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Spatial Analysis of Commuting Mode Choice in Guangzhou, China

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Abstract: Metropolitan cities in China are commonly confronted with unresolved traffic congestion issues, primarily due to rapidly increasing traffic demand. Group disparity between commuting mode choice and its spatial distribution on road networks has enabled us to examine the factors that give rise to the discrepancies and the fundamental spatial causes of traffic congestion. In recent years, micro-perspective, individual, and behavior-based spatial analysis have mushroomed and been facilitated with effective tools such as temporal geographic information systems (T-GIS). It is difficult to study the interrelations between transport and space on the basis of commuting mode choice since the mode choice data are invisible in a specific space such as a particular road network. Therefore, in the field of transport, the classical origin destination (OD) four-stage model (FSM) is usually employed to calculate data when studying commuting mode choice. Based on the relative principles of T-GIS and the platform of ArcGIS, this paper considers Guangzhou as a case study and develops a spatio-temporal tool to examine the daily activities of residents. Meanwhile, the traffic volume distribution in rush hours, which was analyzed according to commuting modes and how they were reflected in the road network, was scrutinized with data extracted from travel diaries. Moreover, efforts were made to explain the relationship between traffic demand and urban spatial structure. Based on the investigation, this research indicates that traffic volumes in divergent groups and on the road networks is driven by: 1) the socio-economic characteristics of travelers; 2) a jobs-housing imbalance under suburbanization; 3) differences in the spatial supply of transport modes; 4) the remains of the *Danwei* (work unit) system and market development in China; and 5) the transition of urban spatial structure and other factors.

Keywords: transport; travel mode; China; temporal geographic information systems (T-GIS)

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1 Introduction

Since reform and opening-up in the late 1970s, urbanization and industrialization in China have significantly promoted economic growth. The level of urbanization for China as a whole grew from 17.9% in 1978 to 46.6% in 2009. The annual increasing rate is 2.14% faster than the average level for the rest of the world (Fang, 2009). Rapid expansion of urban space became a distinct characteristic during China′s urbanization process. To be more specific, the area of urban construction land in China jumped from 13 000 km^2 to 36 000 km^2 between 1990 and 2008 (Cai and Cheng, 2011). As a result, urban space in China has grown quickly. Its inner spatial structure is under fierce reorganization due to the scale and speed of such urbanization and land expansion. Meanwhile, great pressure has been imposed on urban transport because of the large number of urban immigrants. Even though transport infrastructure in urban China has improved markedly, traffic congestion remains severe, especially in rush hours. Take Guangzhou for instance: the road surface area per capita had risen

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from 3.7 m^2 to 14.13 m^2 between 1990 and 2007. During this period, four underground rail lines were opened. However, the existing transport system is still not equipped to efficiently handle the large traffic demand in peak hours. In this case, analyzing the spatial characteristics of travelers′ daily activities and conducting a further study of their influence on macroscopic urban traffic demand should deserve more attention as they are essential for effective implementation of travel demand management (TDM). The tradition of *Danwei*① management (derived from China′s planned economy days) plays a vital role in relieving the conflicts between rapidly increased travel demand and public facility supply. *Danwei* provides sufficient facilities to cover its employees′ requirements, including jobs, housing, schools, *etc*. This characterizes China′s transition in terms of travel demand and transport supply. Therefore, TDM focusing on transitional characteristics is regarded as an important solution for urban transport problems in China.

Two issues need to be considered in regard to traffic congestion: one is increasing travel demands, and the other is the changing nature of transportation mode choice. Some scholars believe that mode choice is mainly driven by human behavior, for which they have different explanations. Market segmentation based on travel patterns is fully documented (Button and Hensher, 2001) and research on market segments has become a common practice (Button and Hensher, 2001). As for other factors influencing the choice of travel mode, some scholars focused on land use and workplace (Cervero, 1996), while others pointed out that income level, residence, race and even the relationship between income and location were key factors. Time, expenditure and opportunity cost were what commuters consider when attempting to minimize their commuting problems (DeSalvo and Huq, 1996). Golob and Hensher (1998) argued that some personal and situational explanations, opinions and perceptions were attributable to traffic pattern choices, while other explanations were independent of residents′ behaviors. In order to reveal the residents′ behavior towards traffic congestion from the perspective of human behavior, Carlos and Daganzo (2002) discussed the role of different lanes formed in traffic jams. However, some scholars argued that human behaviors were too complex to understand, therefore research in the field of behavior and traffic congestion problems should be considered in an ′artificial neural′ framework if the problem was to be solved (Hensher and Ton, 2000). As far as travel time is concerned, urban structure, income and other factors have influenced the choice of travel mode. The scholars have not come up with a satisfactory answer for the causes of traffic mode choice even though research in this field has made substantial achievements. Research in this field is currently very important and meaningful given China′s rapid urbanization and industrialization, and the related increasingly serious traffic congestion problem, exacerbated by the socialist market economic system.

