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Research Article

The rise of big data on urban studies and planning practices in China: Review and open research issues

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Abstract

The year 2014 marked the rapid expansion of big data in urban studies and planning practices in China. Big data has advantages of revealing individual characteristics rather than a general feature by traditional statistics, and it is consistent with the idea of people-oriented urbanization and urban–rural planning. The research progress of big data since 2000 in China is reviewed in this paper. Focusing on behavior big data mining and big data application in urban studies and planning practices, the review is proposed from four parts, involving behavior data acquisition & analysis, spatial analysis, plan making & management application and new methodologies with big data. Lastly, some open research issues such as potential challenges and possible directions of development are discussed.

Keywords: Big data; Review; Urban studies; Urban planning; China

1. Introduction

1.1. Big data in urban studies and planning practices

The year 2014 marked the rapid expansion of big data in urban studies and planning practices in China. The Annual National Planning Conference of China, as well as The Forum of China Urban Planning Studies, both involved big data as one of main subjects. Meantime, main academic journals in urban studies and planning practices in China like *Urban Planning International*, *Planners* and *Shanghai Urban Planning Review*, all introduced big data column to comply with the trend. Undoubtedly, big data is becoming a hot topic frequently discussed in urban studies and planning practices in China.

It should be noted, though, that this rise of big data is not only embodied in traditional academic achievements boom, but also in new characteristics covering academic community expansion and amalgamation, self-organized

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research institutes development, and academic-industry-media integration. Specifically, academic community expansion is embodied in a deeper cooperation among geography, urban planning and information science, as well as a more frequent interaction between traditional research institutes and IT companies, such as Baidu, Alibaba, etc. Research institutes development is embodied in emergence of new self-organized research institutes, like Beijing City Lab (BCL), CITYIF, Xicheng & Tsinghua-Tongheng Urban Data Lab, Metro Data Team as well as a leading development of traditional research institutes represented by universities and urban planning institutes. Academic-industry-media integration is embodied in the emerging of new media represented by The Paper-Shi Zheng Ting (澎湃-市政厅), CAUP. NET (国匠城),Urban Data Party (城市数据派) and Fruitalk (果说). At the same time, Wechat group introduced a new approach in academic communication, cooperation platform construction, and public popularization of planning, contributing to expand related disciplines' social reputation and influence.

This paper reviews literatures of big data application in China in Chinese and English in the fields of urban studies and planning practices since 2000, as well as their references. Focusing on behavior big data mining and big data application in urban studies and planning practices, the review is proposed from four parts, involving behavior data acquisition & analysis, spatial analysis, plan making & management application and new methodologies with big data. Lastly, some open research issues such as potential challenges, possible directions of development are discussed as well.

1.2. Literatures selection and classification

According to sample size and update frequency of data, related literatures exploring regional & urban issues and planning issues through big data in China are selected in this review. This paper defines high-frequency with large-sample-size data and low-frequency with large-sample-size data as big data, which includes GPS Log Data from Handheld GPS Devices, Mobile Phone Data (MPD), Smart Card Data (SCD), GPS Data from Floating Cars (Taxis), Point of Interests (POIs), Volunteered Geographic Information (VGI), Search Engine Data, detailed digital landuse data, parcel data and road network data displayed by GIS, CAD, etc. Literatures published after the year of 2000 in Chinese and English both are reviewed in this paper. Literatures in Chinese mainly come from cnki.net, udparty.com, thepaper.cn, as well as Symposium on big data and spatio-temporal behavior planning held in Tongji Univ., Jan., 2015, while literatures in English mainly derive from Web of Science and Working Papers on beijingcitylab.com.

(1) Keywords searched in cnki.net include "big data AND cities (大数据AND城市)", "big data AND planning" (大数据AND规划), as well as (GPS/mobile phone (手机) /smart card(s) (公交刷卡) /floating car (浮动车) /taxi (出租车) /POI (兴趣点) /VGI (志愿地理信息) /weibo (微博) /checkin (签到) /search engine (搜索引擎)) AND (cities (城市) /spatial (空间) /spatiotemporal (时空)/ mobility (移动) /planning (规划)) in TITLE. Literatures selected must include at least one word in the first group AND at least one word in the second group. Then the related references of searched literatures also are selected.
(2) Keywords searched in Web of Science include (GPS/mobile phone/smart card(s)/floating car/taxi/POI/VGI/checkin/search engine) AND (urban/spatial/spatiotemporal/mobility/planning) in TITLE. Then the related references of searched literatures also are selected.
(3) Related literatures on beijingcitylab.com, udparty.com, and Symposium on big data and spatio-temporal behavior planning hold in Tongji Univ., Jan., 2015.

Literatures selection mainly emphasizes journal articles, excluding monograph, academic dissertation, and some conference articles. Thus, we get 189 literatures in total, involving 183 core literatures and 6 representative literatures not directly relevant to the theme. Among 183 core literatures, 126 ones are in Chinese while 57 ones are in English.

1.3. Literatures analysis

These 183 core literatures have been analyzed from multi-aspects:

(1) Publication Quantity: Number of literatures has begun increasing since 2008, especially presenting a rapid increase trend after 2011. And literatures number has reached as high as 47 in 2014 and 41 by Apr., 2015 (see Fig. 1).

(2) Research Theme: Themes are distributed as follows: 42 literatures in behavior data acquisition & analysis (A), 65 literatures in spatial analysis (B), 51 literatures in plan making & management application (C), and 25 literatures in new methodologies with big data (D). Thus, Theme A, B, and C are the key research themes. Yet literatures in Chinese focus on different themes from ones in English. Literatures in Chinese cover all above-mentioned four themes, while most English ones merely focus on Theme A, B, and D (see Fig. 2). On the other hand, literatures in Theme B and C grow significantly, while ones in Theme A and D keep stable. This illustrates that studies in spatial analysis and plan making & management application are current "hot topic" (see Fig. 3).
(3) Data Application: 131 literatures conducted empirical studies using big data, and SCD, GPS Data from Floating Cars (Taxis), MPD, VGI, GPS Log Data from Handheld GPS Devices and POIs (in order by using frequency) are the most used big data in literatures.
(4) Areas Focused: 128 literatures involve specific areas, and Beijing, Nation, Shanghai, Shenzhen, Wuhan, Nanjing, Changsha and Dongguan are the chief areas focused on. Further, Beijing attracts nearly half of attention, which ranks No. 1 in all research areas. And, more remarkably, areas focused on more emphasize cities, with little research on megalopolises like Yangtze River Delta and Beijing–Tianjin–Hebei region.
(5) Source Journals: There are 127 journal literatures in total. Among these, 31 English literatures are mainly published in *Computers Environment & Urban Systems*, *Journal of Transport Geography*, *Landscape & Urban Planning*, *Physica A Statistical Mechanics & Its Application, Transactions in Gis*, *Plos One, etc.*, while 96 Chinese literatures are mainly published in *Acta Geographica Sinica*, *Progress in Geography*, *Planners*, *Urban*

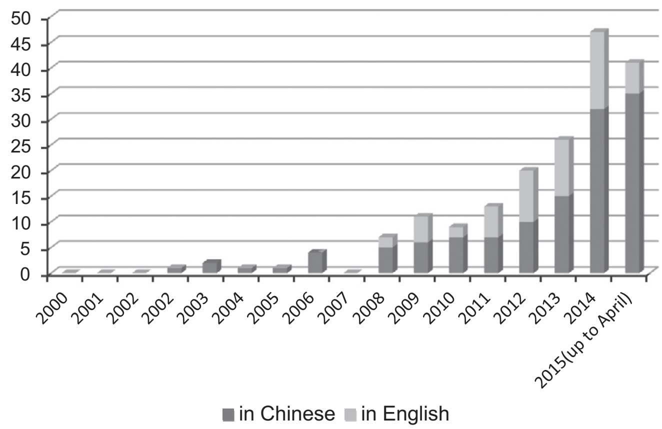

Fig. 1. Number variation of literatures from 2000 to 2015 (up to Apr.).

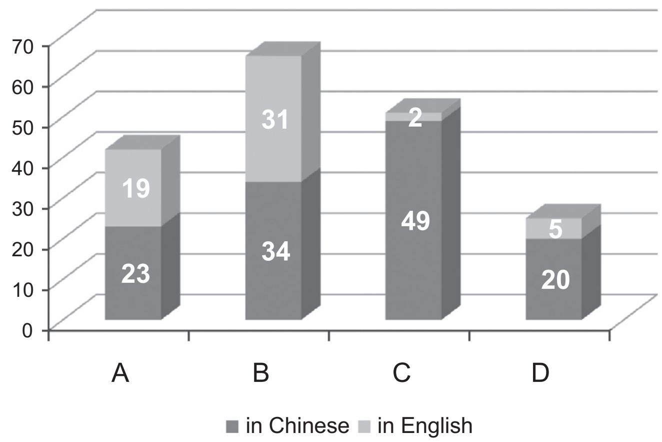

Fig. 2. Distribution of themes focused.

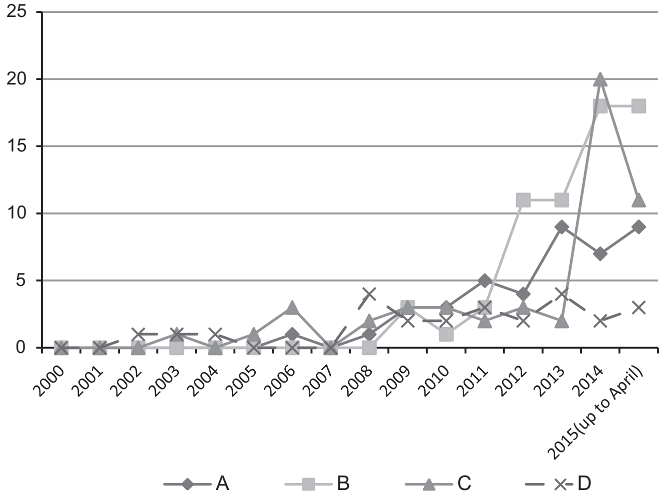

Fig. 3. Number variation of literatures classified by theme from 2000 to 2015.

Planning Forum, *City Planning Review*, *Beijing Planning Review*, *Shanghai Urban Planning Review*, *Human Geography*, *Urban Planning International, etc*.

(6) Authors Distribution (in alphabetical order): chief reseachers include Team of *Pro. Yanwei CHAI*, and *Chaogui KANG*, *Yu LIU*, *Jin SHI* in Peking University; *Song GAO* in University of California, Santa Barbara; *Haoying HAN* in Zhejiang University; *Xiaoting HUANG* in Shandong University; *Qingquan LI* and *Yang YUE* in Shenzhen University; *Xia LI* and *Suhong ZHOU* in Sun Yat-sen University; *Yuan LI* in Xiamen University; *Cuiling LIU* in Ministry of Housing and Urban–Rural Development of China; *Ying LONG* and *Mingrui MAO* in Beijing Institute of City Planning (BICP); *Ping LUO* and *Qiang NIU* in Wuhan University; *Yue SHEN* in East China Normal Universiy; Team of *Pro. De WANG*, and *Xinyi NIU* in Tongji University; *Jingyuan WANG* in Beihang University; *Peng WANG* in Tsinghua-tongheng Urban Planning & Design Institute (THUPDI); *Honghui ZHANG* in Central South University; Team of *Pro. Feng ZHEN* in Nanjing University; *Yu ZHENG* in Microsoft Research Asia; and *Jiangping ZHOU* in The University of Queensland, Australia, etc.

The rest of the paper is organized as follows: Section 2–5 summarize 183 related literatures according to four themes A–D, and Section 6 discusses some open research issues (see Fig. 4).

2. Behavior data acquisition and analysis: refinement of spatial, temporal and individual attributive data

Individual behavior and its spatio-temporal variation are main subjects and foundation in urban studies and planning practices. Individual behavior data at different spatio-temporal scales could be decomposed into spatial data, temporal data and individual attributive data. In terms of spatial data, traditional researches mainly emphasize static spatial data, ignoring temporal variation, dynamic elasticity, fragmentation and mutual overlapping of spatio-temporal data. And these disadvantages especially outstand in comprehensive studies and planning practices. Moreover, temporal data in traditional studies are usually depicted and analyzed at one-year scale, resulting in relatively low precision. In addition, individual attributive data in the past studies by questionnaire emphasizes on some fixed features, such as age, gender, occupation, etc., making it difficult to reflect some attributes which are dynamic at spatial–temporal scale including preference, emotion and satisfaction of individuals. Big data provides an opportunity to the refinement of spatial, temporal and individual attributive data, thanks to its massive size and realtime information collection. This refinement of spatial, temporal and individual attributive data is the focus and direction of current researches. The following will particularly introduce the refinement from spatial, temporal and attributive perspectives, as well as the main application fields of different types of big data.

