connections between UGBs, indicated by the spatial differentiation of the travel flows, were not consistent with the plan's intention and strategy. It indicated the potential underdevelopment of the public transit serving several new cities.

1. Introduction

Evaluation of plan implementation is important because it reflects the extent to which a plan succeeds in predicting, guiding, and controlling future urban development. One common way to determine what a plan has accomplished is to measure the conformance degree between the actual outcomes or impacts and the proposed plans. By doing so, planners can acquire insights on how the planning decision-making process operates and validate whether planning efforts do contribute to goal achievement (Alexandar & Faludi, 1989; Alexander, 2009; Laurian et al., 2004; Talen, 1996b). This evaluation helps establish a responsive and accountable plan-making and -implementation process, thus improving the overall quality of planning. Since the early 1970s, numerous studies have contributed to the theoretical and methodological understandings in the field of planning evaluation. A few studies have illustrated the evaluation approaches with one particular aspect of planning, including land development (Alterman & Hill, 1978; Berke et al., 2006; Chapin, Deyle, & Baker, 2008), environmental planning (Brody & Highfield, 2005), public facilities and infrastructure (Laurian et al., 2004; Talen, 1996a), and urban sprawl control (Altes, 2006; Brody, Carrasco, & Highfield, 2006; Nelson & Moore, 1993).

In this study we focused on assessing plan implementation in terms of the effectiveness of urban growth boundaries. As one of the most widely adopted urban containment policy tools, urban growth boundaries (UGBs) have been used to control the expansion of urban areas, increase urban land use density, and protect open spaces (Pendall, Martin, & Fulton, 2002). The basic concept of implementing a UGB is to set a physical boundary separating urban and rural areas. Usually, urban developments are not allowed outside the predefined boundary. Broadly speaking, the implementation of UGBs also encompasses various regulatory techniques such as zoning and land development permits. Proponents argue that urban growth boundaries may have at least the following six merits (Staley, Edgens, & Mildner, 1999): (1) preserve open space and farmland; (2) minimize the use of land generally by reducing lot sizes and increasing residential densities; (3) reduce infrastructure costs by encouraging urban revitalization, infill, and compact development; (4) clearly separate urban and rural uses; (5) ensure the orderly transition of land from rural to urban uses; and (6) create a sense of community. An increasing number of cities in the U.S. and Europe have regarded UGBs as a key tool in controlling urban sprawl. However, the empirical

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studies measuring the effectiveness of UGBs are not common. This is partly because that plan implementation evaluation has rarely attracted adequate attention in the planning profession. It has been an afterthought to the planning decision-making or implementation framing (Berke et al., 2006; Talen, 1996a). The lack of data, robust evaluation theories and methodologies, as well as of the linkages between theory and practice are among some of the major reasons for its limited applications in planning practices (Brody, Highfield, & Thornton, 2006; Laurian et al., 2004; Oliveira & Pinho, 2010; Talen, 1996a, 1996b).

In addition to these general issues, the development of UGBs implementation evaluation has also been constrained by the oversimplified evaluation dimension. To date, most relevant studies focused on assessing the physical outcomes, that is, the degree to which the actual urban extent and development layout conform to the proposed UGBs. For instances, several studies utilized remote sensing images and geographic information system to track land use/cover changes (e.g. Hasse, 2007; Hepinstall-Cymerman, Coe, & Hutyra, 2013). Among them, Han, Lai, Dang, Tan, and Wu (2009) examined the effectiveness of the UGBs in Beijing over two planning implementation periods, 1983–1993 and 1993–2005, and concluded that the UGBs failed to contain urban growth. Some studies focused on analyzing the driving forces of the urban expansion (Boarnet, McLaughlin, & Carruthers, 2011; Brueckner & Fansler, 1983; Burchfield, Overman, Puga, & Turner, 2006; Long, Gu, & Han, 2012). Using quantitative techniques such as regression models, these studies helped identify the effects of particular variables (e.g. planning and political elements like UGBs, built environments, and socioeconomic attributes) on urban expansion or land development. Ideally, one could look into the land use data to examine the land use changes. However, in China, an accurately and timely monitoring of land use changes is never an easy task. A comprehensive land use survey of a Chinese city may take as long as 10 years, and even longer in some large cities. Even after planners acquire the results of the most recent land use survey, they may find that the data are either inadequate or inaccurate. Polygons in land use maps are usually very big, omitting much useful information. Also, some areas that have been lately developed as urban uses or urban infrastructures may still be marked as agricultural use (Long & Liu, 2013). Due to the burdensome task to provide real-time changes of land uses, a relatively easier way to acquire a city-scale change of human activities would be a helpful supplement to the traditional land use examinations with poor reliability. Moreover, one of the major problems associated with these studies is that they simply equal urban expansion to the changes in land cover or use. What has been ignored is the assessment of how human activities actually react to the UGBs when people utilize urban spaces and development where UGBs intend to regulate. What are the relations between urban activities and UGBs? Do the UGBs really work on shaping and controlling human mobility and activities? Unfortunately, previous studies have provided few clues or solutions to these questions.

