Implementation Evaluation of Beijing Urban Master Plan Based On Subway Transit Smart Card Data

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***Abstract*—Urban planning is a decision process that needs to mine rich information to serve plan development, decision making and plan implementation evaluation. There is little research to date on the evaluation of urban master plan implementation by big data. This study aims to analyze Beijing subway transit smart card data and evaluate the implementation of Beijing's urban master plan (2004−2020). This paper introduces the conceptual framework of the study including: a literature review; an analysis of master plan implementation evaluation requirements; and the features of subway transit smart card data. The research approaches are described and the implementation evaluation of Beijing's master plan in terms of city space layout, coordinated development and city development patterns are presented. Finally, the evaluation conclusions are summarized and the key role of subway transit smart card data in urban master plan implementation evaluation is discussed, proving the valuable support capability of big data.**

Keywords- Big data; Subway transit smart card data; Urban planning; master plan evaluation; Beijing; Geographic Information System (GIS)

I. INTRODUCTION

The term "big data" emerged to describe the phenomenon of massive data amounts being quickly generated as technologies such as networks and sensors advanced. The big data era reveals an important new era transition and represents a significant living, work and thinking reform [1]. To date, big data has attracted considerable attention from researchers in information sciences, government policy and decision makers and enterprises [2]. However, the big data era also challenges us. We must be fully ready to meet changes to our organizations and selves resulting from big data technology.

Undoubtedly, the big data era derived from the evolution of information and technology; however, its influence stretches far beyond data and technology. As the leader in city construction and management, the urban-rural planning industry faces huge pressure and challenges from rapid urbanization in China. The planners undertake critical tasks such as the promotion of city and town coordinated development, the maintenance of public interests, the protection of history and cultural relics and the construction of a harmonious residential environment. Each planner should now consider how to meet the opportunities and challenges facing the urban-rural planning industry in relation to the big data era.

It is almost 10 years since the Beijing urban master plan (2004–2020) was implemented. Only a comprehensive and objective evaluation can: establish if its implementation completely realizes its original ideas and intent; identify problems in the plan implementation; and summarize the experiences and lessons. This would allow an effective promotion of plan generation and implementation management, continuous improvement, orderly construction and healthy development of the city. However, the evaluation of the urban master plan implementation is problematic in the planning field because of the plan implementation complexity, the diversity of the plan's values, the relevancy of evaluation content and the lack of data reflecting constant comprehensive current city conditions.

There are many studies on big data analysis and mining in relation to city traffic; however, few relate to urban planning, particularly urban plan implementation evaluation. Based on an analysis of big data features and its influence on the urban-rural planning industry, this paper analyzes the Beijing subway transit smart card data and evaluates the implementation of the Beijing urban master plan that embodies the support capability of big data for city plan evaluation, analysis and decision.

The paper is structured as follows. The conceptual framework is described in the second section. The third section introduces the research approaches for dealing with subway transit smart card data that include research content, foundational data and the key technical method. The fourth section provides a detailed description of implementation evaluation in city space layout, coordinated development and city development patterns. Finally, the paper summaries the conclusions and discusses the key role of subway transit smart card data in the evaluation of urban plan implementation.

II. CONCEPTUAL FRAMEWORK

Smart card automated fare collection systems are increasingly used by public transit agencies. Marie-Pier Pelletier et al. (2011) reviewed literatures about using smart card data in the public transit context before 2011 which revealed that smart card data can be beneficial to transit planners and researchers [3]. Marcela A. Munizaga et al. (2012) presented a methodology for estimating a public transport Origin-Destination (OD) matrix from smart card and Global Positioning System data that provided an opportunity for extensive transport system analysis in Santiago, Chile [4]. A further study used Advanced Public Transportation Systems (APTS) data to analyze transit commuter travel demands. The study collected APTS data and boarding stops information by combining smart card data and intelligent dispatching data that provided a fast and economic new approach to acquiring transit commuters OD distributions[5]. Milan Lovrić et al.(2013) used real-world smart card transaction data collected from a major Dutch public transit authority to evaluate an agent-based modeling and simulation approach. That study contributed to work on revenue management for complex transportation networks that considers individual customer needs and requirements and environmental impacts[6] .