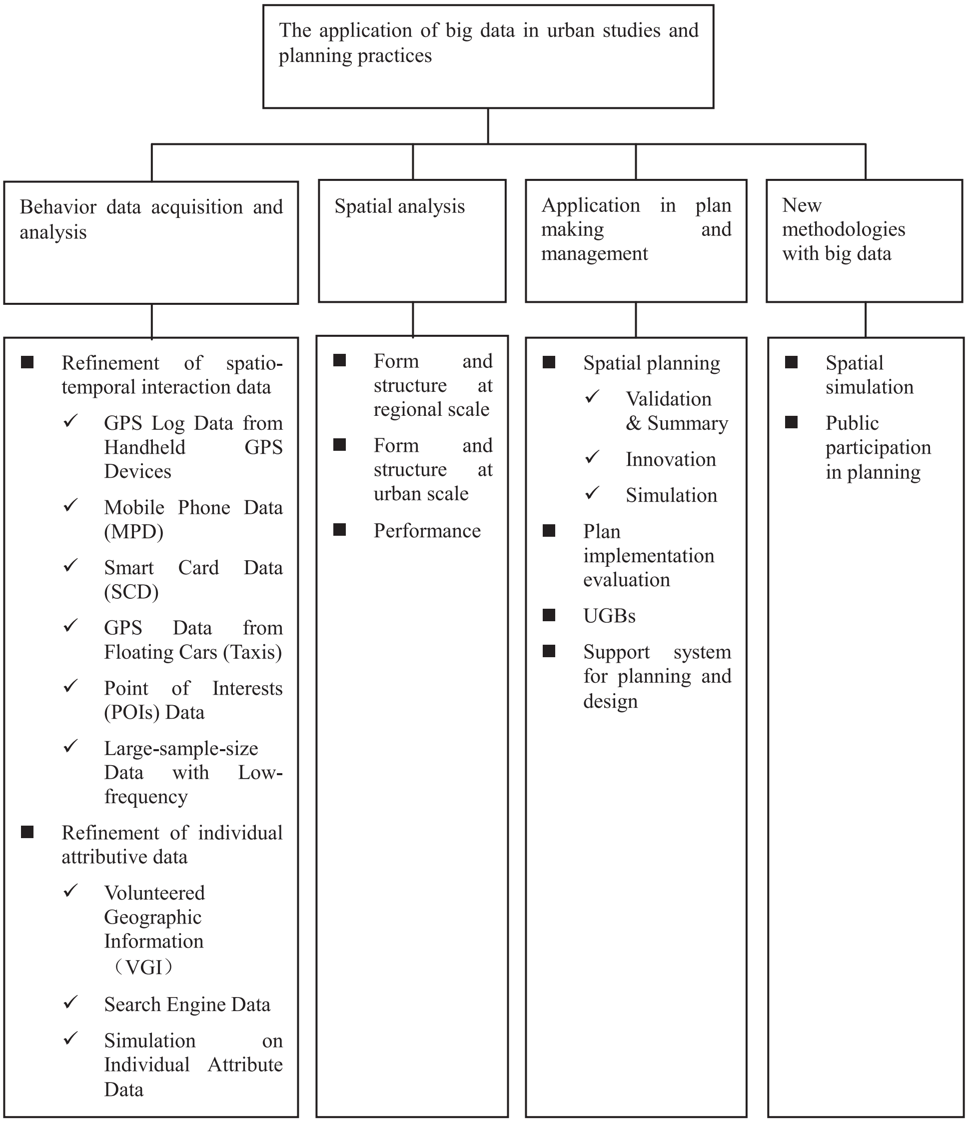

Fig. 4. Framework of the review.

2.1. *Refinement of spatio-temporal interaction data*

(1) GPS Log Data from Handheld GPS Devices

The early application of GPS log data mainly revolved in transport parameter estimation and model calibration. It has advantages of high spatio-temporal precision and collected in realtime. Specifically, individual behavior could be located in relatively precise points and trajectories in realtime and visualized in panoramic views by using GPS log data, realizing the refinement of spatio-temporal interaction data. However, disadvantage of failing to obtain information of individual attributes also exists (Chai, Shen, Ma, & Zhao, 2013). But such disadvantages may be partly supplemented by questionnaires and face-to-face interviews.

Representative researches focusing on spatio-temporal characteristics of individuals by GPS Log Data come from Behaviour Geography Research Group led by *Pro.Yanwei CHAI* in Peking University. Team of *Pro.CHAI* established research framework of urban space studies in the perspective of travel-activity based on time geography (Chai & Shen, 2006; Chai, Zhao, Ma, & Zhang, 2010; Chai et al., 2012). They explored the impact of age, gender, education, occupation and income on individual behavior in several Chinese cities by GPS Log Data (Chai, Zhang, Zhang, Yan, & Zhao, 2009; Shen, Chai, & Kwan, 2015). Since 1995, the team studied spatio-temporal characteristics of individual behavior in Beijing, Shenzhen, Tianjin and Dalian by activity-diary survey, depicting individual behavior from a scale of day or week to a scale of hour and even more accurate scales, which builts foundation for further studies (Ma, Chai, & Zhang, 2009; Zhao, Chai, Chen, & Ma, 2009; Xu, Chai, & Yan, 2010). An investigation to huge suburban communities, such as Tiantongyuan and Yizhuang in Beijing, operated in 2010 by Team of *CHAI*, firstly used GPS Log Data combined with GSM Data, online interactive survey, interview by telephone or face-to-face ones. This study firstly realized combination of traditional activity-diary and location data in realtime in China as well as achievement in accuracy and refinement of spatio-temporal data based on studies by diary survey before 2010. Moreover, they used space-time prism to visualize these data and carried out a panoramic view to individual behavior. To explain phenomenon of mutual interaction and overlapping of spatio-temporal data resulted from uncertain factors of individual behavior, the team also proposed the concept of "commuting flexibility" (Shen & Chai, 2012; Shen, Kwan, & Chai, 2013). And further they extended research fields more widely like spatial pattern of individual behavior in suburbs, suburban spatial structure and suburbanization, etc. (Chai et al., 2013; Guo, Zhang, Chai & Shen, 2013; Shen & Chai, 2012, 2013; Shen, Chai, & Kwan, 2015; Ta & Chai, 2015). Besides, Zheng, Li, Chen, Xie, and Ma (2008), Deng et al. (2010), Chen et al. (2011), Huang and Ma (2011), Huang (2015), Li, Wang, Zhang, Wang, and Fang et al. (2015) also studied spatio-temporal characteristics of individual commuting behavior and tour behavior as well.

To sum up, GPS log data application in urban studies and planning practices could be regarded as the initial stage of big data application. As handheld equipments have to be distributed to individuals surveyed, GPS log data belongs to a kind of active data, which is hard to apply to general survey needing large samples. Due to the limited information obtained from GPS log data, it is more suitable to be used in experimental study or research survey which only requires limited samples. And its survey results are appropriate for theory innovation and support for big data analysis.

(2) Mobile Phone Data (MPD)

MPD is the most common type of LBS (location-based services) data, which could be classified into call detailed record (CDR) and signaling data. It typically contains anonymous user ID, cell tower ID, and latitude & longitude, etc. Mobile phone data has advantages of high spatio-temporal precision and no extra equipments, with disadvantages of failing to obtain individual attributes and information bias (Chai et al., 2013; Wang et al.,

Table 1
Main application fields and representative studies by MPD.

Main application fields	**Representative studies**
Travel features of different groups with various travel purposes in specific areas; Maximum of travel distance of residents in different locations.	Wang et al. (2015b)
Jobs-housing sites and chief commuting corridors.	R. Mao (2014); Xu, Yin, and Hu (2014).
Community structure.	Gao, Liu, Wang, and Ma (2013); Li, Cheng, Duan, Yang, and Guo (2014).
Distribution of several groups of people.	Kang, Liu, Ma, and Wu (2012); Ran (2013).
Urban function division.	Niu, Ding, and Song (2014).
Urban spatio-temporal structure and dynamics.	Sun, Yuan, Wang, Si, and Shan (2011); Yuan, Raubal, and Liu (2012); Niu et al. (2014); Wang et al. (2015b).
Regional connection.	Kang et al. (2010); Mu and Liu (2011); Kang, Zhang, Ma, and Liu (2013); Chi, Thill, Tong, Shi, and Liu (2014).
Features of flows in a certain region, traffic aisle and section.	Ran (2013); R. Mao (2014); Fang et al. (2015); Wang et al. (2015b).

2015b). Moreover, such missing information may not be supplemented by questionnaires. MPD was originally applied in transportation analysis and simulation (Wu et al., 2012), and later it was applied to regional and urban studies. Due to large sample size, MPD could well identify urban spatio-temporal charateristics at micro scale as well as meso and macro scale, laying foundation for further spatial analysis and planning practices. Main application fields and representative studies by MPD are listed in Table 1.

(3) Smart Card Data (SCD)

SCD is traced from public transport, like buses, subways, public bicycles, etc. It bears rich information like card ID, line NO., trip time, up and down stations and fares. Thus, SCD is a kind of frequently used data in current literatures with advantages of consistency, mass coverage, complete information and realtime update.

Originally, SCD was deployed for bus line optimization, public transport site selection and public transport operation & management (see Table 2). Moreover, it is widely used in analysis of travel spatial distribution, travel distance, travel time, traffic flow and traffic community structure.

Earlier studies on analysis of urban spatial structure by SCD in China come from Liu, Hou, Biderman, Ratti, and Chen (2009), Long, Zhang, and Cui (2012), Du, Yang, and Lv (2013). Subsequent studies based on above-mentioned researches were conducted by more and more researchers (see Table 2).

However, compared with high precision of MPD, SCD has the limitations of relatively smaller sample size and bias between real jobs-housing places and public transportation stations. Moreover, overall trips fail to be obtained, since most buses only record information of getting on the bus, missing the information of getting off the bus. Thus, it may be hard to extend study achievements by Beijing SCD to other cities. And similar to MPD, SCD fails to contain individual attributive information of card-holders. Therefore, SCD is suitable to be applied to analysis at meso and macro scale for its relatively limited representative of all trips characteristics, like failing to reveal characteristics of individuals taking other kinds of non-public transportation such as walking and cycling. Thus, SCD should be used combining with other types of data in order to reveal characteristics of individual behavior comprehensively.

(4) GPS Data from Floating Cars (Taxis)

GPS Data from Floating Cars is traced from vehicles equipped with GPS, and stored in text type, covering latitude & longitude, driving period, speed, and direction, etc. In China, floating cars trajectory data is mainly traced from taxis. Due to floating cars having high consistency with roads, GPS Data from Floating Cars (Taxis) has a wide application in analysis of transportation structure, travel pattern and traffic volumn simulation (see Table 3). Many studies identified hotspots, commuting trips, landuse function, community structure and shopping center attractiveness, etc. (see Table 3).

Similarly to SCD, GPS Data from Floating cars lacks high precision and representativeness due to its instability and relatively small sample-size. Thus, it is limited to researches at macro scale. In addition, as high cost in taking taxis, a compararive analysis between taxi trajectory data and SCD could be conducted, to unveil different characteristics in jobs-housing sites and commuting modes of groups at various income levels.

Table 2
Main application fields and representative studies by SCD.

Main application fields	Representative studies
Travel spatial distribution; Travel distance; Travel time; Traffic flow; Traffic community structure.	Liu et al. (2009); Gong et al. (2012); Ma and Wang (2014); Zhao, Tian, Zhang, Xu, and Feng (2014).
Urban spatial structure (Earlier studies).	Liu et al. (2009); Long, Zhang, and Cui (2012); Du et al. (2013).
Urban spatial structure (Subsequent studies).	Long, Liu, Zhou, and Chai (2014); Long, Liu, Zhou, and Gu (2014); Wang, Zhou, and Long (2014); Zhou and Long (2014); Zhou, Murphy, and Long (2014); Zhou, Wang, and Long (2014); Gao and Long (2015); Han, Yu, and Long (2015); Long and Thill (2015); Meng, Zhu, and Wang (2015); Zhou, Wang, Long, and Ruan (2015).

