Chin. Geogra. Sci. 2010 20(6) 554–561
DOI: 10.1007/s11769-010-0431-3

Transportation Characteristics Change under Rapid Urban Expansion: A Case Study of Shanghai

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Abstract: This paper focuses on the economic development and urban morphology as well as its impact on the transportation system during the urban expansion of Shanghai in the last more than 20 years (1986–2008). Based on data from 3 comprehensive transport surveys of Shanghai since 1986, the changes in residential trip demand, vehicle use, and the spatial distribution of trips were studied to understand the demands on the transportation system. The factors contributing to those changes in transportation demand were discussed, by which the conclusions were arrived: 1) economic development promotes population growth and stimulates residential trip demand greatly; 2) unsynchronized migration of population and job from central district to periphery district of Shanghai make trips and congestion diffuse in the same way; and 3) urban sprawl from a city center encourages the single-occupant vehicle mode, which imposes greater pressure on the roadway system. It is concluded that urban development should coordinate with the transportation system planning and expansion.
Keywords: transportation; urban expansion; urban morphology; Shanghai

1 Introduction

The relationship between urban development and transportation has always been of great concern. To date many studies focus on the reactive mechanism between transportation demand and land use, and put forward some planning ideas such as TOD (transit-oriented development), TND (traditional neighborhood development) and Smart Growth, *etc*. (Zhou and Yan, 2005).

In addition, Gakenheimer (1999) pointed out that mobility and accessibility are declining rapidly in most of the developing world because of the rapid pace of motorization, conditions of local demand that far exceed the capacity of facilities, the incompatibility of urban structure with increased motorization and limited management among responsible officials. The developing world should learn from the developed countries as regards to the roles of new technologies, the forms of institutional management and the long-term consequences of different effective policies toward the automobile. To meet the needs of mobility cities several focuses should be laid on in the developing countries: 1) highway building, hopefully used as an opportunity to control access, 2) public transport management improvements, 3) pricing improvements, 4) traffic management, and 5) an emphasis on rail rapid transit based on new revenue techniques.

There are similar studies that focus on mutual relationship between urban transport system and urban space pattern both at home and abroad. Huang *et al*. (2009) took Beijing as a typical research area, and quantitatively compared 3 basic urbanization modes from the viewpoint of spatial analysis, including polygon-urbanization, line-urbanization and point-urbanization, from 1991 to 2004, with the support of GIS analysis. The analysis found that the micro-level factors, such as the altitude, slope, aspect and location, limited the possibility of urban expansion and showed that the distance to freeway is the most important factor to encourage the urban expansion. Mao and Yan (2005) took Guangzhou as an example to study the mutual mechanism between urban transport system and urban space pattern in the city, analyzed the impacts of urban transport system on the urban space pattern, and found the feedback effects

Received date: 2010-03-12; accepted date: 2010-08-23
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 70803034)
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of urban space pattern on urban transport system layout. Zhu (2005) suggested that the historical development laws and patterns in Chengdu have not been in consistent with transportation capacity, and proposed holistic optimization tactics between urban space structure and transportation system planning. The similar study is also of great interest abroad. In 1995, Parsons Brinkerhoff Quade and Douglas Inc. provided a review of studies that investigated the relationship between transit and urban form. Cervero and Kockelman (1997) focused on 3 elements of urban form (the 3D′s): density, diversity of land use, and urban design and relationship with mobility. Subsequently, Badoe and Miller (2000) reviewed the literature on empirical studies of transportation, trip demand, and land use interaction. In García-Palomares′s study (2010), three elements of urban sprawl were addressed (metropolitan expansion, low density and work and leisure facilities in suburban areas) and discussed the main characteristics of mobility (flow networks, mode-choice, and trip times).

More specific to Shanghai, Shen (1997) analyzed its increase of transportation demand from 1985 to 1994, and found that the seven most important factors to result in the explosive growth of transportation demand, involving population growth, economic and income growth, urban expansion, land use reconfiguration, the emergence of labor market, disappearance of enterprise-based housing provision, and government decisions to nurture auto industry. Based on this analysis, he suggested that the future planning and policy of Shanghai should encourage mixed land use to reduce the gap between transportation demand and supply, charge licensing fees and/or gasoline tax on personal vehicles and encourage flexible work schedules.