The evaluation of master plan implementation is a complex task and is the source of much discussion. Richard K. Norton (2008) used a content analysis method and presented an array of criteria for evaluating local master plans and zoning codes[7]. A further study evaluated China's Guangzhou city master plan by comparing the land use plan and actual land use and presented results on accordance, deviation and lack of implementation[8]. Xueqin Liao, Wei Liet al. (2013) evaluated ecological vulnerability based on a geographic information system (GIS) in China's Fuxin mining master plan environmental impact assessment. An investigation on the effects of land-use master plans on actual control of land use through the maximization of detailed grid data with advanced GIS functions found that disordered developments resulted in an increase of vacant areas in urban fringes [10]. A study using GIS to evaluate the greenery in the National University of Singapore (NUS) found that the 3% decrease in greenery (from 55.10 to 52.31%) contained in the NUS Master Plan 2005 would have a significant influence on the entire city[11]. Ying Long et al. (2012) proposed a spatiotemporal approach to evaluate the effectiveness of urban planning implementation based on logistic regression and GIS by identifying the spatiotemporal heterogeneous effects of urban planning on urban expansion [12].

As evidenced by the above literature, GIS is widely used in the evaluation of urban master plan and smart card data is in common use for traffic analysis; however, combining big data and GIS technology is seldom found in the evaluation of urban master plans.

The Beijing Municipal Administration and Communication Card is a smart card issued in Beijing in 2006. Supported by advanced computer networks, automatic control, information handling, and communication technologies, card holders can now use contactless pay to settle public bus, subway, and taxi fees in Beijing. Over 35 million smart cards are now issued because of its convenience and security. The city subway transit smart card data recognize the smart cards when Beijing Municipal Administration & Communication Card is used on the subway in Beijing. Its main data attributes are shown in Table I including card information, travel trade information, line and station information and shows features of high volume, high velocity and high value.

The Beijing urban master plan (2004–2020) proposes policies relating to city space development and layout optimization focusing on traffic guidance, and aims to establish a comprehensive passenger transport system with public traffic as the main body, rail transit as the backbone and multiple transport modes as the coordination by 2020. It aims to ensure that the public backbone lines based on the rail transit, their interchanges, and fast rail transit network such as subway, light rail and skirt railway can cover the entire inner city and connect the new peripheral cities such as Tongzhou, Shunyi, Yizhuang, Daxing, Fangshan and Changping [13].

TABLE I. SAMPLE ATTRIBUTES OF SUBWAY TRANSIT SMART CARD DATA

Column Name	***Column Type***	***Description***
DEAL_TIME	DATE	Complete Transaction Time
DEAL_STATUS	NUMBER	The Status Of Transaction
ENTRY_LINE_NUM	NUMBER	Entry Rail Line Number
ENTRY_STATION_NUM	NUMBER	Entry Rail Station Code
EXIT_LINE_NUM	NUMBER	Exit Rail Line Number
EXIT_STATION_NUM	NUMBER	Exit Rail Station Code
ENTRY_TIME	DATE	Entry Rail Station Time
....	....	......

Based on master plan targets, the subway transit system in Beijing has quickly developed in the past 10 years. As of January 2014, the Beijing subway system has 17 operation lines (including 16 subway lines and one airport rail) covering 11 districts administered by Beijing, 273 operation stations and 465 km of operation mileage. From the view of passenger flow volume, the Beijing subway carried an average of 8.76 million passengers a day from January to November, 2013; an increase of 30.5% over the previous year. The maximum daily passenger flow volume is 11.06 million passengers; this is approximately 40% of the total public passenger transport volume.

Therefore the passenger travel records contained in the subway smart card data are valuable for handling and operations during city master planning. They particularly provide massive and current evaluation data sources that can objectively and truly reflect space and time status and changes in people streams in cities and improve the accuracy of master plan evaluation.