Table 3
Main application fields and representative studies by GPS data from floating cars (taxis).

Main application fields	Representative studies
Transportation structure; Travel pattern; Traffic volumn simulation.	Zheng, Zhang, Xie, and Ma (2009); Liu, Andris, and Ratti (2010); Liang, Zheng, Lv, Zhu, and Xu (2012); Gao, Wang, Gao, and Liu (2013); Wang, Mao, Wang, Li, and Xiong (2014); Wang, Pan, and Yuan (2014); Liu (2015).
Hotspots and commuting trips; Landuse function; Community structure; Shopping center attractiveness.	Yue, Zhuang, Li, and Mao (2009); Zheng, Liu, Yuan, and Xie (2011); Qi et al. (2011); Liu, Kang, Gao, Xiao, and Tian (2012); Liu, Wang, Xiao, and Gao (2012); Yue, Wang, Hu, Li, Li, and Yeh (2012); Kang, Liu, and Wu (2014); Zhou, Hao, and Liu (2014); Zhou (2015).
Dynamic accessibility measure.	Li, Zhang, Wang, and Zeng (2011).

Table 4
Main application fields and representative studies by POIs data.

Main application fields	Representative studies
Urban function division.	Long, Han, and Yu (2013); Long and Liu (2013a); Long and Liu (2013b); Wang, Gao, Cui, Li, and Xiong (2014); Han et al. (2015).
Boundaries of cities.	Long, Wu, Wang, and Liu (2014).
Boundaries of commercial district.	Yin (2015).

(5) Point of Interests (POIs) Data

POIs data possesses an affluent data source, including commercial facilities, public facilities, tourist spots and transportation facilities, etc. POIs data usually contains information such as name, type, and address, which could be applied to landuse function identification, regional structure analysis, site selection of public facilities, etc. When combined with VGI (Volunteered Geographic Information) data, it could demonstrate more detailed individual activities. Furthermore, it could also be used in plan implementation evaluation, wisdom travel system, etc. Main application fields and representative studies by POIs data are listed in Table 4.

(6) Large-sample-size data with low-frequency

Though large-sample-size data with low-frequency pales in information capacity when compared with large-sample-size data with high-frequency, it still has a wide range of adaptability. It is mainly classified into two types in current literatures.

The first type is data with massive geo-spatial features, ie. landuse data, parcel data, road network data, POIs data displayed by GIS, CAD, etc. Such data could be applied to indentification of urban boundary and spatial expansion simulation, analysis of urban spatial form, flowing spatial structure, landscape analysis and design, as well as evalution of liveabability of walking space, etc. (see Table 5). In addition, massive data of geo-spatial features is also widely applied in regional and urban simulation, which will be discussed in detail in Part 5.

The second one is data with large-sample-size and fine-grain mined from statistics and field investigation, which is mainly used to reveal fine-grain spatial features of cities and regions at macro scale, such as ones focusing on population exposure evaluation of ambient PM2.5 at the subdistrict level, the population density variation and urbanization pattern evolution, industry & commerce spatial structure, social-map, as well as correlation between urban built-up area and individual commuting time (see Table 5).

2.2. Refinement of individual attributive data

(1) Volunteered Geographic Information (VGI)

VGI generates from emergence of online service platform providing geographical location, and it is mainly mined from check-in data from Sina Weibo (the most popular micro blog in China), Baidu Map (the most popular search engine in China), Dianping.com (a popular O2O platform for urban service involving catering, entertainment and tour, etc. in China), Douban.com (a popular Chinese SNS website allowing registered uesers to record information and organize offline activities relating to film, reading, music, etc. in cities), etc. It enables users to record and share their geographical location information in text style at any time. Though VGI pales in sample size and representativeness when compared with MPD and SCD, VGI has advantages of obtaining individual attributive information through text information mining, such as preference, emotion, motivation and satisfaction of individuals, as well as social network. Thus, VGI realizes refinement of individual attributive data, and it is well applied to facilities site selection and evaluation. For example, Team of *Pro. Feng ZHEN* in Nanjing University has conducted fruitful researches ranging from framework establishment, data mining to spatial analysis (Zhen, Wang, & Chen, 2012; Zhen, Zhai, Chen, & Shen, 2012; Chen, Zhen, Wang, & Zou, 2012; Qin, Zhen, Zhu, & Xi, 2014; Wang et al., 2013; Wang, Zhen, & Wei, 2014; Wang, Zhen, & Zhang, 2015). *Dong LI* from China Academy of Urban Planning & Design (CAUPD) also established VGI analysis framework from spatial distribution, movement, text and social network, providing support for subsequent studies (D. Li, 2015).

Specifically, in terms of individual and group behavior, D. Li (2015), Wu and Qiu (2015) respectively studied individual tour, catering, and innovation behavior using check-in data from Weibo and location data in Douban.com.

Table 5
Main application fields and representative studies by large-sample-size data with low-frequency.

Main application fields	Representative studies
Urban boundary;Spatial expansion simulation.	Long, He, Liu, and Du (2006); Long, Han, and Mao (2009); Long, Mao, and Dang (2009); Long, Mao, Shen, and Du (2010).
Urban spaial morphology.	Long and Mao (2009).
Flowing spatial structure.	Xi (2015).
Landscape analysis and design.	Yang (2015).
Liveabability of walking space evaluation.	Y. Li (2015).
Population exposure to ambient PM2.5 evaluation.	Long, Wang, Wu, and Zhang (2014).
Population density variation.	Mao, Long, and Wu (2015).
Spatial industrial & commerce structure.	W. Z. Zhang (2015).
Social-map.	Liu, Su, and Cheng (2015).
Correlation between urban built-up area and individual commuting time.	Sun and Dan (2015).

Table 6
Main application fields and representative studies by VGI data.

Main application fields	Representative studies
Individual behavior.	D. Li (2015); Wu and Qiu (2015).
Spatial pattern of specific behavior.	Qin et al. (2014).
Visualization of social network.	Mao (2013).
Connection intensity between cities.	Chen et al. (2012); Zhen, Wang, and Chen (2012); Li, Chang, Shaw, Yan, Yue, and Chen (2013); Liu, Sui, Kang, and Gao (2013); Wang et al. (2013); Chang et al. (2014); Li (2014); D. Li (2015).
Urban spatial structure and function division.	Yuan, Zheng, and Xie (2012); Long and Liu (2013a, 2013b); Wang, Pan, and Yuan (2014); Wu, Zhi, Sui, and Liu (2014); Han et al. (2015); Wang et al. (2015).

Furthermore, Qin et al. (2014) analyzed spatial pattern of catering behavior in Nanjing through satisfaction evaluation extracted from Dianping.com. In addition, Mao (2013) explored scale, spatio-temporal distribution, social network of urban planners and influence of core experts in Beijing through Weibo data, firstly exhibiting social network map in urban planning industry. Based on these researches, VGI has been also applied to regional and urban spatial studies, such as connection intensity between cities, urban spatial structure and function dicision (see Table 6).

(2) Search Engine Data

One significant feature of search engine data is massive sample, while it has its own limitations, such as duplicate and invalid information, uncertain source and false message. Such technologies as text mining and image judgement have been usually adopted in data analysis. Current main literatures using search engine data to study regional and urban issues in China are listed in Table 7.

(3) Simulation of Individual attribute data

Current simulation of individual attribute data is mainly conducted in experimental environment. They could be classified into three types. (1) Simulation of regional and urban space through Mircro Simulation Model (MSM), Cellular Automata (CA) and Agent-based Microsimulation Model (ABM) (this section will be discussed in detail in Part 5). (2) Simulation of spatio-temporal characteristics of people flow at large-scale exposition such as EXPO 2010 through online virtual tour (Wang & Ma, 2009; Wang et al., 2009, 2015a). (3) Urban micro-simulation under scarce data environment by disaggregating heterogeneous agent attributes and location (Long, Shen, & Mao, 2011; Long & Shen, 2013), and further simulation on urban expansion of all cities in China at parcel-level (Long, Wu, Wang, & Liu, 2014).

2.3. Solution and use of bias in big data application

Bias is the key problem for big data application which needs to be solved. There exist several solutions for such problem in current literatures. The first one is a combination of big data with small data. Small data is used for model construction, and big data is applied to simulate and verify the model established on small data (Wang, 2014). Concerning correlation between small data and big data, Zhu (2015) indicated that if small data could reveal features of subjects, we should adopt small data. Because it could not only solve big data's problems, like scarce resource and high threshold, but also realize the low-carbon goal. Further, Zhu (2015) calculated minimum data sample size in various settings of variations and precisions requirements by chi square test.

The second one is verifying reliability of big data by current theory model (Zhou, Wang, Long, & Ruan, 2015). In the process of verification, new discoveries may be found when we ingeniously utilize big data's bias. For example, SCD was used to identify characteristics of economically underprivileged residents (Long, Liu, Zhou, & Gu, 2014), college students (Wang, Zhou, & Long, 2014), and extreme commuting patterns like Early Birds (EB), Night Owls (NO), Tireless Itinerants (TI), Recurring Itinerants (RI) (Long, Liu, Zhou, & Chai, 2014). In addition, Zhou, Wang, Long, and Ruan (2015) proposed that theory model could be optimized, or even innovated when it failed to verify reliability of big data.

2.4. Summary

The acquisition and analysis of behavior data, involving refinement of spatio-temporal interaction data and individual attributive data, both are the basis of urban studies and planning practices. Above-mentioned types of big data have been widly used in urban studies and planning practices, and these types of data have respective advantages and disadvantages (see Table 8). Owing to this, every type of big data has its suitable application field.

Table 7
Main application fields and representative studies by serach engine data.

Main application fields	Representative studies
Urban network spatio-temporal evolution.	Xiong, Zhen, Wang, and Xi (2013); Xiong, Zhen, Xi, Zhu, and Wang (2014).
Pictorial expression of city image.	Zhao, Xu, and Li (2015).

Table 8
Advantages and disadvantages of various types of data in application.

	Kinds of data	Advantages	Disadvantages
(1)	GPS Log Data from Handheld GPS Devices	(1) High spatio-temporal precision (2) Collected in realtime (3) Missing individual attributes may be partly supplemented by questionnaires and face-to-face interviews (4) Overall trips could be obtained	(1) Failing to obtain information of individual attributes (2) Handheld equipments have to be distributed to individuals surveyed (3) Relatively hard to apply to general survey based on large sample size
(2)	Mobile Phone Data (MPD)	(1) High spatio-temporal precision (2) No extra equipments (3) Large sample size (4) Overall trips could be obtained	(1) Failing to obtain individual attributes (2) Information bias (3) Missing information may not be compensated
(3)	Smart Card Data (SCD)	(1) Consistency (2) Mass coverage (3) Complete information (4) Realtime update	(1) Relatively smaller sample size than MPD (2) Bias between real jobs-housing places and public transportation stations (3) Overall trips fail to be obtained, failing to reveal characteristics of individuals taking other kinds of non-public transportation such as walking and cycling (4) Relatively hard to extend study achievements to all cities (5) Failing to contain individual attributive information
(4)	GPS Data from Floating Cars (Taxis)	(1) Collected in realtime (2) Smaller bias between real jobs-housing places and sites of getting on the car and getting off the car than SCD	(1) Lacking high precision (2) Instability (3) Smaller sample size (4) Overall trips fail to be obtained
(5)	Point of Interests (POIs) Data	(1) High spatio-temporal precision (2) Relatively easy to obtain	(1) Relatively difficulty to collect in realtime
(6)	Large-sample-size data with low-frequency	(1) High spatio-temporal precision (2) A wide range of adaptability (3) Relatively easy to obtain and process	(1) Relatively difficulty to collect in realtime
(7)	Volunteered Geographic Information (VGI)	(1) Realize refinement of individual attributive data (2) Well applied to facilities site selection and evaluation	(1) Smaller sample size (2) Information bias
(8)	Search Engine Data	(1) Massive data (2) Relatively easy to obtain	(1) Duplicate and invalid information (2) Uncertain source (3) False message
(9)	Simulation of Individual attribute data	(1) Simulation under scarce data environment	(1) Lacking high precision (2) Relatively difficulty to collect in realtime

3. Spatial analysis: form, structure and performance

65 literatures with the theme of spatial analysis have involved spatial form, structure and performance, and these literatures could be divided at regional scale and urban scale. In addition, literatures at urban scale have been discussed from three main issues including commuting & transport structure, urban general structure and urban function division. When it comes to literatures quantity, literatures discussing regional form & structure and general structure at urban scale are the majority (see Fig. 5).