Sperling (2003) also took Shanghai as an example when he discussed the interaction between urban development and transportation, based on a particular viewpoint which included the following factors: 1) national and local support on the domestic automotive industry, 2) the effect of China′s accession to the World Trade Organization on the consumer credit and the vehicle availability and prices, 3) success of the multi-centralization plan, 4) investments in bus and rail transit, 5) investments in road infrastructure, 6) control and pricing of parking and road use, and 7) policies for motorcycles and scooters.

While the aforementioned studies provided useful insights to the problem of understanding the interactions between urban development and transportation, the data used were obtained during a period of relatively slow urban growth in Shanghai. In this paper, the newly available and abundant data during a period in which Shanghai experienced rapid economic growth and urban expansion will shed new light on this age-old problem, and the analyses of those data for the purpose of gaining a better understanding of the interaction of land use and transport will be the focus here.

2 Study Area and Data Acquisition

2.1 Study area

Shanghai covers an area of 6 340.5 km^2 and is the most populated city in China with a population of more than 1.7×10^7. Since the opening and developing of Pudong in the early 1990s, the land use in Shanghai has expanded from the west of the Huangpu River to the east, from the central district (area within the inner ring) of the city to the periphery district (area between the inner ring and the outer ring). In this paper, the authors defined central city as the area within the outer ring (including central district and the periphery district) and outskirts area as the area beyond the outer ring (including the suburb and satellite cities). And the city is still under rapid expansion.

2.2 Data acquisition

To better understand the changes of the transportation system during Shanghai′s urban expansion, 3 comprehensive transport surveys for the whole city were conducted in 1986, 1995 and 2004, respectively (LGSCTSS, 1998; LGTCTSS, 2005). The differences of survey items in those surveys are shown in Table 1.

Table 1 Three comprehensive transport surveys of Shanghai

	Time	Item
First survey	December, 1986	Traffic volume and speed; resident trip; vehicle trip; freight transport and car parking
Second survey	November, 1995	Besides items of the first survey, this survey includes migrant population trips, employment information, traffic attraction, transit passenger and other 3 new items
Third survey	May, 2004	Besides items of the second survey, this survey includes urban rail transit passenger trips, traffic accident, traffic environment and other new 9 items

As an example, the third survey included 23 survey items. The survey method and sample rate used in those items are shown in Table 2.

3 Urban Expansion and Its Impact on Transportation System

Many indices could be used to evaluate the development of a city, including economic output, population and employment, price level, the amount of foreign trade, *etc*. In this paper, economic output, population, job and urban morphology are selected to describe Shanghai′s development and spatial expansion in the recent 20 years, from which the effects urban expansion takes on the transportation system development are revealed and analyzed.

3.1 Economic and population growth

From 1986 to 2004, per capita GDP of Shanghai has increased from 4 008 to 22 505 yuan (RMB), an increase of 4.6 times. At the same time, the composition of GDP has shifted: the percentage of the primary industry in GDP decreased from 4.0% to 1.3% while the percentage of the tertiary industry in GDP increased from 27.5% to 47.9%.

The economic development, especially the growing up of the tertiary industry, brings about an urgent need for a greater labor force. During the years from 1986 to 2004, the number of employees in the three industries has increased from 7.83×10^6 to 8.37×10^6, including more than double increase of the number of employees in the tertiary industry from 2.14×10^6 to 4.54×10^6.

Since 1993, the registered residents of Shanghai have decreased. Therefore, to meet labor force demand brought about by the economic expansion, Shanghai absorbed an influx of migrant workers. From 1986 to 2004, the migrant population increased from 1.23×10^6 to 5.36×10^6, whose percentage in the total population increased from 9% to 28%. As a result, the gross population in Shanghai increased from 1.296×10^7 in 1986 to 1.742×10^7 in 2004, and that in Beijing increased from 8.72×10^6 in 1978 to 1.538×10^7 in 2005 (Shanghai Statistical Bureau, 2005; Huang *et al*., 2009).