III. RESEARCH APPROACH

A. Research Contents

Based on Beijing subway transit smart card data, this research performs planning data analysis and mining on traffic, time and space in relation to the contents of the master plan, including:

- Based on traffic distribution and changes in space in different periods, observe the main city activity areas and analyze space layout in city development and construction;
- Analyze the direction of main people streams based on the point-to-point commuting flows between stations at the morning or night peaks;
- Analyze the space distribution of the working and living locations of city residents and evaluate the planned space layout appropriateness;
- Analyze the influence of the new subway lines on the

development and construction of the surrounding cities;

- Analyze the subway station radius of influence on the travel mode selections of the surrounding populations.

B. Foundational Data

The study uses Beijing subway transit smart card data from Friday, May 24, 2013. The data contains the complete take on/off smart card records of 8,743,932 passengers, including time and space position information such as card number, card type, time, and entry/exit subway line and subway station for each passenger.

For a comprehensive city analysis, it is essential to include further data reflecting the development status across the entire city in addition to track traffic data [14]. To facilitate the analysis of Beijing's urban master plan, the following main data is used:

- subway station data
- subway line data
- current land use data
- land use planning data
- plan implementation approval data

C. Technical Methods

Although the big data are diversified in terms of source and type, they remain data in essence. Thus, data processing and analysis still includes data acquisition, data pre-processing, data storage and management, big data retrieval and use (including data mining and smart analysis) and data presentation. Along with progresses in science, technologies such as cloud computing, cloud databases and parallel processing are introduced in big data processing to meet the high efficiency and availability application requirements of big data. In essence, city planning is spatial material planning. Focusing on the analysis and application of big data in the field of urban-rural planning requires plan analysis and data features in addition to the key technologies mentioned above.

The study first considers the spatialization of subway transit smart card data. Its data is structural text information in a database. To mine the rich hidden time and space information, it is important to associate the space position, namely spatialization of non-space data. This enables a connection between big data and other data based on space position and thus become a useful resource for city planning. The value of these big data can be analyzed and mined via the geographic dimension to improve coordination of the professional plan data and traffic data and to help planners in decision-making. This paper establishes space associations between smart card data and other GIS data—subway station, subway line and land use data—thus creating conditions for planners to apply spatial analysis.

The study next focuses on spatial analysis of Beijing subway transit smart card data. Besides data mining and business intelligence (classification, prediction, clustering, association rule, sequential pattern, time series and statistical) methods, the spatial analysis methods for geological space problems such as space clustering, overlapping, buffer area analysis, network analysis and space statistical analysis should be used according to the urban plan space properties. This allows the analysis of the focused space position, distribution, form, distance and relation in the city plan. This paper studies the spatial relationship between people OD streams, subway stations and subway lines with the city construction land by using spatial analysis that better supports the plan evaluation.

Finally, the paper examines and analyzes spatial visualization of Beijing subway transit smart card data. To better express plan ideas and design intent, the plan achievements should be displayed intuitively so that planners, decision makers, and the general public can understand them and be willing to participate in the planning course. To evaluate the plan and its space analysis, a GIS system visualizes the time and space dimensions of the subway transit smart card data. This includes data representations and explanations in forms such as graphs, tables, subject charts and flash animation, so the data can be observed from different dimensions and thus deeply analyzed and understood. This paper visualizes the subway transit passenger flow, flow direction and relationship with the land use type.

To realize the above three requirements in urban planning, the big data should be operated in an integrated environment of both the geographical information system and spatial database to fulfill the research contents and targets.

IV. Evaluation Achievements

The current research studies how to apply the subway smart card data; handles and computes how the day-long passenger flow changes over time at single station (Fig. 1); and examines the point-to-point commuting traffic between different stations at morning peaks in the operated lines in Beijing (Fig. 2). Based on these, the research evaluates the implementation of Beijing's master plan in the past 10 years, examining current city space layout, coordinated development and city development patterns.