3.1. Form and structure at regional scale: from static total amount to dynamic flow

In terms of form and structure at regional scale, current researches mainly concentrate on the regional linkage, city scope, etc., which both belong to traditional geography research areas. In the past, the Gravity Model and Breaking Point Model were frequently applied in Urban Scope indentification and polycentric spatial structure analysis. Wang and Zhao (2002) even developed an Urban System Analysis Package (USAP) assisted with spatial calculation. Traditional researches by using Gravity Model have certain advantages in reflecting the total amount, but they have also neglected the effect of a large number of individuals from bottom to up and the analysis of flow space, resulting in a certain bias in planning practices. Secondly, with the development of highly integrated economy, formation of urban-region and enhancement of flow space, regional structure have evolved from the urban hierarchy to urban network (Luo, He, & Geng, 2011), and more attentions have been paid on dynamic flow. Data used in these researches is mainly small size data, like various kinds of transport linkages (ie. linkages by air, high-speed rail, etc.), the structure of the Internet users, enterprise headquarters and branches linkages, telecom traffic and web postings, etc., which could reflect flows of people, goods, capital and information among regions and cities. The introduction of big data could directly describe flow space from the individual level, and panoramically illustrate regional spatial structure and flow space. And this could further promote a deeper researches aiming from static total amount to dynamic flow, reflecting fine-scale of regional spatial changes. In terms of flow space, the majority of the present studies reveal the economic and social linkages among cities from the total level based on MPD, VGI data and Search engine data, etc. (see Table 9).

The followings are two representative cases. Zhen, Wang, and Chen (2012) analyzed China's city network characteristics using social network analysis based on the data mined from Sina Weibo (see Fig. 6). The result of Zhen's study showed that China's city network based on the micro-blog social space has a clear hierarchical structure and level distinction, performing a visible regional development pattern which contains "Three Main-regions and Four Sub-regions". The three main-regions contain the Beijing–Tianjin–Hebei region represented by Beijing, Pearl River Delta region represented by Guangzhou and Shenzhen, and the Yangtze River Delta region represented by Shanghai, Hangzhou and Nanjing. The four sub-regions contain Chengdu–Chongqing region, West coast of the Taiwan Straits region represented by Fuzhou and Xiamen, Wuhan region represented by Wuhan and Changsha, Northeast China represented by Shenyang, Harbin and Changchun. Furthermore, the result showed that there is a significant difference of the network links among Eastern, Central and Western China. Lastly, it also found that the high-level cities have an absolute dominance in the city network pattern. Chi et al. (2014) used the method of

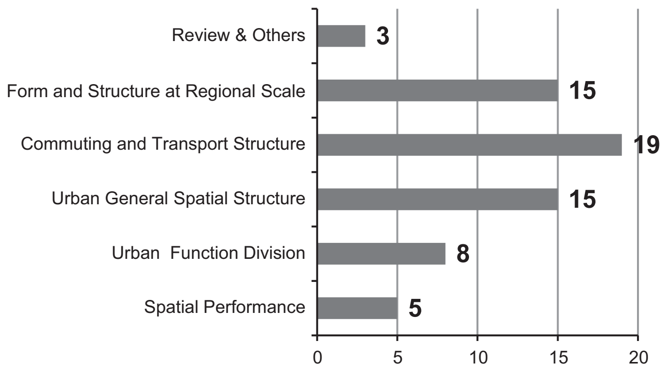

Fig. 5. Sub-theme distribution of spatial analysis by big data.

Table 9
Main types of data and representative studies on form and structure at regional scale.

Main types of data	Representative studies
MPD	Kang et al. (2010, 2013); Mu and Liu (2011); Chi et al. (2014).
VGI data	Chen et al. (2012); Zhen, Wang, and Chen (2012); Li et al. (2013a); Liu, Sui, Kang, and Gao (2013); Wang et al. (2013); Chang et al. (2014); Li (2014); D. Li (2015).
Search engine data	Xiong et al. (2013, 2014); Liu, Wang, Kang, Gao, and Lu (2014).

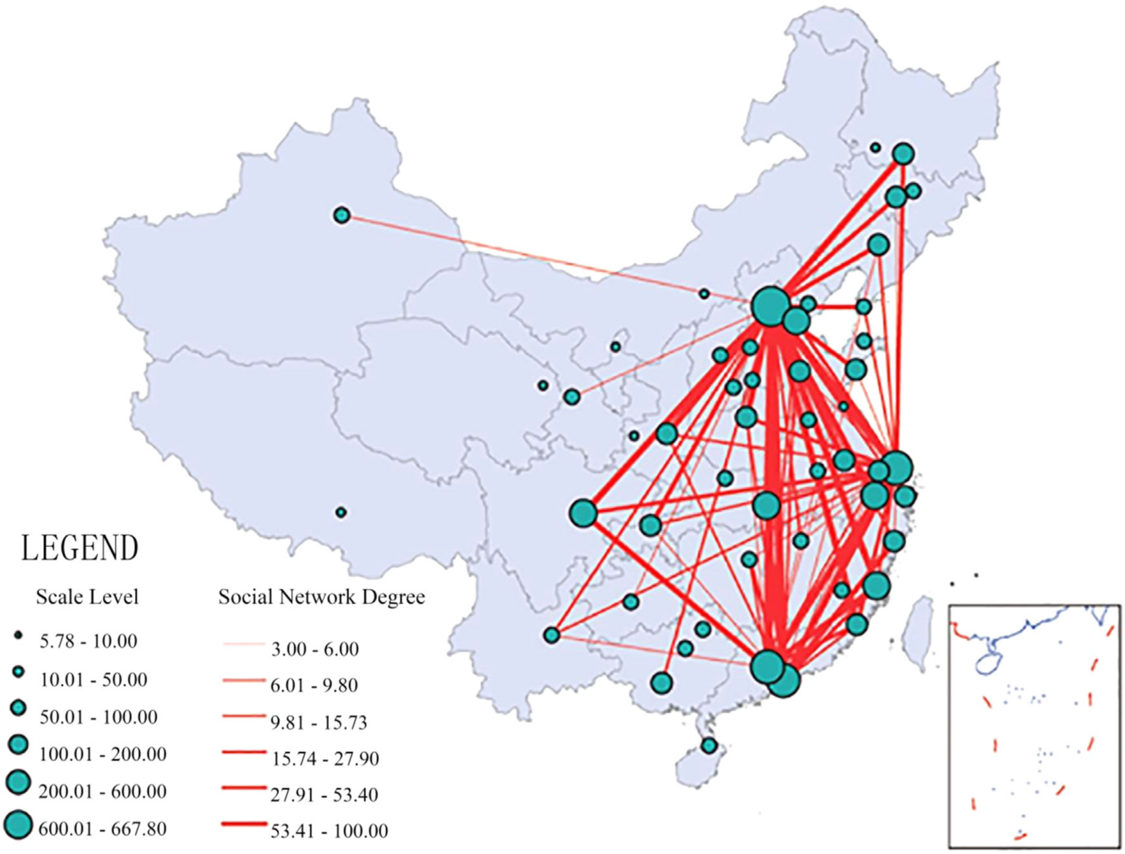

Fig. 6. The network connection between major cities in China based on data from Sina Weibo (Zhen, Wang, & Chen, 2012).

community detection for understanding the functional relationships and framing the spatial organization of a region and the resulting territorial structures. The result of empirical research in Heilongjiang Province is shown in Fig. 7. It consisted of 109 communities, which matched county boundaries rather well.

3.2. Form and structure at urban scale: mobility, complexity and ambiguity

The traditional researches on urban form and structure were mainly based on qualitative methods, such as image interpretation, land use investigation and visualization, as well as questionnaire survey. Afterwards, some quantitative analysis such as GIS spatial analysis, spatial syntax and network analysis has been gradually introduced, while most data used were static. Under the background of informatization, traditional methods could not meet the need of increasing uncertainty and diversity of urban space. The introduction of the big data may provide support for

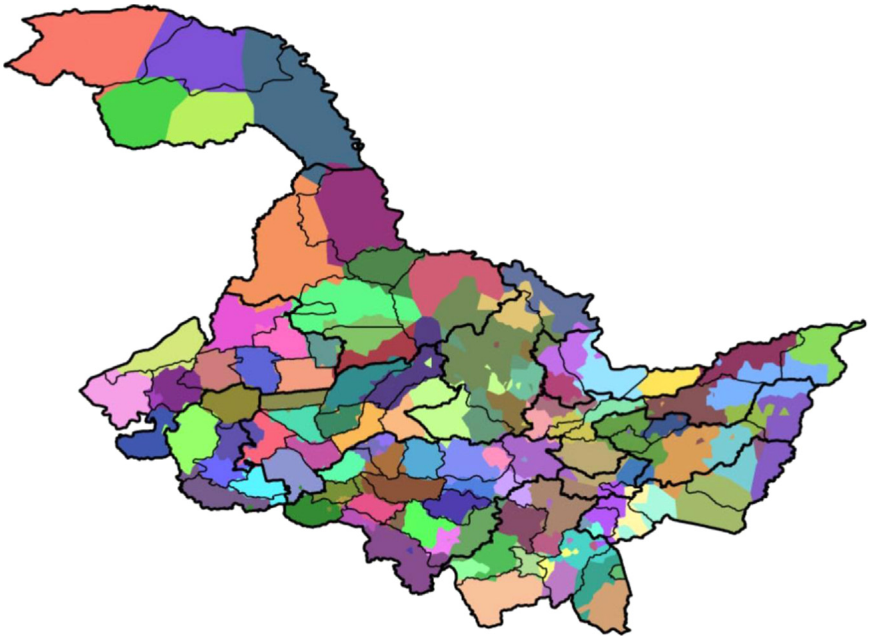

Fig. 7. Results of community detection by first network on the basis of standard G1 in Heilongjiang Province (Chi et al., 2014).

Table 10
Main types of data and representative studies on commuting and transport structure.

Main types of data	Representative studies
SCD	Liu et al. (2009); Long, Zhang, and Cui (2012); Long, Liu, Zhou, and Chai (2014); Long, Liu, Zhou, and Gu (2014); Du et al. (2013); Wang, Pan, and Yuan (2014); Zhou, Murphy, and Long (2014); Zhou, Wang, and Long (2014); Zhou and Long (2014); Gao and Long (2015); Han et al. (2015); Long and Thill (2015); Meng et al. (2015); Zhou, Wang, Long, and Ruan (2015).
GPS Data from Floating Cars (taxis)	Yue et al. (2009, 2012); Qi et al. (2011); Zheng et al. (2011); Liu, Kang, Gao, Xiao, and Tian (2012); Liu, Wang, Xiao, and Gao (2012); Kang et al. (2014); Zhou, Hao, and Liu (2014); Zhou (2015).
MPD	Xu et al. (2014); R. Mao (2014).

dynamic urban space researches. The application of big data in the current literatures could be divided into the following categories.

(1) Commuting and transport structure

Commuting and transport structure indentification are both the basis of urban spatial structure researches and the cutting-in point of the big data practices in China. The identification of jobs-housing sites and commuting corridor could lay foundation for the general urban structure optimization and urban transport improvement as well, especially the public transport system optimization (ie. public transport lines with larger stop spacing, customised public transport system, bus lines with different routes in up and down direction, day and night transport routes, etc.). The current researches on this issue mainly are operated by SCD, GPS Data from Floating Cars (taxis), and MPD (see Table 10).

Current representative studies in this area could be devided into 4 types as follows:

The first type is recognition and simulation of individual commuting behavior. GPS Log Data from handheld GPS divices is used to accurately recognize trajectory of commuting (already discussed in Section 2.1(2)). The other kind is the simulation of urban residents commuting behavior by ABM in a virtual environment, with comparison of energy consumption of commuting in different urban forms (Long, Mao, Yang, & Wang, 2011).