On one hand, economic growth produced urgent need for a greater labor force, which resulted in a great increase of the migrant population. On the other hand, the development of the economy brings more social activities, which makes residents trip more. Therefore, the economic growth is the fundamental factor for the trip demand increase. Provided that the current pattern of economic development in Shanghai continues, it is worth noting that this cycle will continue and economic development will continue to impose additional and lasting pressure on the transportation system.

Table 2 Items of third comprehensive transport survey

No.	Item	Survey method and sample rate	No.	Item	Survey method and sample rate
1	Migrant population trip	9 outward passenger transport spots, 4500 questionnaires	13	Traffic speed	Manual measuring in at-grade roads and auto detecting in elevated roads
2	Resident trip	29600 families (sample rate 0.5%)	14	Transit net	Statistical data
3	Traffic attraction	Typical sampling, 408 samples	15	Transit passenger	In-bus interview with 54 bus routes
4	External transport passenger	Interview	16	Urban rail transit passenger	31 stops, 8500 questionnaires
5	Passenger and freight trip	50000 passenger car, 18000 trucks (sample rate 10%)	17	Parking characteristic	65 samples in 13 zones (sample rate 5%–20%)
6	Taxi trip	2300 cars (sample rate 5%)	18	Social and economic information	Data acquisition from government
7	External transport vehicle	19 roads (sample rate 50%)	19	Land use characteristic	Data acquisition from government
8	Commodity corridor	83 typical highways	20	Geographic information	Data acquisition from government
9	Road facilities	Data collection and compilation	21	Traffic zone system	Planning zones
10	Traffic volume	Auto detecting and manual counting	22	Traffic environment	Test in typical crossings
11	Traffic accident	Existing statistical report	23	Parking facilities	General survey of different building parking facilities and collection of in-road and off-road parking date
12	Commodity flow	Data acquisition from government and manual counting			

3.2 Migration of population and job

Moving the population and job from the over-populated central city to its suburb and satellite cities has always been the most important strategy for Shanghai′s urban planning. During the last 20 years (1988–2008), the distribution of population and job has been changed with a decrease in the central district and an increase in the periphery districts of the city. Tables 3 and 4 show the distributional changes of the population and job distribution.

It can be seen from Table 3 that the population in the central district was reduced slightly, but the density was still high. The population in periphery district and suburban area increased dramatically. The same is true of job redistribution according to Table 4. From 1986 to 1995 the number of jobs in the central district decreased slightly, while that in the periphery district and the suburban area increased greatly. It is worth noting that the changes in population and job did not go along in the same pace, which suggests that the distribution imbalance of the workplaces and residences is a major contributing factor to transportation demand and congestion.

The distribution of population and job determines the spatial distribution of traffic demand. The movement of population and job from the central district to the periphery district and outskirts area can make the trip demand diffuse in the same way. Furthermore, the different pace of changes for population and job created an imbalance between workplaces and residences, which causes the increase of long-distance trips between central district and periphery district. This phenomenon was also described in García-Palomares′s (2010) study in Madrid, which found that there is now a clear dissociation between residence (increasingly dispersed) and employment (concentrated decentralization), where workers from those same municipalities trip to other municipalities to work.

3.3 Urban expansion

Lacking of effective guidance and control in the last 5 decades, urban sprawl around the central district or central city has been the main pattern for Shanghai′s spatial expansion (Fig. 1). The urban built-up areas experienced remarkable expansion during 1985–1998, increasing from 200 km^2 in the 1980s to 550 km^2 in 2003. Many Chinese large cities had the similar experiences in the last two decades, Guangzhou from 187 km^2 in 1990 to 297 km^2 in 2000, Chengdu from 144 km^2 in 1997 to 383 km^2 in 2003. The range of the urban built-up areas gradually exceed the planned areas, with Baoshan District which was to the north of the central city and the Minhang District which was to the south of the central city being sprawling to the central city gradually, thereby the outer ring around the city is no longer the boundary of central city and suburbs as it was intended (Chen, 1998; Xu, 2007).