A. City Space Layout and Coordinated Development

a) South City and North City

The Beijing urban master plan (2004−2020) proposes overall area development planning and considers coordination of the south city and north city development plan as one measure for the active promotion of coordinated area development. On November 5, 2009, the "action plan for speeding up development of the south area" that was in preparation for 3 years was formally published. Morning peak subway transit smart card data reveals that the commuting traffic south city and north city ratios are 17% and 83% respectively (table II). The difference in numbers is huge, indicating the significant gaps between the south and north city in terms of both "city" and "business".

TABLE II. Commuting North City And South City Traffic Ratio

Region	North City	South City
Flow Quantity	934409	191945
Ratio	83%	17%

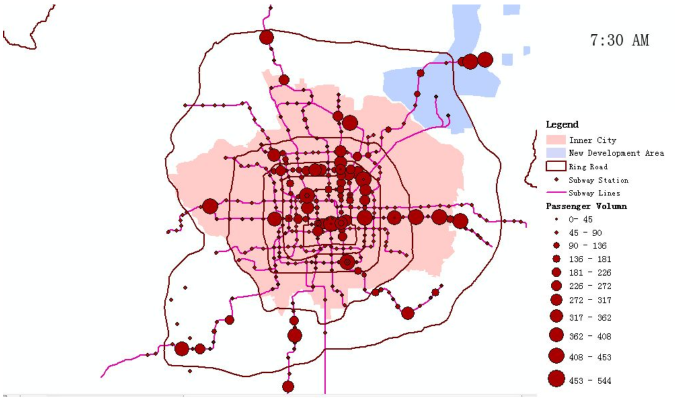

Figure 1. Flow quantity at 7:30 AM in the morning peak

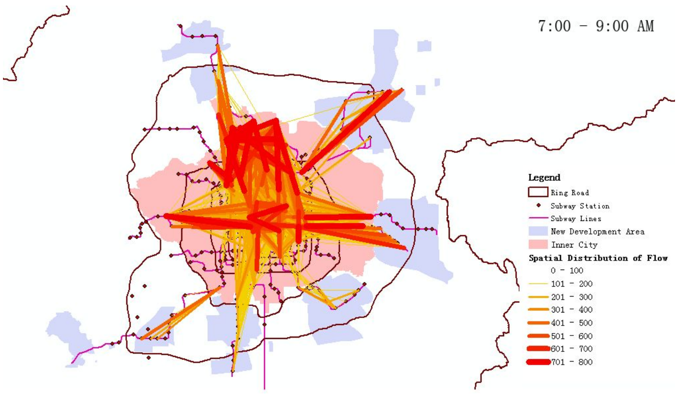

Figure 2. The morning peak flow spatial distribution

b) Inner City and New Development Area

The master plan has been in operation for 10 years. The subway transit operates across the central construction area of the new Development Area, including the new cities of Tongzhou, Shunyi, Daxing, Changping and Fangshang. Subway transit has become the most important commuting method in the new cities. Morning peak subway transit smart card data shows that the commuting traffic ratio of new city and inner city is 1:9 (table III). Although there are extensive residential and industrial lands in the new cities, the employment attraction of the inner city remains considerable in the past 10 years. This hinders the new cities to relocate populations from the inner city and thus exert industry and public service functions to fulfill the requirements of becoming sizable new cities. Overall, there is still a significant separation between working and living locations in the new cities.

TABLE III. INNER CITY AND NEW DEVELOPMENT AREA COMMUTING TRAFFIC RATIO

Region	*Inner City*	*New Development Area*
Flow Quantity	1011440	106961
Ratio	90%	10%

c) "Sleepy Cities" and "Dormitory Cities"

Prior to the implementation of its urban master plan, Beijing had several famous "sleepy cities" or "dormitory cities", such as Wangjing, Tiantongyuan, Huilongguan and Tongzhou. This led to serious problems relating to regional residential functions and industrial support. City residents were merely sleeping at home at night and were neither working, paying local taxes nor consuming in those areas. The plan has now been implemented for 10 years and these areas are changing for the better, which can be seen from Fig. 1 and Fig. 2. The Wangjing area is maturing via continuous improvement of measures such as high technology park construction, business upgrades, medical treatment and entertainment; it has remarkably broken free from the "dormitory city" status. However, there should be reform of infrastructure construction and industry developments in Tiantongyuan, Huilongguan and Tongzhou areas for their substantial improvement.