The second one is the analysis of transportation connections between different locations in cities. For example, Liu et al. (2009) classified passenger flow volume between stops in the various periods into several grades, to identify the

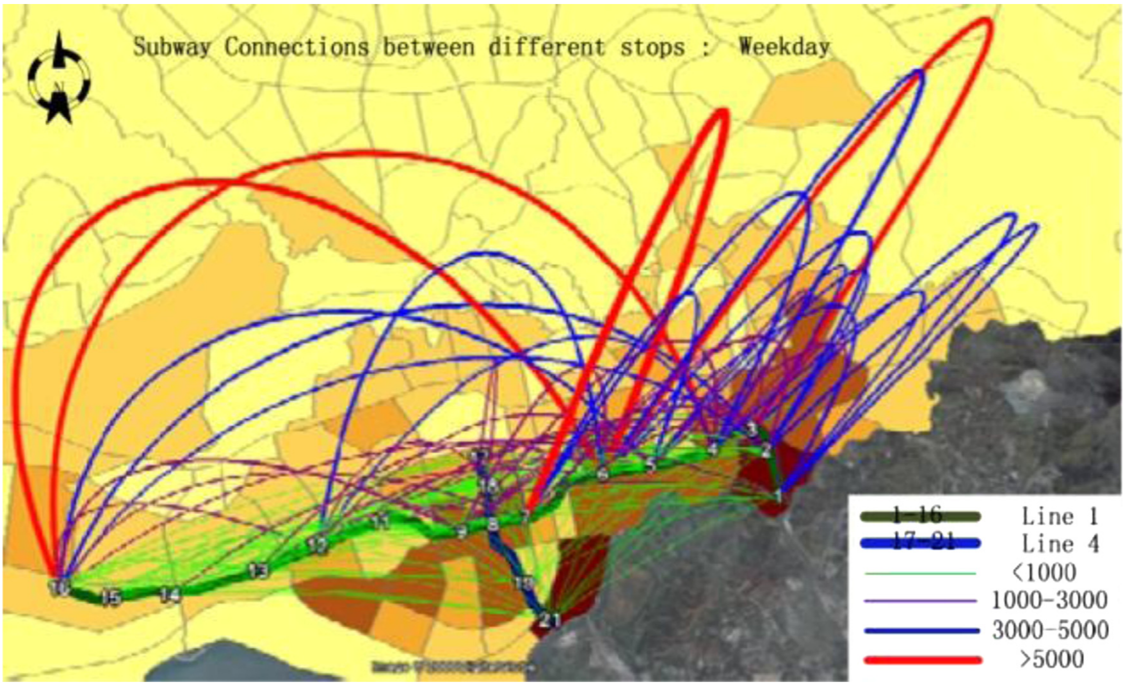

Fig. 8. Connections between different stops in weekdays in Shenzhen (based on SCD) (Liu et al., 2009).

locations which had close connection by metrocards data of Shenzhen (see Fig. 8). Zhou, Wang, Li, and Cao (2015) further analyzed the two-way flow of passengers by SCD.

The third one is the identification of jobs-housing sites and commuting corridors according to residents' presence in hotspots, as well as the analysis of jobs-housing balance in cities at structural level. Yuan, Raubal, and Liu (2012), Xu et al. (2014) both identified home locations and work locations based on MPD. Long, Mao, Yang, and Wang (2012), Long and Thill (2015) used one-week Beijing SCD, combined with the trip survey data in 2005, to identify jobs-housing sites, commuter travel trajectory of card holders and the main direction of traffic flow in Beijing. Long's study also classified the commuting links between jobs sites and housing sites into six levels based on their trip counts. In levels 4 to 6 with heavy commuting traffic, 175 links (0.5% of all links) account for 32, 156 commuting trips (14.8% of all trips) (see Fig. 9), which laid a foundation for further researches and planning improvements. Based on these studies, Zhou and Long (2014), Zhou, Murphy, and Long (2014), Zhou, Wang, and Long (2014) conducted some further studies on excess commute and commuting efficiency. In addition, Liu, Wang, Xiao, and Gao (2012) observed direction distributions of trips in Shanghai from taxi trajectory data, and Mao, R. (2014) analyzed flowing law of people in different areas of Wuxi and the commuting relationship between Taihu New Town and the old (see Fig. 10).

The fourth one is the identification and analysis of community structure by MPD, SCD and GPS Data from taxies. In megacities, commuting has its own hierarchical property. Some relatively independent communities will form if some people's tours mainly exist inside community. If this kind of community could be identified, more effective transportation modes and spatial structure improvement will be laid down in plan, further guiding and promoting commuting inside the community rather than trans-community, to ease the common commuting burden of single-center megacities. Facing this problem, many studies (Liu et al., 2009; Yue et al., 2009, 2012; Qi et al., 2011; Zheng et al., 2011; Gong et al., 2012; Liu, Kang, Gao, Xiao, & Tian, 2012; Liu, Wang, Xiao, & Gao, 2012; Gao, Liu, Wang, & Ma, 2013; Kang et al., 2014; Li et al, 2014; Ma & Wang 2014; Wang, Gao, Cui, Li, & Xiong, 2014; Zhao et al., 2014; Gao & Long, 2015; Zhou, Wang, Li & Cao, 2015) recognized the spatial community structures of transportation by MPD, SCD and GPS data from floating cars, supporting follow-up spatial plan and transport organization at meso scale, as well as community planning, etc. The representative case comes from Gao, Liu, Wang, and Ma (2013), whose research explored patterns embedded in the network of MPD interaction and the network among mobilephone-holders' movement, by analyzing the geographical context of MPD. They proposed an

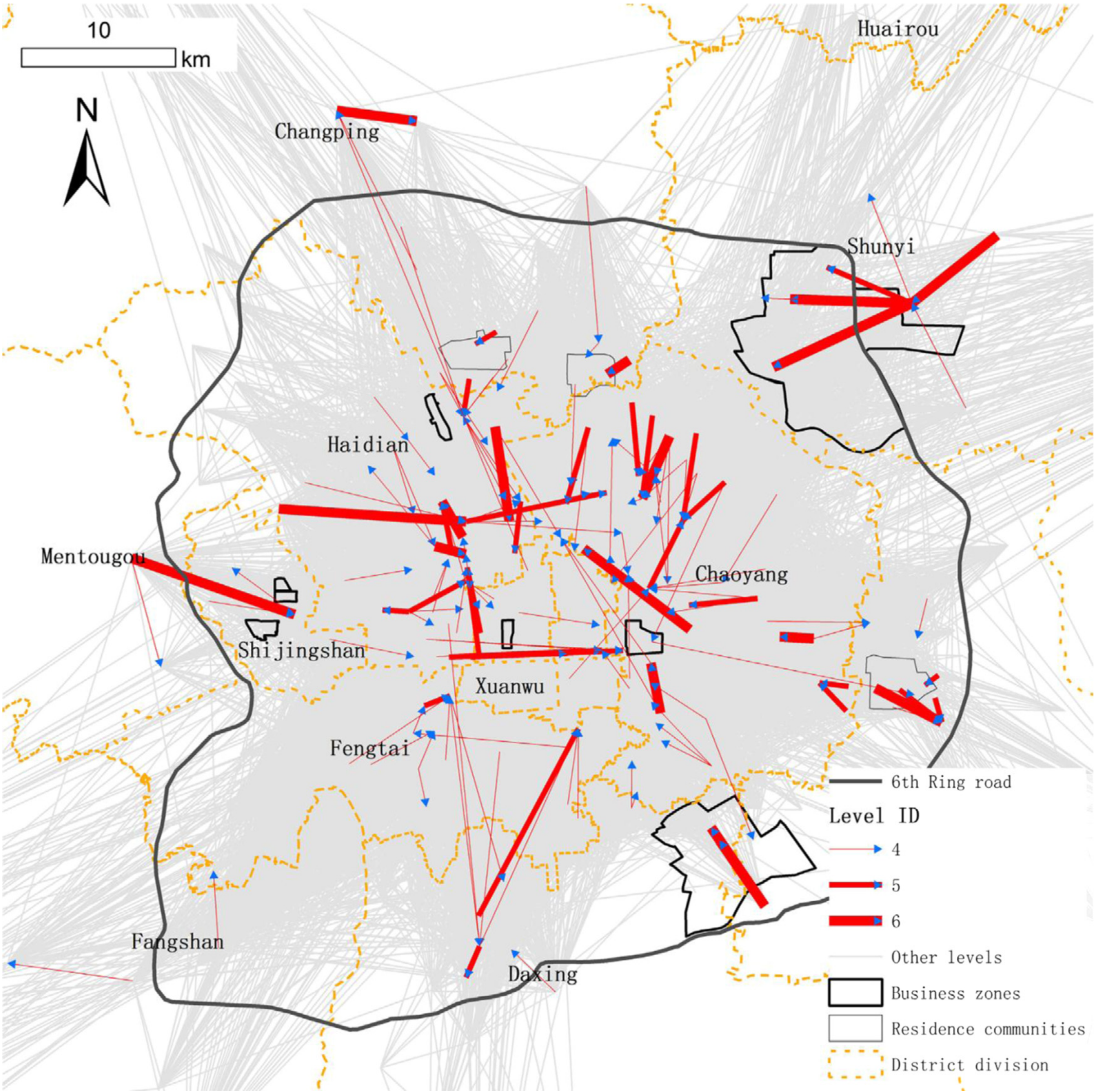

Fig. 9. Trip links at the TAZ (Traffic Analysis Zone) scale illustrating dominant commuting patterns in Beijing (Long & Thill, 2015).
Note: Arrows denote the commuting direction from home location to jobs location.

alternative modularity function incorporating a Gravity Model by a method of agglomerative clustering algorithm based on a Newman-Girvan modularity metric, to discover the clustering structures of spatial-interaction communities using MPD of one week in one city in China. The results also verified a high correlation existed between phone-users' movements in physical space and phone-call interaction in cyberspace. Their studies and findings are valuable for urban structure studies and planning practices.

(2) Urban general spatial structure

Under the background of informatization, the spatial structure of cities presents a growing dynamic and liquidity. Thus, the use of data with high-frequency (such as GPS Log Data from Handheld Divices, MPD, SCD, VGI and Large-sample-size data with low-frequency), and even realtime data to characterize and monitor urban form and spatial structure is demanded increasingly. In terms of presenting of dynamic nature, the existing literatures focus on

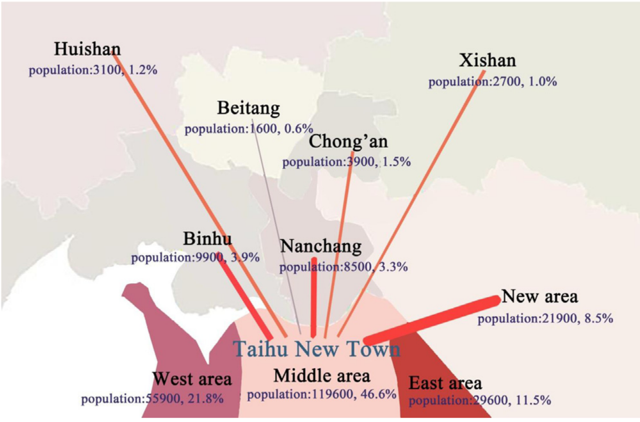

Fig. 10. The commuting spatial distribution of resients who live in Taihu New Town of Wuxi at night (based on MPD) (R. Mao, 2014).

Table 11
Main types of data and representative studies on urban general spatial structure.

Main types of data	Representative studies
MPD	Niu et al. (2014).
SCD	Liu et al. (2009); Liu, Wang, Xiao, & Gao (2012); Du et al. (2013); Zhuo, Murphy, & Long (2014); Long and Thill (2015); Zhou (2015); Zhou, Wang, Long, and Ruan (2015); Zhou, Wang, Li, and Cao (2015).
VGI data	Long and Mao (2009); Qin et al. (2014); Wang, Zhen, and Wei (2014); Wang et al. (2015); Wu and Qiu (2015); Xi (2015).
GPS Data from Floating Cars (taxis)	Zhou (2015).
Large-sample-size data with low-frequency	Liu et al. (2015).

the development of traditional methods. At the macro scale, MPD, SCD, VGI data, GPS Data from Floating Cars (taxis), Large-sample-size data with low-frequency could clearly depict urban overall structure (see Table 11).