With the rise of humanism, more emphasis is being placed on the study of microscopic individual behavior. Despite factors relating to society, economy and politics (Watts, 2009), an active-based approach and search theory are also being considered in the analysis of related models (Bowman and Ben-Akiva, 2001). Study of residents′ spatio-temporal relationships, as an important perspective in explaining the interaction of urban space and travel demand, has been widely facilitated by GIS (Zhou and Yan, 2005; Yu and Shaw, 2008; Zhou and Deng, 2010). Based on travel diary surveys, studies on the spatio-temporal characteristics of microscopic individual activities and their footprints on transportation have become an important direction in urban transport analysis. The application of T-GIS effectively sorts out the relationship between spatio-temporal contexts and an individual′s features such as social and behavioral attributes. It helps to provide a platform to detect connections of urban space and transport demands. Therefore, combined with T-GIS, an examination of spatial characteristics of residents′ daily activities and a further analysis of the influence of these activities on macroscopic urban transport requirements are important for implementing efficient TDM.

In 1944, the Bureau of Public Roads in the United States carried out the first origin to destination (OD) investigation and built up the static four-stage model (FSM) (Haxson, 1995). Over time, the OD FSM analysis methods has been widely verified, improved and applied. They have been an important tool, used to con-

① After the founding of the People′s Republic of China, the state considered all social elements to allocate the limited resources effectively through *Danwei* (work unit) which enabled the state to connect with its members directly. *Danwei* tends to represent the party and government organizations, state-owned companies and other social organizations.

sider and predict travel demand, and have simultaneously become the theoretical basis for relevant software in the field of transport. However, the aggregate model of classical OD FSM is unable to reflect and record the dynamic process of individual daily activities effectively. Limits are placed, especially on the analysis and prognosis of mode choice (Gong, 2007). The disaggregate model, which provides a supplement for its aggregate counterpart, has mushroomed and become one of the crucial models adopted for predicting transport mode distribution (Liu *et al.*, 2000; Jiao and Lu, 2005; Liu *et al.*, 2008; Zhang *et al.*, 2008). At the same time, numerous derivative models of the basic logit model and the multinomial logit (MNL) model emerged (McFadden, 1973), including the nested logit (NL) model (Williams, 1977), and another two types of derivative models in the generalized extreme value (GEV) family (Koppelman and Sethi, 2000). One is the models exploring the flexible cross-elasticity choice for alternatives, including the paired combinatorial logit (PCL) model (Koppelman and Wen, 2000), the general nested logit (GNL) model (Wen and Koppelman, 2000), the GenMNL model (Swait, 2000), *etc*. The other is the models estimating elastic choice on the basis of a preliminary relationship structure, including the ordered GEV model (Small, 1987), and the principles of differentiation (PD) model (Bresnahan *et al*., 1997). Even though the development of research in this field seems optimistic, not much existing literature combines the spatio-temporal relationship of travel mode with road networks well enough to evaluate the dynamic state and spatial characteristics of travel mode distribution on road networks, as well as to analyze the connections between traffic demand and urban land use based on travel mode choice. The development of T-GIS provides potential technical value in this field (Zhou and Deng, 2010).

The combination of GIS and transport analysis has become one of the key directions in transport studies since the 1990s. Relevant research and practice predominately focus on how to connect the investigation and prediction of traffic demand with other factors (social identification, spatial behavior of respondents, urban spatial attributes, *etc*.) to conduct spatial analysis and other research. An example is using GIS to examine the spatio-temporal accessibility and the cognition of residents for transport networks (Miller and Wu, 2000; Yang and Zhou, 2006), or to study the relationships between land use and transport on the basis of T-GIS (Shaw and Xin, 2003).

With the multiple interactions of globalization, marketization and the growth of information, the structure of urban space is undergoing tremendous transformation in China. Explaining the transformation through analysis of microscopic individual behavior and macroscopic statistics is a vital new field in urban studies. Several questions are presented: What are the characteristics of spatio-temporal relationships of commuting mode choice in rush hours? What are the influences as of these characteristics on traffic demand? What are the causes of these characteristics?

Based on elementary principles of T-GIS and the ArcGIS secondary development platform of Visual Basic for Applications (VBA), this paper develops a T-GIS tool to scrutinize residents′ behavior. In the case study of Guangzhou, T-GIS and the data of residents′ travel diaries on working days were adopted to analyze the spatial distribution of commuting mode choice on road networks during rush hours and the spatial distribution features of transport relating to different workplaces. Then, this study attempts to reveal the relationship between urban travel demand and urban spatial structure, as well as the features and factors contributing to social disintegration behind this phenomenon.

2 Materials and Methods

2.1 Study area and data

Guangzhou, used as an empirical example in this paper, is the center of South China and the capital of Guangdong Province. It is located in the central district of the Zhujiang (Pearl) River Delta, adjacent to Hong Kong and Macao. As one of the original sites of the Marine Silk Route, a traditional trade and business city in China, as well as the frontier region of reform and opening-up, Guangzhou is amongst a list of cities featuring fast development in China. Its urbanization level grew from 48.1% in 1978 to 90.3% in 2008 (Guangzhou Statistical Bureau, 2009). Furthermore, the city benefited from holding the 16th Asian Games in 2010, winning urban development opportunities and a significant international reputation. By the census of 2010, Guangzhou had a population of 1.27×10^7 in a total area of 7434 km^2, with a downtown population of 1.107×10^7 in

3843 km^2. The expansion of urban space has increased the average travel distance from 3.17 km in 1984 to 5.03 km in 2005 according to a travel survey undertaken by the local government. The increase in travel distance and volume has been promoted by the separation of housing and jobs, along with the spreading out of activities related to daily life. Traffic congestion in Guangzhou is so severe that it has become emblem of Chinese cities.