B. *City Development Pattern*

TOD (Transit-Oriented Development) is a development pattern taking public traffic as its guidance and aims to solve the limitless extension of cities in America after Second World War. TOD establishes the city area integrating work, business, culture, education and residence, with subway transit stations and bus arterial lines as the center. It takes 400 to 800 m (5 to 10 minutes walking distance) as the radius and realizes the organic coordination of the compact development of the city groups. TOD is a typical worldwide city community development pattern and is extensively used in city development.

The Beijing master plan (2004–2020) proposes the city development pattern taking public traffic, particularly subway transit, as guidance. Land development coordinates with the construction of traffic facilities to establish the city layout, and the land use pattern connects with public traffic to promote reasonable growth of new cities.

Beijing's subway line No. 15 (M15) is approximately 40.8 km and connects the core areas of Wangjing and Shunyi new cities and passes through the north of Beijing as a trunk line. The new city of Shunyi is ranked in first position of all 11 new cities for the number of land use certificates issued in the past 10 years during the master plan implementation and management. Hence, the M15 is selected to evaluate the TOD development pattern after 10 years of master plan implementation.

Data relating to travel from Shunyi to the inner city in the morning peak show that Wangjing is the largest work destination for the residents around the M15 rail line. Guozhan, Houshayu and Hualikan have gradually become the central employment areas in Shunyi new city; with Fengbo, Shunyi and Houshayu becoming the central residential areas (Fig. 3). Additionally, commuter numbers from the inner city to the new city in the morning peak show that Guozhan and Houshayu have become the central employment sites in Shunyi and attract residents from the surrounding Tiantongyuan, Huilongguan, Lishuiqiao and Huoying areas. Houshayu and Guozhan show a gathering effect from the surrounding area since the implementation of the master plan. Compared with the barren state around these areas at the master plan outset, the growth point is roughly formed (Fig. 4).