Mode availability and mode choices have changed during Shanghai′s urban expansion. When the urban space was limited, walking and cycling were more appropriate modes of trip. Along with the urban expansion, buses were more important and a part of the non-motor trips transferred to bus. When the urban expansion took a further step, the percentage of walking and cycling decreased greatly because the distance made those modes impractical. As urban areas expand and trip patterns become more dispersed it is more costly and difficult to design an efficient and effective transit system, taking buses will cost more time. On the contrary the advantages

Table 3 Distribution change of gross population by traffic zones

Traffic zone		Area (km^2)	1986		1995		2004	
			Population	Density	Population	Density	Population	Density
Central district	Puxi	79	439	5.56	396	5.01	368	4.66
	Pudong	31	46	1.48	57	1.84	41	1.32
	Total	110	485	4.41	453	4.12	408	3.71
Periphery district	Puxi	294	257	0.87	313	1.06	412	1.40
	Pudong	239	45	0.18	80	0.33	158	0.65
	Total	533	302	0.57	393	0.74	569	1.07
Central city		642	787	1.23	846	1.32	977	1.52
Outskirts area		5698.5	509	0.09	569	0.10	735	0.13
Whole city		6340.5	1296	0.20	1415	0.22	1712	0.27

Note: Unit of population is 10000 persons and unit of density is 10000 peosons/km^2

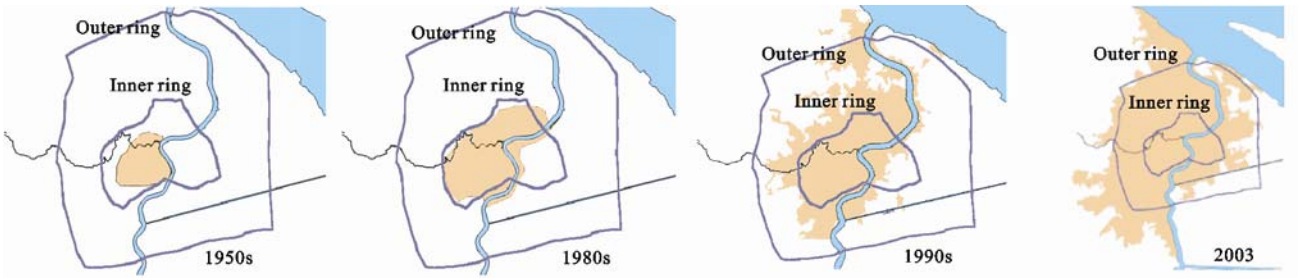


Fig. 1 Expansion of urban built-up area of Shanghai

Table 4 Change rate of distribution of population and job

Traffic zone		Change rate of population	Change rate of job
Central district	Puxi	9.8% (–)	5.9% (–)
	Pudong	23.9% (+)	60.9% (+)
	Total	6.6% (–)	1.8% (–)
Periphery district	Puxi	21.8% (+)	22.6% (+)
	Pudong	77.8% (+)	142.6% (+)
	Total	30.1% (+)	39.6% (+)
Central city		7.5% (+)	9.6% (+)

of using personal vehicles, such as more comfort, door-to-door service, *etc*., cause the increase of vehicle trips but it brings more pressure on the road system (LSE, 2006).

4 Characteristics Changes of Transportation System

Based on the urban expansion and its impact on transportation system in Shanghai, resident trips, vehicle trips and the spatial distribution of traffic demand are employed to study the change of the transportation system characteristics during the last several urban expansions.

4.1 Residential trip demand

Increase of the gross population and trip rate made the amount of residential trip demand rise from 2.068×10^7 person-times per day to 3.790×10^7 person-times per day, an increase of 83% for the late 20 years (Table 5). At the same time, the urban expansion and the separation of the workplaces and residences caused the average length of residential trip to be longer.