The data used for this paper stems from a random sample of door-to-door questionnaires conducted in Guangzhou between May and August in 2007. Eleven typical neighborhoods approximately 1 km^2 in size were chosen from the central, transitional and marginal districts as study areas (Fig. 1). Consideration was given to the history, location and housing types in neighborhoods before they were selected. Housing in the selected neighborhoods covered all forms and included ancestral housing, *Danwei* housing, mixed housing, commercial housing, urban villages, and affordable housing (Table 1). Considering the average population density of 2 × 10^4 person/km^2 in the city and 3% as the sample rate, about 60 families were selected from each neighborhood, although sample numbers differed amongst the neighborhoods. In total, 800 families (1006 samples) were chosen, among which children younger than school age (under 6-years-old) and the unemployed were excluded. Excluding those who did not complete the travel dairies, there were 982 valid samples. The investigative data collected included the basic attributes of the respondents, the spatio-temporal data of their latest commuting dairies, their travel objectives and modes of transport, the factors travelers considered when selecting job locations and housing during the period from 1998 to 2007. The first two factors (basic attributes and data of travel dairies) were regarded as the principal data.

2.2 Methods

Using a spatio-temporal framework, residents′ trip modes are examined in this paper. The distribution of commuting mode choice in rush hours, as seen in the road network, was examined in conjunction with the

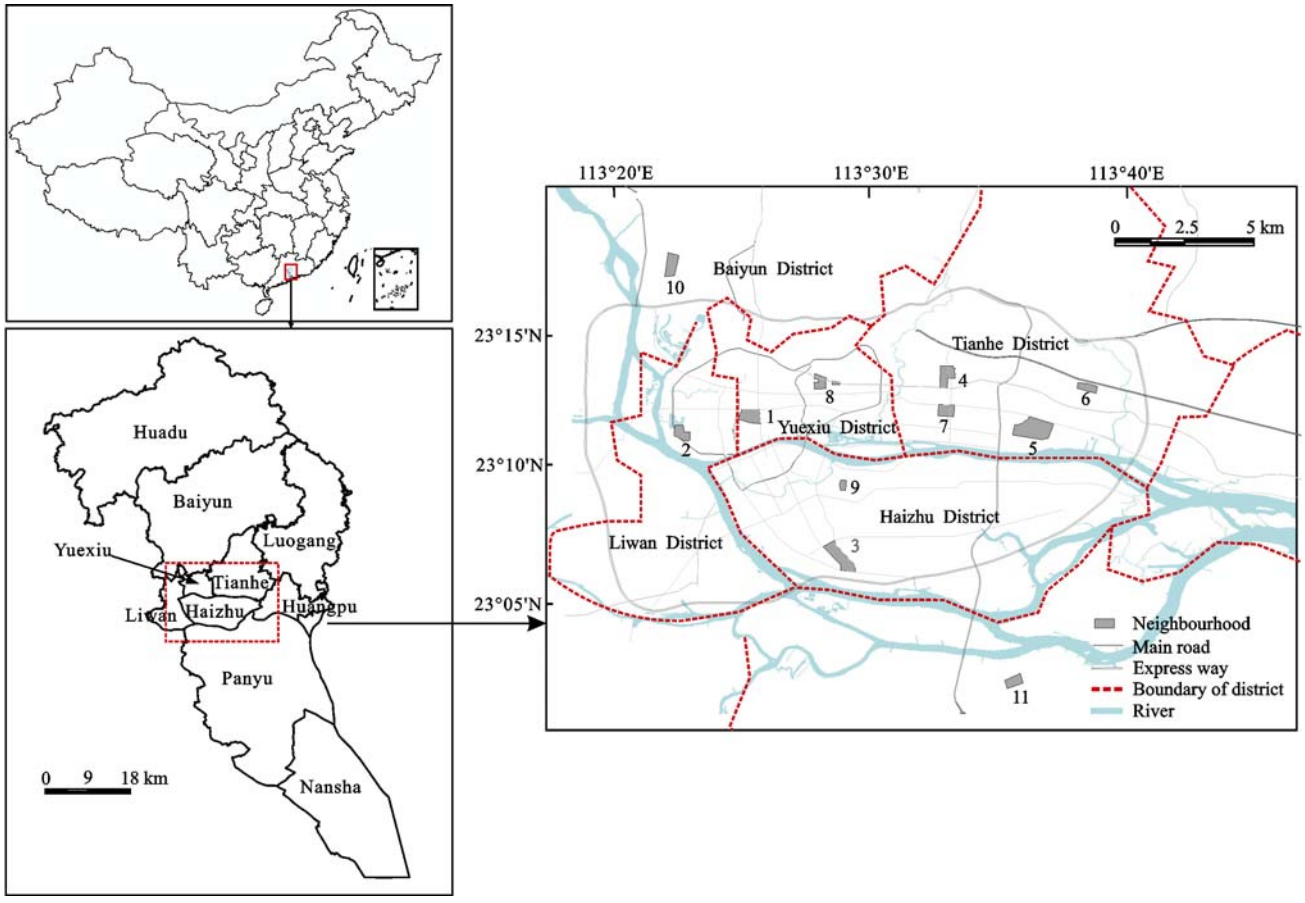

Fig. 1 Locations of study neighborhoods

Table 1 Location, construction time and residential types of selected typical neighborhoods