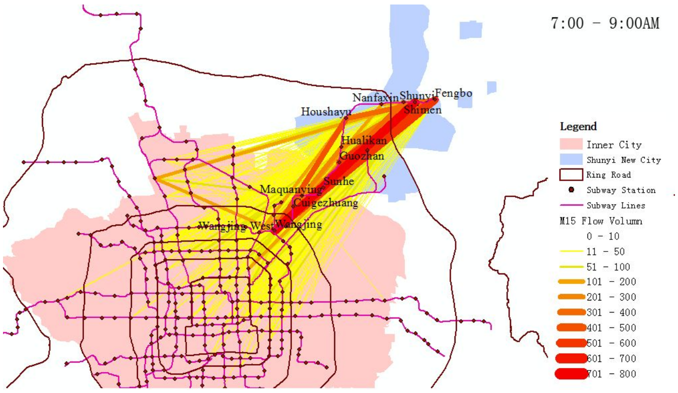

Figure 3. M15 flow from Shunyi new city to inner city in the morning peak

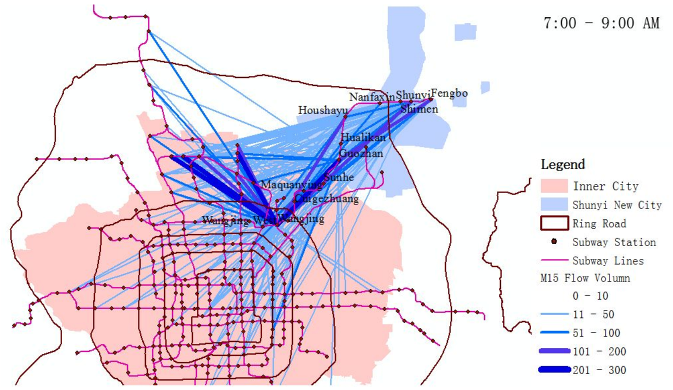

Figure 4. M15 flow from other areas to Shunyi new city in the morning peak

Analysis on the land use indicates that the construction of the M15 line promoted the development of the surrounding municipal administration, traffic and utility service facilities (Fig. 5). The three columns in Fig. 5 represent the years 2003, 2007 and 2010 that respectively signify the early urban master plan implementation, the planning of the M15 line and the opening to traffic of the M15 line. As can be seen, with the implementation of the urban master plan, the planning, construction and operation of line M15, and the scale of land used for municipal transportation facilities, public service facilities and public safety facilities have increased both in the quantity and percentage ratio that indicates a clear rising trend. Moreover the ratio between them and the residential and industrial land is more balanced and there is a higher mix of land use fuction. Hence, the posotive effects are archived in the industry development, population gathering and area development promoted by the M15 line.

V. CONCLUSIONS

This paper evaluates the overall implementation of Beijing's urban master plan in the past 10 years from the perspective of the city space layout, the coordinated development and the city development pattern by analyzing and mining the subway transit smart card data records. The research reveals the following master plan implementation achievements:

- There is a transfer in Beijing's spatial strategy. Data on the quantity and spatial distribution of people flow in the morning peak shows that the construction of the new cities in Beijing's surrounding area is reinforced compared with the status of those areas before the urban master plan implementation. Further, there is a change in single-center space patterns. The inner city - new city - town multi-level space structure, (particularly the inner city - new city spatial structure) is becoming clear. However, there is no substantial progress on the coordinated development of south and north cities and on work site and residential site balances in partial areas.

- The new cities have adopted the city development pattern using public traffic (particularly subway transit) as a guide. This pattern actively guides infrastructure and industry development, focusing on the coordinated development of land and traffic facilities construction. It establishes the city layout and land use pattern with public traffic as the link, thus promoting the reasonable growth of new cities. From the city development pattern analysis in section IV, it is evident that urban development is increasingly concentrated near subway lines and transit stations in the wake of traffic and utility service facility construction.

- Subway transit in inner and new cities has developed at an unprecedented speed: this can be seen from the total mileage and the number of people using it. The changes in city space layout and the development scale of urban construction over the same period proves that the aspects that subway transit facilitates are in favor of forming (such as new city centers, multiple centers and compact city forms) and the hybrid development of land functions have come to pass.

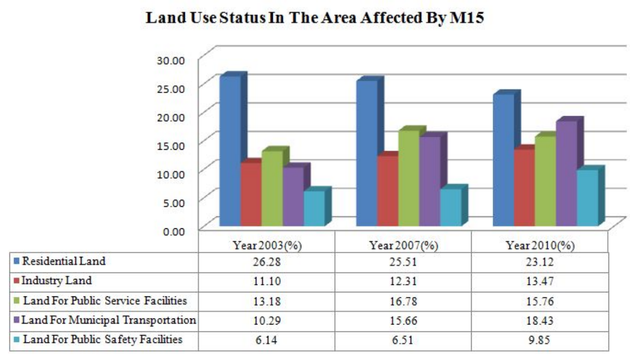

Figure 5. Land use status in the area affected by the M15 line

Additionally, as one big data application case, the subway transit smart card data is applied in the city planning area, embodying the following important facts and conclusions:

- Big data does not solely indicate bulky data. Deep and valuable information can be acquired only via analysis and mining of big data.

- To analyze big data in the urban-rural planning industry, different big data types should be used in conjunction with plan-related, multi-source data such as land use, population and society to attain plan attributes and mine purposeful value of relevance to planning.

- Big data can: assist planners in finding hidden facts; verify subjective recognition and prediction; and improve the accuracy of plan evaluation during the evaluation of the urban master plan implementation.

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