Setting the index of economy, population and job in 1986 as ′1′, the changes of each urban development index and the transportation system characteristic for the last 20 years can be attained (Table 6). It can be seen easily that although the population rose only by 39%, the residential trip demand and the average trip length increased by 83% and 58% respectively.

4.2 Traffic demand on roads

4.2.1 Sharp increase of individual motorized trip

The fundamental change of the structure of residential trip is caused by the urban sprawl from the central city. From 1986 to 2004 the percentage of motorized trip, including motorbike, car, taxi, rail, and bus and trolly tram, increased evidently, growing from a share of 26.7% in 1986 to 40.2% in 2004. The proportion of trips using individual motorized mode including car, motorbike and taxi increased from 2.6% to 21.7% (Fig. 2). But with the development of urban mass transit system, there was a slight increase for transit share. Owning to improved service of buses during 1986–2004 (Table 7), the decline of bus usage has been halted. The percentage of buses in 2004 was almost equal to that of 1995. Even though the nonmotorized trip takes the majority, this is different from some cities in western country where car trip takes the majority. As many Chinese cities, Shanghai has very high population densities both in central city and suburb.

Table 5 Change of residential trip demand

Year	Population ($\times10^7$)	Trip rate (times/(person·d))	Residential trip demand ($\times10^7$ person-times/d)	Average trip length (km)	Person kilometers of trip ($\times10^7$)
1986	1.2323	1.68	2.068	4.3	8.938
1995	1.2667	1.87	2.365	4.5	10.643
2004	1.7120	2.21	3.790	6.8	25.539

Table 6 Relationship among economy, population, job and residential trip demand

Year	Per capita GDP	Population	Job	Trip rate	Average trip length	Residential trip demand	Person kilometers of trip
1986	1	1	1	1	1	1	1
1995	2.19	1.03	1.04	1.11	1.05	1.14	1.19
2004	5.62	1.39	1.10	1.32	1.58	1.83	2.86

Note: Job number of 2004 was replaced by total employees

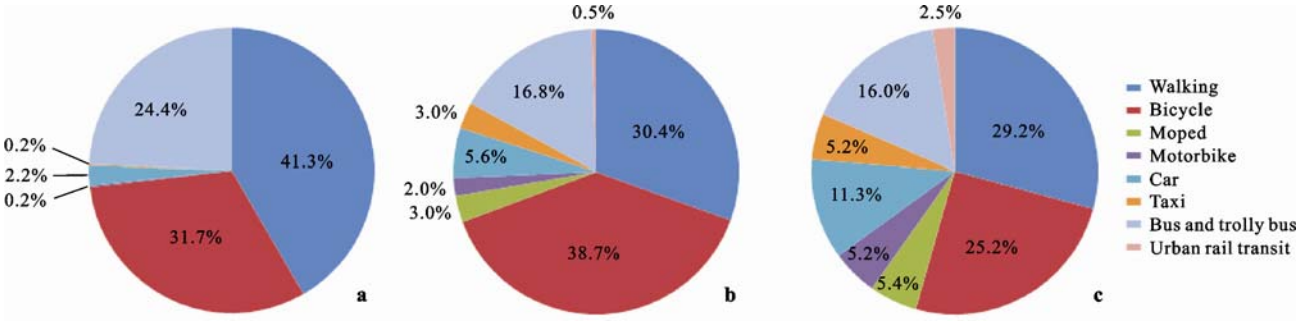


Fig. 2 Structural change of trip modes (a. 1986, b. 1995, c. 2004)

Table 7 Improvement in trip speed of transit system during 1986–2004

Year	Trip length (km)	Trip time (min)	Trip speed (km/h)
1986	8.7	48	10.9
1995	6.6	62	6.4
2004	8.4	58	8.7

Notes: Transit system includes bus and urban rail transit; trip time means the average time spent on a trip

4.2.2 Dramatic increase of private vehicle trip demand

With the dual amplification of the total volume of residents′ trips and the motorized trip mode share, a dramatic increase of the vehicle trip volume (including buses) from 2.23×10^6 vehicle trips in 1995 to 7.14×10^6 in 2004 was observed. At the same time, the increased trip length resulted in an increase of 2.7 times the vehicle traffic volume on the road in the last decade.