	Neighborhood										
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11
Location	CA	CA	TA	TA	TA	TA	TA	CA	TA	PA	PA
Construction time	Before 1970s	Before 1950s	1990s	End of 1980s	1960–1970s	1990s	1990s	1960s	1980s	1990s	2000s
Residential type	MH	AH	CH	DH	DH	AFH	UV	DH	DH	AFH	CH

Notes: CA (Central area); TA (Transition area); PA (Peripheral area); AH (Ancestral housing); DH (*Danwei* housing); MH (Mixed housing); CH (Commercial housing); UV (Urban villages); AFH (Affordable housing)

spatial jobs-housing relationship of commuters. The investigation comprised five stages: a) acquiring the latest travel diaries based on the questionnaire; b) establishing a spatio-temporal database; c) extracting the information from individual samples at any time by using a spatio-temporal analytical tool developed on the platform of ArcGIS. Information extracted from individual samples included the position and the state of the person (movement or stop), the spatial distribution of the moving individuals at any time and their personal information (e.g. social identification, commuting modes and travel objectives). We assumed that the travelers used the shortest path from origin to destination when developing the spatio-temporal tool and used it to simulate the travel track of the samples; d) analyzing the transport volume on road networks based on travel modes and social identification. We examined the routes of the samples who are traveling during the analyzed period of time (e.g., 7: 00–9: 00), separated the routes into sections according to the nodes, and calculated the frequency of the samples on each section of the road network. Finally, the road network distribution of travel modes was simulated; e) analyzing jobs-housing relationships of the corresponding groups. We searched the jobs and housing locations of the people traveling during the analyzed time, and linked their jobs and housing places.

According to the travel diaries, travel activities were concentrated in two periods (7: 00–9: 00 and 17: 00–19: 00), which are believed to be the primary contributor to traffic congestion. Thus, a comprehensive study of commuting mode choice characteristics in rush hours becomes essential for alleviating traffic pressure. Since the basic characteristics in the two rush periods are similar, the data of commuters between 7: 00 and 9: 00 was adopted to analyze the basic commuting characteristics.

3 Characteristics of Commuting Mode Choice

3.1 General characteristics and group distinction

Six main types of travel modes were recognized: public transport (bus and subway), individual transport (walking and bicycling), private automobile, *Danwei* vehicle, estate bus[②] and others. According to the investigation, individual transport is used by most residents, which makes up 70%, followed by public transport, with the percentage exceeding 15%. *Danwei* vehicles and private automobiles account for approximately 4%. In addition, small numbers of residents chose an estate bus (Table 2).

Individuals were divided into different groups according to different mode choice. The groups and the characteristics of their mode choice are analyzed below.

(1) Individual transport

The travel distance is relatively short, varying from 3 to 5 km. Even though average speed is only 8.76 km/h, this mode scores the highest percentage of satisfaction at more than 70%. Since individual transport is low cost and energy-efficient, it has become an essential mode of transport for short-distance commuters. Compared with other modes, residents who use this mode have the lowest income index. Around 70% of them are at a low-income level below 1000 yuan per month, illustrating the impact of an individual′s financial state on their commuting mode choice and travel distances. In addition, the age structure in this group is diverse and equally distributed amongst the different ages as walking or bicycling is relatively easy and safe compared to other modes.

② Estate buses are provided by real estate companies and mainly used by commuters living in suburbs, thus connecting the residential districts and city downtown.

Table 2 Information of commuting mode choice (7: 00–9: 00)

	Percentage of residents (%)	Average travel speed (km/h)	Average travel distance (km)	Index of income(1)	Percentage of satisfaction (%)	Predominant employment destinations(2)
Individual transport	74.5	8.76	5.68	1.94	73.86	Private enterprise, individual enterprise
Public transport	15.7	13.1	8.33	2.09	33.84	Private enterprise, state-owned enterprise
Danwei vehicle	4.6	22.5	13.89	2.18	40	State-owned enterprise, public institution
Private automobile	4.2	26.3	13.23	2.67	51.52	Private enterprise, Hong Kong, Macao, Taiwan and foreign-invested enterprise
Estate bus	0.8	25.2	20.4	2.46	12.5	Private enterprise, Hong Kong, Macao, Taiwan and foreign-invested enterprise, Joint-stock cooperative enterprise
Other modes	0.3	3.73	3.73	2.67	33.33	

Notes: (1) Income is divided into four grades: 1 = below 1000 yuan; 2 = 1000–3999 yuan; 3 = 4000–7999 yuan; 4 = above 8000 yuan. Index of income is weighted mean value of resident percentage in every income grade; (2) Employment categories include individual enterprise, privately-run enterprise, Hong Kong, Macao, Taiwan and foreign-funded enterprise, collective enterprise, stock cooperative enterprise, state-owned business, public institution, agency. The first two employment categories comprise the highest proportion of destinations in Table 2.

(2) Public transport

The medium income group dominates this mode. It has a low speed (13.1 km/h) and low percentage of dissatisfaction (33.84%), which can be explained by negative factors such as insufficient, ineffective line organization and the relatively unpleasant inner environment of public transport modes. Occupying second place in the most popular commuter mode choice, public transport takes up 15%, which means that there is great potential for further uptake.