In this study field, there are several representative cases. The first is a case using MPD which comes from Niu et al. (2014). They identified the ranks and functions of public centers in the Shanghai central city by calculating multi-day average user density at 10:00 and 23:00 h for week days and at 15:00 and 23:00 h for weekend. In addition, they studied the urban spatial structure changes in weekdays and weekend in Shanghai. Based on this, commuting circle boundary of Shanghai central city was identified. The second are some cases using SCD, and earlier studies in China come from Long, Zhang, and Cui (2012), Du et al. (2013), Long and Thill (2015). For example, Long, Zhang, and Cui (2012) identified commuting trips in the BMA (Beijing Metropolitan Area), and Long and Thill (2015) depicted home and jobs kernel density maps in the central BMA, both focusing on the general spatial structure. It worths noting that, in these researches, some conclusions made by traditional methods relating urban spatial structure have been interpreted and testified by some new data. For example, Zhou, Hao, and Liu (2014), Zhou (2015) testified Geographical Spatial Attenuation Law of business center by recognizing spatial characteristic of commercial centers in Shenzhen by floating car data, which revealed that the attraction between two commercial centers showed distinct power function relationship and validates the law of geographic spatial decay. Zhou, Wang, Long, and Ruan (2015), Zhou, Wang, Li, and Cao (2015) also used SCD to verify the attenuation law of bus travel time. The third are some cases using VGI Data, Wang, Zhen, and Wei (2014) used Weibo check-in data to analyze the general spatial pattern of Nanjing central city. Qin et al. (2014) used data mined from Dianping.com to analyze the catering distribution pattern of Nanjing. Wu and Qiu (2015) used data from Douban.com in Shanghai to study the distribution characteristics of innovation space and its relationship with urban spatial properties, main functional areas and public facilities layout. In addition, there are some cases by large-sample-size data with low-frequency. For example, Long and Mao (2009) analyzed the change of urban form and evaluated land use planning by plot data. Xi (2015) used a

Table 12
Main types of data and representative studies on urban function division.

Main types of data	Representative studies
MPD	Niu et al. (2014); Wang et al. (2015b).
SCD	Yue et al. (2009); Zheng et al. (2011); Qi et al. (2011); Liu, Kang, Gao, Xiao, and Tian (2012); Liu Wang, Xiao, and Gao (2012); Yue et al. (2012); Kang et al. (2014); Zhou, Murphy, and Long (2014); Zhou, Wang, Long, and Ruan (2015); Zhou (2015).
POIs data	Yuan, Zheng, and Xie (2012); Long and Liu (2013a, 2013b); Yin (2015).
VGI data	Yuan, Zheng, and Xie (2012); Long and Liu (2013a); Wang, Zhen, and Wei (2014); Wu et al. (2014); Han et al. (2015); Wang, Zhen, and Zhang (2015).
GPS Data from Floating Cars (taxis)	Yue et al. (2009, 2012).

case of Nanjing to study the structure of flow space from five aspects as the nodes, paths, edges, functional areas and the network.

The above-mentioned urban general spatial structure studies still mainly focus on static spatial features, which are difficult to reflect the dynamic and liquidity of urban spatial structure. To solve this problem, Zhou (2015) put forward the concept of "urban rhythm" and studied the dynamic spatial structure in Guangzhou within 24 h at a finer scale like days and hours. Wang, Zhen, and Zhang (2015) used Weibo check-in data from three aspects as time, space and activity to identify the dynamic spatio-temporal characteristics of Nanjing within a day, namely, creating a “scattered-gathered-further gathered-scattered-relatively scattered” mode. In addition, Liu et al. (2015) expected to fully reflect the spatial pattern and evolution characteristics by establishing social map, to accomplish realtime monitoring by certain technical support.

(3) Urban function division

Urban function division is the further refinement of overall spatial stucture. While in traditional planning practices, functional partition is estimated according to the dominant land use type in a parcel, and functional partition boundaries are clear, which could not reflect complex features in parcel like mobility, ambiguity and spatio-temporal overlapping. So single land use classification is hard to reflect the actual situation and meet the demand of plannings. And identifying functional division according to the real human activities rather than only according to space form is becoming one of the most important areas of urban studies and planning practices big data applied. In the process of identification, the residents' perception, activity frequency and density, the stay time, and other information could be captured by big data to help identifying dynamic, mobile, ambiguous and overlapping functional areas. Present studies on urban function division are mainly based on the MPD, SCD, POIs data, VGI data and GPS Data from Floating Cars (taxis) (see Table 12).

In terms of identifying function division and landuse mixing, current studies could be divided into three kinds. The first one is identifying by specific model without text information. For example, Liu, Kang, Gao, Xiao, and Tian (2012), Liu, Wang, Xiao, and Gao (2012) identified land utilization type and urban function divisions respectively by SCD and POIs; Niu et al. (2014) compared urban functional division identified by MPD using Kernel Density analysis with the current situation of landuse in Shanghai, finding that mixed functional areas in the central city had a higher proportion (see Fig. 11). The second one is identifying by data with text such as VGI data, POIs, etc. For example, Yuan, Zheng, and Xie (2012) inferred the functions of each region in Beijing using a topic-based inference model, which regarded a region as a document, a function as a topic, categories of POIs as metadata, and human mobility patterns as words. Long and Liu (2013a) estimated mixing degree of Beijing's commercial and residential land at parcel scale by check-in data and POIs data extracted from Weibo. Wang, Zhen, and Zhang (2015) divided urban areas in Nanjing into employment area, residential area, leisure area, nightlife area and compounds on the basis of mastering the law of urban acitivity spatial change by check-in data mined from Weibo. The identification of mixing function could lay foundation to optimize the urban land classification standards, to support the introduction of diversified classification standards such as ones based on policy. In addition, aiming at the paucity of land functions data in China, Long and Liu (2013b) proposed a method to automatically identify and characterize paicels

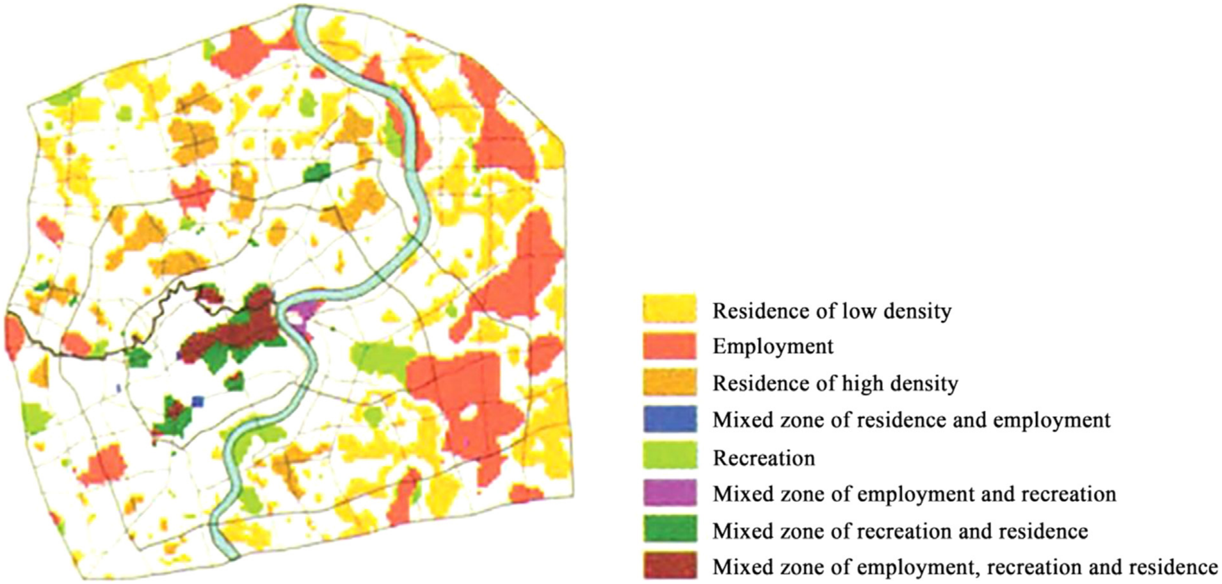

Fig. 11. Identification result of functional areas in the Shanghai Central City (Niu et al., 2014).

(AICP) by ubiquitous available OpenStreetMap (OSM) and POIs, providing a quick and robust delineation of land parcels, to infer urban functions. The third one is identifying by both data of no text information and data with text to further improve the recognition accuracy. For example, Long et al. (2013), Han et al. (2015) identified urban functional areas in Beijing, including the mature residential area, area to be developed, scenic area, commercial area, public management area, culture & education area, emerging residential areas and other functional areas by SCD and POIs data, and they also found that, in suburban Beijing, higher education district, light-industry area, agriculture area and high-end gated community were becoming the new employment and residential centers with the help of SCD (Zhou, Wang, Long, & Ruan (2015)). In addition, Meng et al. (2015) used SCD to find that residential area moved outward while employment area aggregating in the central city.

More notable one is that identification to boundary of shopping center and source areas of individuals in shopping centres, which is becoming a hot topic. For example, Yue et al. (2009) indentified shopping center attractiveness using taxi trajectory data in a case study of Wuhan. Based on this study, Yue et al. (2012) further distinguished and visualized the source areas of individuals in shopping centres, and she simulated the predicted trading area of shopping centre with the calibrated Huff model based on the GPS trajectory data, lastly comparing the predicted results with the observed taxi trajectories (see Fig. 12). Similarly, Wang et al. (2015b) identified commuting groups and consumer groups and source areas of two groups in East Nanjing Road and Wujiaochang area of Shanghai, based on an analysis of individual behavior in different periods by MPD. In addition, Yin (2015) estimated boundary of shopping center of Jiedaokou area in Wuhan by POIs from Baidu Map.

3.3. Spatial performance of structure at regional and urban scale

Space performance is a very important index to measure the spatial structure. The application of big data could better analyze the quality and efficiency of regional and urban space as well as the accessibility of facilities. In terms of performance at regional scale, researches are still relatively rare. However, there have been some interesting studies at urban scale.

Some representative cases focusing on the performance of structure at urban scale are as follows. Long, Mao, Yang, and Wang (2011) investigated the commuting energy consumption under typical urban forms as "compact/ sprawl", "single center/multi-centers", "TOD policy", "green belt", etc. on the basis of a Multi-Agent Model. In terms of performance of spatial planning and form design at meso and micro scale, Kang, Ma, Tong, and Liu (2012) investigated the relationship between the urban form and the intra-urban human mobility patterns using MPD

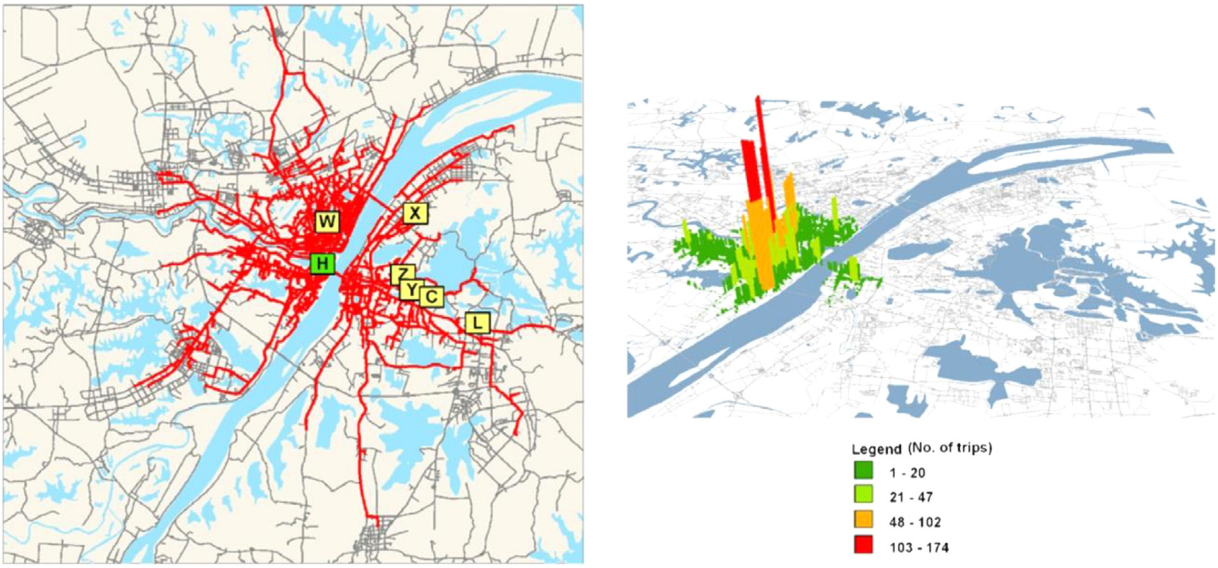

Fig. 12. Distribution of 80% attracted trips of shopping center H over road network (left column), and predicted trading area vs. observed area of shopping center H (right column) in Wuhan (Yue et al., 2012).

collected in eight cities of Northeast China. Long, Shen, Yao, and Gao (2014) argued that urban form features did impact people's mobility to positive and negative extents by perfoming an examination of the relation between urban form and socioeconomic attributes on human mobility in Beijing. Sun and Dan (2015) discussed the relationship between built environment and commuting time by a multivariate regression model based on more than 800 valid questionnaires in Shanghai central city combined with economic census data, verifying the impact of several factors of built environment such as built density, function mixing, spatial design on commuting time. They found that increasing function mixing may not reduce the commuting time effectively. Besides, Y. Li (2015) studied the liveability of walking space in Suzhou through open road network map and facilities layout map.