In this study, we evaluated the effectiveness of UGBs from the perspective of human mobility and activities using location check-ins from social network, taxi trajectories from GPS devices equipped by a large number of taxis, and smartcard records from public transit system. The increasing availability of these urban big data has provided unprecedented opportunities for urban researchers and planners to better understand and manage urban systems. These data have enabled us to describe and analyze real-time human behaviors and movements in a more precise, reliable, and economic way. We also see the potential of applying these data in planning evaluation, particularly in developing countries where official statistics are less sufficient or reliable. Based on the analysis of the massive data on human mobility and activities, the study aims to (1) evaluate the effectiveness of UGBs in confining human mobility and activities, (2) examine whether the intensity of urban activities correlate to that of planned population across UGBs, and (3) measure the interconnections between UGBs and examine whether they conform with plan intentions.

This study selected Beijing as a case to illustrate how the evaluation is developed. Beijing has undergone rapid urban development in the past two decades and can be regarded as a representative among rapid-developing cities. Considering the nature of the methodology adopted in this study, it can also be applied to developed cities. In Section 2, we introduced the study area and data sources. In Section 3, we elaborated the methodology and presumptions, as well as the evaluation results. In Section 4, we discussed the findings in details. In Section 5, we concluded by summarizing our findings, suggesting the strength and weakness of our study and giving recommendations for potential subsequent studies in future.

2. Study area and data

2.1. Beijing's recent urban planning

As the capital of China, Beijing is one of the most populous cities in the world. The population at the end of 2013 was 21.15 million. The Beijing Metropolitan Area (BMA) is 16,410 square kilometers. According to land use dataset of Beijing Institute of City Planning, the total urban area as of 2012 was 1675 square kilometers. The BMA currently comprises 16 administrative subdivisions (districts), as illustrated in Fig. 1.

Since the latest adjustment of the Beijing administrative boundaries in 1958, five urban master plans have been drafted in 1958, 1973, 1982, 1992 and 2004 respectively. Each master plan includes an official land use map. Individual land parcels in the map were assigned according to a classification of either urban (residential, commercial, industrial, public green land, and mixed-use land) or non-urban (farmland, forestland, and wetland) uses (Long et al., 2012). The map guided the future urban development, and uses were expected to conform to the plan.

The BMA has experienced an unprecedented increase in population growth and urban development since early 1990s. By the year 2003, Beijing's population and urban built-up area had already surpassed the capacity set forth in the 1992–2010 Master Plan. To cope with new challenges in the future, the Beijing Municipal Commission of Urban Planning updated the city's master plan for a 2020 planning horizon. Approved in 2005, the revised plan was sought to outline general principles and create new guidelines for Beijing's long-term economic, social, and physical development (Ding, Song, & Knaap, 2005).

In this new plan, the projected population of Beijing was 18 million in 2020. From a spatial perspective, the plan promotes a "two-axes, two-belts, and multi-sub-centers" urban development pattern. A total of 1650 square kilometers of planned urban built-up area would be allocated to the central city and eleven new cities. Urban developments were planned to occur within the planned urban construction areas. The boundaries of these areas can be regarded as the Chinese UGBs which functioned in a similar way as the UGBs in the U.S. The issuance of land use permits outside these boundaries was generally forbidden in order to curb urban expansion and protect open spaces. Four types of UGBs are identified, including those in the central city, new cities, towns, and other small isolated areas.

2.2. Date sources

2.2.1. Location check-in data

Compared to traditional approaches to obtaining information of urban activities, the use of data acquired from mobile devices