(3) *Danwei* vehicle

Similarly, this mode serves the medium income group with about 50% of employees working in state-owned companies. Distances between workplaces and residences are large due to the relocation of state-owned companies. To tackle this problem, the companies use *Danwei* vehicles to cater for staff commuting. This solution is regarded as a kind of *Danwei* welfare which follows the ′enterprises running society′③tradition, attempting to enhance the employees′ working enthusiasm and avoid lateness and absence. Generally, residents who choose this mode travel long distances daily.

(4) Private automobile

More than 50% of passengers express their satisfaction with this mode, which is probably because of its capacity for long distance travel (13.23 km), fast speed (26.3 km/h) and superior comfort. Commuters who choose this mode have high incomes, with 64% of families spending more than 1000 yuan each month on transportation and 15.2% of individuals earning more than 8000 yuan. All of them live on more than a 2000 yuan monthly salary, which, it is suggested, could be considered as an income threshold for users. Deprived individuals are excluded as they can not afford the cost. Even with an increase in the social status of females, males retain a dominant role in driving. In this case, age and gender could be said to influence the use of private automobiles.

(5) Estate bus

Development of this mode is accompanied by residential suburbanization as it connects residents in suburbs with employment areas in the city center. It has the longest travel distance which is 20.4 km and the lowest degree of satisfaction. Individuals in this group predominantly live in commercial housing in the suburbs and have high incomes, high educational levels and high rates of housing ownership.

In light of the analysis above, the conclusion can be drawn that significant group differences give rise to different commuting modes. To be more specific, individual and public transport are popular choices for most people, while private automobiles and estate buses ap-

③ ′enterprises running society′ means that the state-owned enterprise is in charge of establishing and managing some organizations and infrastructure (schools, hospitals, canteens, *etc*.), which do not connect with production directly but guarantee life quality, welfare, security and so on.

peal to citizens who are relatively highly paid and well educated. In terms of the *Danwei* vehicles, the *Danwei* system plays a vital role as *Danwei* staffs are the only users. Opportunities for individuals to choose a transport mode are unequal. Influencing factors include incomes, the *Danwei* system, gender, age and the nature of urban spatial structure. Therefore, examining commuting mode choice enables us to explore the underlying factors behind the disparities displayed.

3.2 Road network distribution of commuting mode choice and spatial job-housing relationship

Sample travel times on main roads in downtown Guangzhou were calculated and the accumulated results illustrated in Fig. 2. Figures 2 and 3 show the spatial characteristics of different commuting mode choices and the urban spatial factors contributing to traffic volume distribution on road networks. Findings include:

(1) With the advantage of short travel distances, individual transport predominates in the vicinity of the study neighborhoods.

(2) As a crucial part of the urban infrastructure, public transport aims to satisfy the residents′ basic need for daily travel. In this case, it makes the widest contribution, covering almost the whole network. As for its spatial contribution, significant traffic volumes lie in the east/west roads which traverse the central business district (CBD), including Dongfeng Road, Ring Road, Zhongshan Road and Tianhe Road. Lesser volumes can be found in the north/south roads which link the old city center with Haizhu District.

(3) Estate bus traffic tends to be distributed in the north/south main roads, thus connecting the city center with commercial housing neigbourhoods in the urban outskirts. High income earners who work in the city center have been moving to the suburbs where there is less built-up land and the living environment is better. Consequently, this group comprises commuters who have to travel long distances between the suburbs and the CBD. At the same time, the construction of infrastructure, including public transport facilities, has lagged behind that of housing, thus setting barriers for commuting. As a solution to mitigate the inconvenience, the estate bus makes up part of the public transport mix and has become an essential mode of commuting choice for the new suburban residents.

(4) According to the data and illustrated by Fig. 3, the main function of *Danwei* vehicles is to carry passengers between their residence and workplace through the east/west main roads. Most of these workplaces are in the suburbs and generated by the relocation of state-owned companies, which means some of their staff become commuters if they are unable to afford and find a residence close to their workplace. To address this problem, *Danwei* arranges vehicles for its staff to minimize the negative impacts. The tradition of ′enterprises running society′ within the *Danwei* system still plays a role in the daily work and life of its staff, which is illustrated by the provision of supplementary *Danwei* vehicles.

(5) Sharing similar group characteristics, the private automobile mode shares the analogical function of estate buses, that is, connecting the city center and the suburbs through the south/north road network. The group using these two modes has high income and educational levels, which has enabled them to become the first batch of commuters to live in the most desirable environment, the suburbs, under residential suburbanization. Despite the homogeneity, passengers using private automobiles possess more freedom of travel, higher travel efficiency, and more flexibility with their job-housing choices. Commuting distances have less impact upon their lives and thus commuting distances are more varied and extensive.

Generally speaking, in regard to commuting mode choice, the above observations reveal a close relationship between the spatial characteristics of the road network and jobs-housing links. The commuters sampled in the research who use individual transport have the best jobs-housing match and the least traffic demand while the other groups, especially those from the suburbs using estate buses and private buses, have a greater jobs-housing mismatch, longer commuting distances and increasingly bigger traffic demand.