In terms of performance of facilities layout. Zhang and Li (2015) studied the accessibility of medical facilities for low-income people in Beijing by GIS network analysis on the basis of data of 376 medical facilities, affordable housings and transportation network.

3.4. Summary

Form and structure at regional & urban scale and the performance of spatial structure have been gradually becoming the most important research fields for big data application, and these spatial analysis are not only the deepening of behavior data acquisition and analysis but also a necessary premise in plan making and management. Although there have been many fruits in this research fields, much blank still exists to be explored. On the one hand, present studies still pay more attention on the overall structure of cities, such as commuting corridors, function division of whole cities. These studies on overall structure actually still do not make full use of advantages of big data to mine individual information, which still only play a supplementary role in researches. Therefore, facing directly mass individuals, studying their behaviors and spatial structures by big data are further directions in future. Fortunately, we have seen some meaningful fruits in this direction, such as a study to economically underprivileged residents (Long, Liu, Zhou, & Gu, 2014), college students (Wang, Zhou, & Long, 2014), and extreme commuting patterns like Early Birds(EB), Night Owls(NO), Tireless Itinerants(TI), Recurring Itinerants (RI) (Long, Liu, Zhou, & Chai, 2014). On the other hand, deeper analysis beyond spatial structure is another direction. For example, a study about excess commute and commuting efficiency (Zhou & Long, 2014; Zhou, Murphy, & Long, 2014; Zhou, Wang, Long, & Ruan, 2014) has been a more profound research than an indentification of jobs-housing sites and

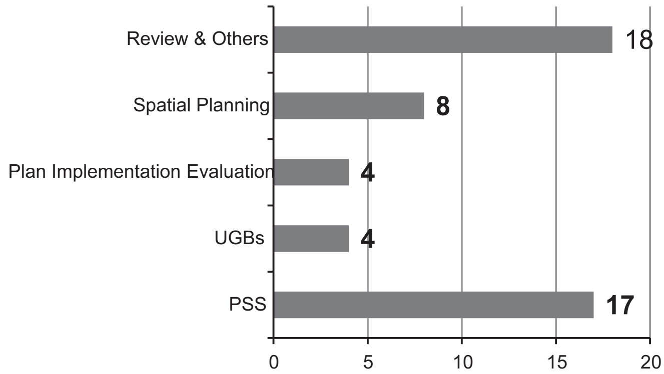

Fig. 13. Sub-theme of theme application of plan making & management.

commuting corridors. Another representative study comes from an investigation to the commuting energy consumption under typical urban forms as "compact/sprawl", "single center/multi-centers", "TOD policy" and "green belt" on the basis of a multi-agent model (Long, Mao, Yang, & Wang (2011)).

4. The application in plan making and management

Present literatures have discussed the potential changes of plan making by big data (Qin & Zhen, 2014; Wang, Yuan, & Li, 2014; P. Wang, 2014; S, Wang, 2014; Wu & Chen, 2014; Ye, Wei, & Wang, 2014; Zhang, 2014; Zhen & Qin, 2014; Dang, Yuan, Shen, & Wang, 2015; M. Mao, 2014; Mao, 2015; Niu, 2014; Xi & Zhen, 2015). They argued that big data would promote transformation and revolution of plan making in terms of idea, value orientation, planning concept and methodology. A more humanistic, public, precise, intelligent, efficient and dynamic planning system would gradually appear under the background of more frequently application of big data in planning practices. In specific plan making process, big data may greatly contribute to simulation, evaluation, monitoring and warning. In 51 literatures concerning the application in plan making & management, 18 ones discussed the development direction and gave a review, and 17 ones mainly concentrated in construction of Planning data Support System (PSS), while researches related to plan making remained to be strengthened (such as spatial planning, plan implementation evaluation, etc.) (see Fig. 13).

4.1. Spatial Planning

Spatial planning is the core part in regional and urban planning, including the landuse layout, traffic system, the open space, etc. The role of big data in spatial planning could be concluded into several processes, namely, validation, summary, innovation, simulation, evaluation, monitoring and early warning. Current literatures mainly focus on the issues as follows.

(1) Validation & summary

The traditional spatial planning which mainly depends on experiences to predict and analyze the future situation is relatively rough. The use of big data could verify the accuracy and summarize the applicability of traditional planning theories and methods, which will perfect the core of planning discipline and enhance the guiding function of theories to planning practices. A representative study comes from Sun and Dan (2015), and they found that density, functisonal mixing and spatial design might not reduce commuting traffic effectively, while increase of employment and residential density could promote jobs-housing balance and thus reduced commuting traffic, as well as increase of road network density would contribute to commuting efficiency. This is a good case of application of big data which provides decisions for the spatial planning, enhancing the pertinence and precision of spatial planning.

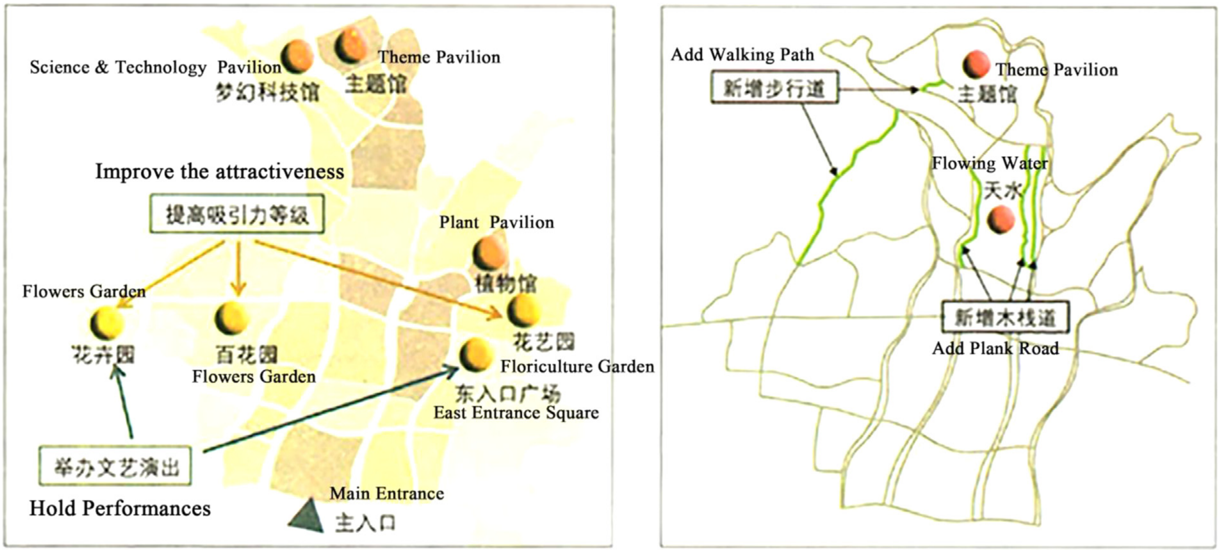

Fig. 14. Planning optimization based on visitors' behavior simulation in a case study of Qingdao International Horticultural Expo. 2014 (Wang et al., 2015).

(2) Innovation

Multiple sources of big data have greatly widened the access of information for spatial planning, so with the help of big data, it is possible to find some problems which may be difficult to figure out in traditional spatial planning and make some innovations in theories. Zhao et al. (2015) analyzed and compared the images of case cities in cyberspace through 2100 pictures of 21 cities in Guangdong Province searched on Google Image, and they analyzed the high-frequency image scene for urban design work, which developed Kevin Lynch's city image theory.

Another innovation is the application of big data in community planning. Prof. *Yanwei CHAI* performed some advanced studies in living space plan, life time plan, life circle plan and smart travel, etc., and he argued that the public facilities planning should be different between day and night (Chai, Shen, & Ta, 2014; Chai, Shen, & Chen, 2014).

(3) Simulation

The simulation of planning scheme by big data could more accurately identify the potential problems of schemes and make some alterations before being carried out. A good example could be found in the simulation of Shanghai Expo. planning and Qingdao International Horticultural Expo. planning (Wang & Ma, 2009; Wang et al., 2009; Wang et al., 2015a). Online virtual tour information could simulate the behavior characteristics of visitors and their trajectories, then providing feedback for planning scheme optimization (see Fig. 14). In addition, Yang (2015) used GIS data to analyze the plot ratio, building density, urban height, public service facilities, landscape view, traffic accessibility, road network density, physical environment, and population distribution, etc. in the process of urban design to provide a basis for visualization, combined with city modeling.

4.2. Plan implementation evaluation

Big data could recognize the boundaries of urban activity zones by its multiple sources and dynamic realtime performance, to evaluate the existing plans. Planning evaluation as well as planning monitoring and warning is also the most likely field where big data could play a role in changing the traditional planning mode in the short term. While the current researches basically focus on planning evalution, and more attentions should be paid on planning monitoring and warning. The application of big data in the field of planning implementation evaluation has the following categories currently.

The first category is using static big data to evaluate planning implementation results, especially the evaluation to landuse and UGBs, which further refines traditional planning evaluation method and improve its accuracy. In terms of evaluation of landuse, Long and Mao (2009) put forward a method using an indicator of parcel direction to characterize urban form, which could not only evaluate the degree of existing shape change, but also accurately evaluated the coordination degree of planning scheme and its surrounding historical texture. Niu et al. (2014) evaluated the comprehensive plan of Shanghai central city on the basis of identifying the public center system, function mixing degree and commuting scope of center city by MPD. In terms of evalution of UGBs, Han, Lai, Dang, Tan, and Wu (2009) examined the effectiveness of the urban construction boundaries in Beijing. Further, Long, Han, Tu, and Zhu (2014) evaluated the implementation of UGBs by check-in data, SCD, taxi GPS data and resident travel survey, finding that although there were a lot of informal development distributions outside the UGBs, UGBs area still covered more than 95% of urban activities, which demonstrated the effectiveness of big data reflecting the characteristics of the activity behavior in the evaluation of UGBs. On the basis of former work, Long, WU, Wang, and Liu (2014) evaluated the planning growth boundaries of more than 300 cities in China by analyzing their expansion, and Long, Han, and Lai (2015) further raised an analysis framework for the evaluation of the UGBs based on the data involving the degrees of conformance and performance between an urban comprehensive plan, detailed plans, development permits and observed development outcomes in Beijing.

The second category focuses on the evaluation of planning implementation process, replacing the traditional static outcome-oriented analysis. Factors of urban expansion have also been taken into consideration (Long, Han, Gu, Shen, & Mao, 2011; Long, Gu, & Han, 2012).

The third category is planning scheme implementation before being carried out. Unlike above-mentioned outcome-oriented or process-oriented evaluation, it focuses on the comparison of planning rules extracted from scheme and implementation policies, to find bias of policies and provide suggestions on planning adjustment before implementation. Long, Shen, Mao, and Dang (2010) evaluated the effectiveness of corresponding policies and measures for designated spatial plan by reverse simulation and derivation, to put forward suggestions for planning scheme optimization. These specific suggestions for optimization included accelerating the speed of population growth, transferring focus from central cities to small towns around, adjusting construction forbidden area, limiting construction along roads and promoting the environment of waterfront space, etc., which were all relatively applicable.

4.3. Urban growth boundaries (UGBs)

Urban growth boundaries and spatial governance are important parts in urban comprehensive plan, and they are current focuses in China's regional and urban planning. A constrained CA Model has been applied in Beijing to delimit the growth boundaries for central city, new towns and townships respectively (Long et al., 2006; Long, Mao, Shen, Du, & Gao, 2008; Long, Han, & Mao, 2009). The necessity of urban growth control planning has also been emphasized, which could be regarded as an extension of the concept of spatial governance. Besides, Long's group put forward Planning Support System (PSS) for urban growth control, which could automatically output growth control scheme according to the control factors of guideline (Long, Shen, Mao, & Hu, 2011).