4 Factors influencing commuting mode choice and its spatial patterns

The characteristics analyzed in section 3 illustrate the connection between urban space and commuting mode choice which is influenced by individual diversity and spatial differentiation. Key issues surrounding this connection include: firstly, socio-economic transition that results in a diversity of social groups; and secondly, rapid urbanization and urban regeneration. These lead to

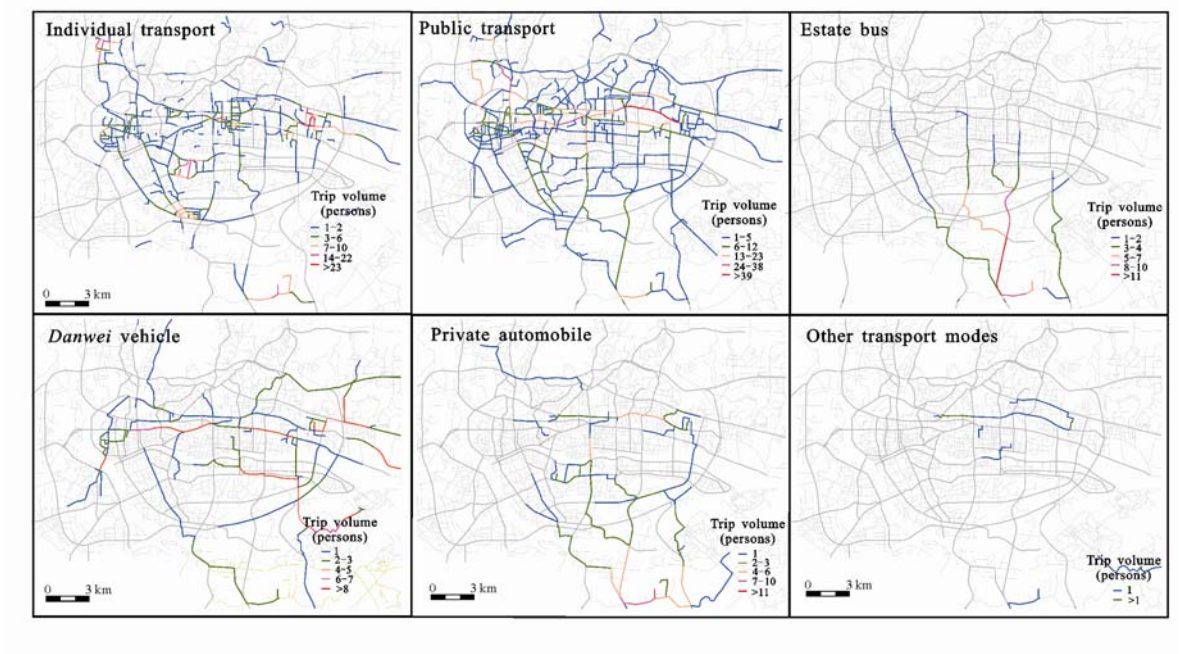

Fig. 2 Road network distribution of commuting modes during rush hours (from 7: 00 to 9: 00)

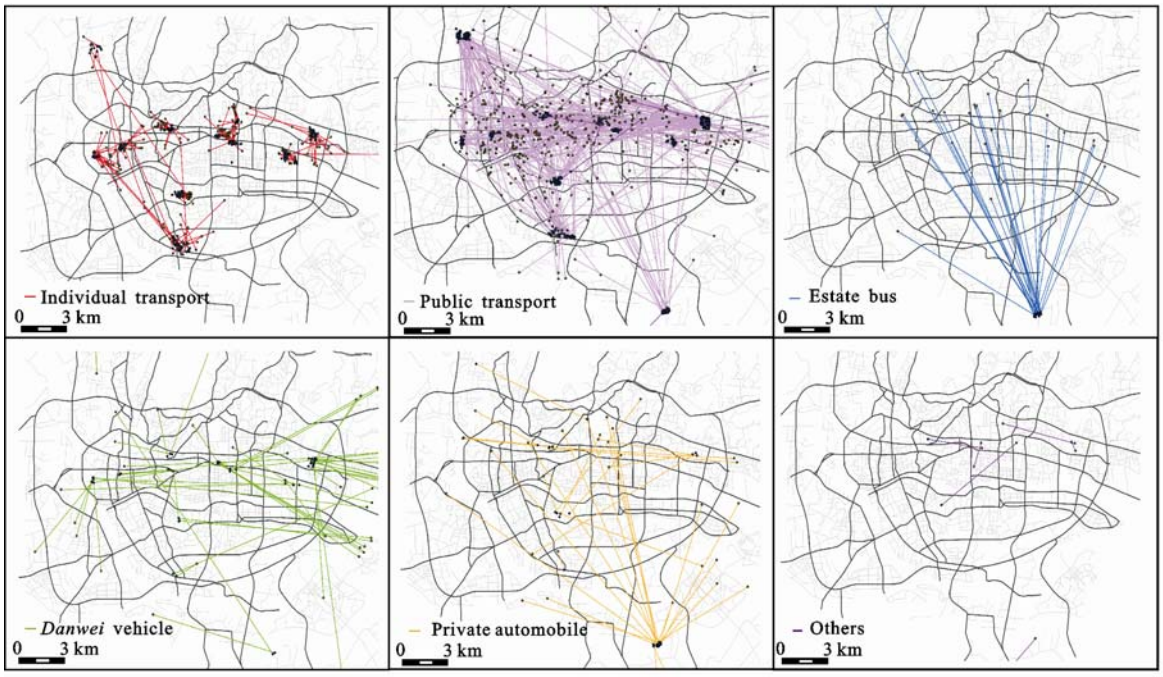

Fig. 3 Jobs-housing links in rush hours (from 7: 00 to 9: 00)

a jobs-housing imbalance and inadequate public transport services that produce a mismatch between transport demand and network supply.