4.4. Support system for planning and design

Database could provide systematic technical support for plan making, approval, maintenance and update. The current researches focus on the framework of Planning Support System (PSS) and its application in planning. *Kai LIU* first introduced PSS to China (AwaisLatif P, H. Detlet Kammeier, & Liu, 2003), then Du and Li (2005) applied "WHAT IF?" system in specific planning practices firstly. Subsequently, Niu (2006), Zhu and Shen (2008), Li (2010) conducted some further studies. In current literatures, Beijing Institute of City Planning (BICP) integrated geo-database, GIS and planning models into PSS to realize such functions as data display, information query, calculation, decision support and map generation, etc., and this integrated PSS was applied in analysis of present situation, spatial development, traffic capacity and infrastructure capacity. It has been also introduced in Beijing Comprehensive Plan Implementation Evaluation, dynamic maintenance for Regulatory Plan in Beijing central city, and Beijing Construction Restricted Area Planning (Yu, Huang, Wang, & Mao, 2006; Long & Mao, 2010; Cheng, Huang, & Mao, 2012; Ma, Shen, Gao, & Dang, 2013; Huang, Long, He, Yu, & Cheng, 2014; Long, Huang, He, Cheng, & Yu, 2015; Wu, Mao, Cui, & Wang, 2015). Furthermore, BCL recently put forward the Data Augmented Design (DAD) system driven by quantitive analysis of city. DAD could support various types of planning and design through data analysis, modeling, prediction, in order to improve the accuracy of planning, and it has been applied in Beijing Green System Planning. Besides, many scholars have conducted PSS studies and obtained many fruits (Wang, Chen, & Qi, 2010; Niu & Song, 2012; Li & Gao, 2014; Peng, 2014; Zhao & Wang, 2014; Li & Wang, 2014; Jin, Zhang, Wang, & Zhu, 2015). Based on these PSS researches, Planner Agent framework was proposed to support land use pattern scenario analysis (LUPSA) (Long & Zhang, 2014).

4.5. Summary

The application in plan making and management of big data is the most closely related to practices, which may determine the depth and breadth of big data researches in the future. There have been some fruits in spatial planning, plan implementation evaluation, UGBs, and support system for planning and design. Future direction of big data application is validation and summary to traditional planning theory, innovation of idea, method and technology, as well as simulation of space development in the plan. Among these directions, simulation may have breakthrough in the near future, which could give some improvement opinions and specific modification to plan schemes. The most convenient features of planning simulation are relatively easy to modify and compare different schemes, with little cost, which could increase accuracy in planning practices. As for validation & summary to traditional theories and experiences, there have been some findings revealing new truth undetected by traditional data (Zhou, Wang, Long, & Ruan, 2015), and there still have been much blank.

5. New methodologies with big data

With the help of big data, some new methodologies emerge in the field of urban studies and planning practices. Spatial simulation is a field of relatively maturity, and public participation is a newly emerging area which has well development prospects.

5.1. Spatial simulation

Spatial simulation based on urban model is one of the most traditional areas of urban studies and planning practices for big data application. The selection of model has experienced three stages of development, namely, morphological structure model, static model and dynamic model. The micro dynamic model based on discrete dynamics is currently a hotspot and development direction. This model analyzes the demands and behavior characteristics of the government, enterprises and residents from the bottom-up view, which is the basis for simulation of the spatial expansion, the selection of jobs-housing sites and enterprise location, etc., laying foundation for plan making. Micro Simulation Model (MSM), Cellular Automata (CA) and Agent-based Microsimulation Model (ABM) are currently the main types of micro dynamic models. Besides, model integration and comprehensive utilization have also been explored.

(1) Micro Simulation Model (MSM)

MSM has mainly two platforms including UrbanSim and ILUTE, which could simulate the spatial behavior of the individuals. Shi, Tong, Zhang, and Tao (2012, 2013) simulated land use layout of new towns under different scenarios and analyzed the interaction mechanism of the living space and the employment space on UrbanSim platform combined with statistics, typical investigation data and distribution data of construction projects.

(2) Cellular Automata (CA)

CA models, which could simulate space system expansion and evolution through partial transformation rules, are normally divided into unconstrained ones and constrained ones. Classical regional and urban spatial model in geography and urban planning could be integrated into the CA models as constraint conditions to simulate regional and urban spatial expansion effectively. According to the transformation rules, CA models could be divided into Multi-criteria evaluation whose transformation rules are relatively fixed and Logistic Regression Model and Neural Network Model whose transformation rules are both usually uncertain. Neural Network Model with some constraint conditions added has been widely used in regional and urban spatial simulation. Furthermore, Li and Yeh (2002), Li, Yang, and Liu (2008) introduced BP Neural Network Model into regional and urban analysis. They constructed transformation rules with constrained conditions, such as agricultural suitability, land resources and the most appropriate amount of land, by exploring regional historical development, to simulate the process of Dongguan's expansion. Luo, Du, and He (2003), Luo, Du, Lei, Chen, and Cao (2004) determined the transformation rules of all kinds of land expansion by expert scoring method. Yin, Zhang, and Liu (2008), Zhang, Yin, Zeng, You, and Chen (2008) introduced planning control conditions like the current situation, compiled regulatory plans and transport network, etc., to define the transformation rules in different areas and then simulated the spatial expansion process of Changsha under multi-scenario. Liu, Long, and Wang (2013) put forward a MoonLoop method by Logistic Regression Model.

In terms of application of CA in planning practices, Long et al. (2008), Long, Han and Mao (2009), Long, Mao and Dang (2009) put spatial constraints, institutional constraints and neighborhood constraints into the CA constaint conditions and set up Beijing Urban Spatial Development Model (BUDEM), to simulate Beijing city's form in 2020 and 2049. In the following studies, Long, Shen, Mao and Dang (2010) evaluated the effectiveness of corresponding policies and measures for designated spatial plan by reverse simulation and derivation, and they put forward suggestions for planning scheme optimization. Based on the BUDEM, Liu and Long (2013) proposed Peixian Urban Spatial Development Model in Spatial Planning of Peixian in Jiangsu Province. In their latest research, Liu and Long (2015) extended the study of BUDEM from the Beijing Metropolitan Area (BMA) to the Beijing-Tianjin-Hebei Region (JJJ Region) and simulated urban growth scenarios for 2049 in JJJ Region under multi-scenario. Furthermore, Zhang and Long (2015) developed a vector-based version of BUDEM (V-BUDEM).

(3) Agent-based Microsimulation Model (ABM)

Based on the simulation and observation of a large number of individual behavior data, ABM could give more reasonable and accurate explanations for evolution mechanisms of complex system. For example, Zhang, Zeng, Jin, Yin, and Zou (2008b), Zhang, Zeng, Tan, and Liu (2011), Zhang et al. (2012) simulated the spatial expansion of Changsha central city and Lianyungang by the analysis of three kinds of agents including residents, farmers and government. Hu, Zeng, Zhang, and Ma (2011) applied ABM in the site selection of ecological space in Changsha. Long, Mao, Yang, and Wang (2011) set up an Urban Form-Transportation Energy Consumption-Environment MAS model (FEE-MAS). They recognized quantitatively potential commuting energy consumption and its environmental influence in cities based on recognizationin individual features, preference of living-employment space, travel mode and physical space form. Futhermore, Li et al. (2013b) simulated the interaction between employment and living space under multi-scenario with the help of ABM. However, ABM applied in former researches could hardly cover the macro policy influence, the effect of regional migration and the impact on individuals from industrial development. Besides, the rules of individual migration in some ABM have strong subjectivity by researchers themselves, lacking of the support from fieldwork. So, there still exist some biases by ABM.

(4) Model Integration

The models mentioned above are respectively independent and there isn't a unified theory system or technical framework. To solve this problem, Li, Li, Liu, and He (2009) set up a geographical simulation and optimization system (GeoSOS) composed of CA, MAS and Intelligent Simulation. Long, Mao, Mao, Shen, and Zhang (2014) also proposed a framework and theoretical model of fine-scale urban modeling applied in urban and rural planning according to requirements in practices, to support spatial policy assessments. Based on former work, Long, Wu, Wang, & Liu (2014) put forward a Big Model concept and framework, which was a fine-scale regional/urban simulation model for a larege-size geographical area, making it possible to overcome the trade-off between geographical scale and simulation resolution. In addtition, W. J. Zhang (2015) proposed an urban simulation model at various spatio-temporal dimensions, with variables in long terms like landuse, population changes and ones in short terms like flexibility of jobs-housing sites, asset price, housing rental, wages, transportation, etc.

5.2. *Public participation in planning*

China has shifted from economic-oriented development to more complex development mode, especially social construction. Originated from social improvement, urban planning should also stress on community planning and community renovation which are closely related to residents' interests. Public participation will then gain further development in the field of planning. The application of big data may better reflect the problems in regional and urban development and residents' demand, providing a platform for public participation and community planning. However, public participation is a much more complicated and political issue, the promotion effect of big data to public participation must be assorted with political development.

Big data's intervention in the field of public participation is still in its infancy. In the existing studies, BCL developed a pricing comparison system of Beijing metro, providing a platform to let citizens' voice be heard. An online platform for discussion on community renovation planning of Zhonggulou area in Beijing (http://archlabs.hnu.cn/bj/) and Beijing cultural heritage APP in Apple Store established by Tsinghua-tongheng Urban Planning & Design Institute (THUPDI) provide public opportunities to engage in the planning, which could well support planning decisions. These practices of public participation all achieved good social effects and improved the public popularity of planning.

6. Open research issues

Big data has become a very heated issue in the field of urban studies and planning practices, while in the end of 2014 Prof. Jordan in UC Berkeley predicted online that the winter of big data would come soon. This reminds us of the short-lived popularity of system science and quantitative research in the middle 20th century. There are still various kinds of difficulties of big data application in urban studies and planning practices, such as the difficulty of data acquisition, privacy protection and correlation not reflecting causality. Currently, some researches tend to verify the existing conclusions or obvious truthes by the new big data, but there have been some findings revealing new truth undetected by traditional data. Therefore, we still should lay a positive attitude to big data application. Good ideas, meaningful issues, innovative methods and new techniques, as well as a combination with traditional data and methods, are all the development direction of big data application in future.

In terms of big data application in urban studies and planning practices, it could be summed up into two aspects, that is, "traditional field supporting" and "innovation leading". At present, both of these two aspects are at initial stage, and the development in these two aspects determines the extent of big data application in urban studies and planning practices.

Specifically, in the improvement of traditional field supporting, big data will allow a higher degree of refinement in urban studies and planning practices. More accurate empirical studies will appear, making the discipline system and framework further perfect. At the technical level, planning evaluation, monitoring, early warning and simulation system based on big data are recently the most possible areas where big data could exert its power. The integrated system could not only improve the precision and pertinence of traditional spatial planning, but also provide support for the follow-up dynamic even realtime evaluation, with the ability to connect plan making and management organically and dynamically. And at the business level, the elementary big data application still faces some problems, such as how to reduce cost, forming the industrial chain, etc. All these important issues need to be considered in the further development.

In terms of the role of innovation leading, the following points deserve to be expected. Firstly, the application of big data may cause a revolutionary change in relations among stakeholders in planning, way of plan making, contents and management maintenance mode of planning in the long term. Social spatial planning may become the emerging field of urban planning, and thus the core of urban planning will come back to the social attribute, leading an overall change of the discipline and profession. Secondly, it may bring revolution to planning theory system, technology and the talented professionals. In the theoretical transition, it will promote the diversity of research paradigm and methodology in related subjects such as human geography, urban and rural planning, etc. In this process, the system of urban planning theory will be perfected, and the core of the discipline will be further strengthened, which could guide planning practices better (Zhen, Wang, & Chen, 2012; Qin, Zhen, Xiong, & Zhu, 2013; Yang, Long, & Nicolas, 2015; Zhen, Xi, & Qin, 2015). While this change is not simply a paradigm shifting into another different paradigm, but a diversified mixing paradigm evolution and an application combined with explanatory paradigm and positivism paradigm, etc. In terms of technological change, the application of big data in plan making and management will greatly reduce the amount of work in traditional planning and provide conditions for innovation. Big data will also stimulate multi-disciplinary communication and cultivate more talented professionals. Thirdly, the further opening of data will continue to generate self-organizing research institutions and the birth of research media, and BCL is a representative example. In addition, the public will gradually become real participants in planning practices, so planning popularity is one of the most important directions of urban studies and planning practices in this big data era.

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