(1) Diversity of social groups

China has been undergoing socio-economic transition since the late 1970s. As a result, social groups are becoming increasingly diverse and distinct, which further influences jobs-housing relocation and commuting mode choice.

Within a principal component analysis, four indexes were selected: 1) education level (x_1); 2) monthly income (x_2); 3) monthly mobile phone fee (x_3); and 4) employment position (x_4). One major factor (F_1) was extracted to take the place of 63.34% of the whole re-

search cohort. The formula was: $F_1 = 0.740x_1 + 0.859x_2 + 0.769x_3 + 0.810x_4$.The higher the value of F_1, the higher the education level, monthly income, mobile phone fee, and position. The result of boxplot analysis shows that a relationship between social attributes and commuting mode choice exists. The average F_1 (see the center line of each box in Fig. 4) is much higher for commuters using the categories of estate buses, private automobiles and others (such as taxis) while it is comparatively low for commuters using individual and public transport and the remaining modes. The rectangle of each mode in Fig. 4 means the F_1 for 25% to 75% of the samples. They are much higher for the *Danwei* vehicle and private automobile commuters than for the individual transport, public transport and estate bus commuters, which suggest greater social diversity of the first two types (Fig. 4).

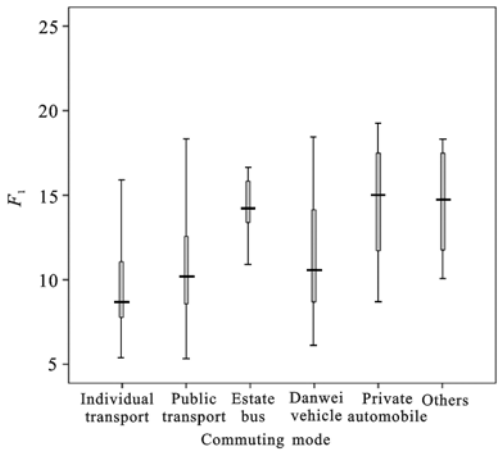

Fig. 4 Boxplot reflecting relationship between socio-economic status (F_1) and commuting mode choice

Under the dual economic system in China, the planned economy still plays an important role in individuals′ daily activities (such as commuting mode choice). *Danwei* compounds and *Danwei* communities were the most popular basic units of urban space before the reform and opening-up in China, and it enabled inhabitants to conduct daily activities (such as residence, work, entertainment, education, medical care) there. A high level of jobs-housing balance was reached in the *Danwei* units. However, this balance is disintegrating gradually due to socio-economic transition and the spatial reconstruction of urban areas. The patterns of jobs-housing have shifted considerably as a consequence, which has impacted on residents′ daily travel. A special travel mode, the *Danwei* vehicle, was thus created to compensate commuters for their loss of travel ease. These vehicles are buses or cars supplied by *Danwei* to their employees, and their drivers are paid for by the *Danwei*.

Transport modes are determined by a number of criteria, the economy, the *Danwei* system and so on. For instance, the private automobile solely serves only those who can afford the high cost (the group with the highest income index, see Table 2). The *Danwei* vehicle is the particular mode of transport used by staff in state-owned companies. To avoid being excluded, travelers tend to choose the mode that best matches their socio-economic attributes. Marginalized individuals with low incomes, education, skills, *etc*. are excluded from most of the travel modes. The majority of them are only able to choose individual transport, the mode with the least requirements (the group with the minimum income index, see Table 2). With the increase in living standards, the private automobile becomes prevalent. According to the Transportation Commission of Guangzhou, the city had a vehicle capacity of 2.145×10^6 by 2010, 1.61×10^6 of which were estimated to be private automobiles with an additional 3×10^5 added in 2010 alone. In addition, private automobiles in Guangzhou have increased by 22.1% in the last five years, with 90 owners per thousand individuals (Wei, 2011). As a rapidly increasing and popular transport mode, the private automobile not only occupies a great deal of transport infrastructure with a low efficiency usage, but also inhibits the uptake of disadvantaged modes that are more efficient and eco-friendly. Traffic congestion is caused by this imbalance. In fact, contests among transport modes result from the competition among groups with distinct socio-economic attributes. Specifically, the more vulnerable the users are, the more disadvantaged the transport mode they use is, which aggravates the deprivation of the users and vice versa. Despite commuting mode choice, socio-economic attributes play a role in selecting jobs-housing locations as well. For instance, the high income group is willing and able to afford jobs-housing imbalance if the separation provides them with better living and working conditions, which enhances traffic demand.

(2) Jobs-housings mismatch

The rapid growth of urbanization and industrialization requires more urban space, which is becoming increasingly scarce, leading to a number of urban prob-

lems such as traffic congestion, functional disorder, environmental deterioration and insufficient housing. To alleviate this conflict, Guangzhou has converted a traditional single-core pattern (development within the old city centre) to a multi-core structure through mega-project implementation in the suburbs. During this process, new urban space is created. Examples include some new jobs centers such as the Guangzhou Economic-technological Development Area, Biology Island, Guangzhou Science City, Guangzhou Higher Education Mega Center, Nansha New Zone, and the three major automobile manufacturing bases. New residential areas have also been developed. These examples have exerted a tremendous influence on the spatial structure of the urban economy and dwellers′ activities, which has significantly altered the jobs-housing balance. To meet the needs of daily commuters, some enterprises in the new jobs centers supply *Danwei* vehicles for their staff, while some employees use private cars to undertake the long commute. At the same time, individuals living in the peripheral residential areas also have to use estate buses or private cars for their daily long commute. Often new developments in the suburbs are not complete and/or their functions are not comprehensive enough to meet the needs of their residents. As a consequence, residents may work or live in peripheral satellite suburbs, on the one hand, and, on the other hand, their daily activities such as shopping and meeting friends may remain largely dependent on the old city centre, which boosts traffic demand and aggravates the traffic congestion on the roads connecting the old city centre and the peripheral satellite suburbs.

Another factor altering the jobs-housing balance is urban regeneration. Dependence on the old city centre has been a tradition in Chinese cities. Insufficient consideration of the sustainable development of industries and living conditions has caused insertion of industrial spaces in the old city centre and its vicinity, which severely restricts the extension of industrial spaces and treads on the residents′ living environment. Urban regeneration is a way to bring about compact development for underused land and disordered functional zones, under the context of intensified land use, increasing land prices and better living conditions. Relocation of state-owned companies and reconfiguration of the old city centre and urban villages are the main means of urban regeneration in internal Guangzhou. As a consequence, the traditional administrative transfer of land supply has been replaced by the compensated transfer. Industrial land in the inner city has been upgraded into commercial and service space which produces higher returns. Meanwhile, state-owned enterprises are considerably impacted through the restructure of the national economy, with outcomes of eviction from the inner city or closure. This makes room for tertiary industry and stimulates the growth of other urban functions. Against this backdrop, relocation of state-owned enterprises has destroyed the original jobs-housing balance under the *Danwei* system and stimulates new traffic demands. In addition, the old city centre and urban villages have been converted into expensive residential or commercial areas owing to their competitive location, and gentrification ensues. The original residents are usually evicted to urban outskirts where transport facilities are underdeveloped and employment opportunities are limited, which forces them to travel long distances daily. Therefore, the jobs-housing imbalance and long distance travel are caused by urban regeneration and functional change.

(3) The inadequate supply of public service

The supply of public service facilities has lagged behind the new traffic demand described above. Some systems and markets have responded to this by producing indigenous options such as *Danwei* vehicles and estate buses. *Danwei* vehicles cater for the long travel distance of their staff and provide company welfare and ′enterprises running society′, which indicates that the *Danwei* system remains crucial for commuters. To enhance sales figures for suburban residences not well connected to bus stops or subway stations, estate buses were created to connect peripherally located residents with the city centre, thus mitigating residents′ travel inconvenience. Estate buses illustrate a market response to undertake adequate land use planning.

(4) The mixed land use in city center

According to Fig. 3, which illustrates the jobs-housing links in rush hours, it is obvious that individual transport commuters mostly live in the center area of the city and their jobs-housing distance is short. Different from the suburban area mentioned above, land use in the center of the city is mixed and the jobs-housing of residents is in balance. At the same time, adequate public services also enable residents′ daily activities such as shopping and recreation to be undertaken within a short

distance.

5 Conclusions

In the field of transport study, the classical OD FSM uses a probabilistic approach to demonstrate the characteristics of commuting mode choice, which is mostly not related to road networks and other specific spatial dimensions. In this case, it is difficult to illustrate the relationship between transport and space based on commuting mode choice. Based on the background of socio-economic transition and rapid urbanization in China, this paper takes Guangzhou as an example to show the spatial distribution of different transport modes on the main road networks, along with the jobs-housing travel track based on different modes, in order to explain the connection of residents′ traffic demands with the urban spatial structure, as well as the causes of social disintegration behind the connection. This research will act as a reference for models aiming to optimize traffic mode distribution and prediction.

The survey in this paper used individuals in typical neighborhoods as samples owing to the inaccessibility of a citywide investigation. Sample distribution and volume in the survey have limitations and certain errors are likely to exist in the results arising from the analysis. As a result, the sample volume of some commuting modes, such as the estate bus, is less in the specific spatial analysis. Therefore, the contribution of this paper to the connection between transport requirements and urban spatial structure would be more significant if a sufficient quantity and more balanced distribution of samples had been achieved.

The empirical study reveals that the distinctive travel mode distribution based on different groups and road networks is influenced by diverse factors including diversity of social groups caused by socio-economic transition, jobs-housing imbalances led by rapid urbanization and urban regeneration as well as to inadequate public transport services. Distinct groups and urban space varies from mode to mode to different degrees. As for groups, it can be said that individual and public transport modes are favoured by low and middle-income groups as well as high accessibility; *Danwei* vehicles solely provide support for the people within the *Danwei* system. With regard to private automobiles and estate buses, high incomes and educational levels are characteristics of the groups which use them. In terms of spatial differentiation, individual transport is used widely in the city center, and a balanced distribution of public transport, private automobiles and estate buses is found in areas between the city center and the suburbs. Practically, the spatial analysis presented gives further direction for urban planning with advice for efficient urban land use through providing public service facilities. It also addresses problems in urban planning and management, such as how to make urban life more convenient, equal and harmonious.

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