The average trip speed of taxi reflects the level of service on road network to some extent. In 1995, the average trip speed of taxi was 22.3 km/h, while in 2004 it slowed down to 15 km/h. With the dramatic increase of vehicle trip, the level of service on roads becomes noticeably worse during the recent 10 years. It is right to build necessary road, but the ultimate way is to develop public transportation and take TOD (Transit-Oriented Development) policy (Zhu, 2005).

4.3 Traffic diffusion in whole city

4.3.1 Concentration of traffic in central district

The density of population and job in the central district is still very high despite urban expansion. The density of the population in central district of Puxi was 4.66×10^4 persons/km^2, and the building density was 1.31×10^4 m^2/km^2 in 2008. The figures were higher than those of Tokyo and New York in 2008 (Luo *et al*., 2008). The high density of population and job makes traffic overly concentrated in this area: the traffic demand in central district of Puxi took up 23.5% of the whole demand but with an area just 1.2% of the land area and 9.8% of the road network capacity.

4.3.2 Exchange traffic demand between central district and periphery district

During the migration of population and job from central district to periphery district and suburb, the exchange traffic demands from central district to periphery district, or from central city to suburb increased a lot. Figure 3 shows the increase of traffic (absolute volume and percentage) passing in and out from central district and

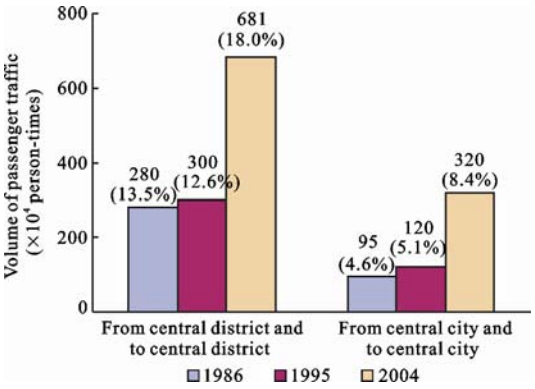
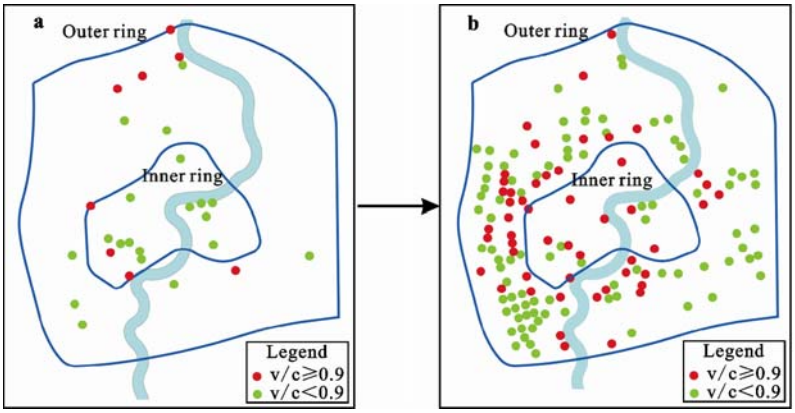


Fig. 3 Increase of exchange traffic demand



v / c: volume / capacity

Fig. 4 Extending of traffic jam (a. 1995, b. 2004)

central city in 1986, 1995 and 2004.

4.3.3 Spreading of traffic congestion

The over concentration of traffic in the central districts creates distinct peaks in the morning and evening. At the same time, the diffusion of traffic demand from central district to periphery district or suburbs spreads traffic congestion outward. On the other hand, the rapid private motorization commonly speeds up the urban sprawling (Zhu, 2005). Figure 4 shows the congestion along main radial roads′ intersections from 1995 to 2004.

5 Conclusions

Based on the analysis above, some conclusions can be drawn from the characteristic changes of the transportation system during the nearly 20-year urban expansion of Shanghai:

1) Urban sprawl around the central district changed the transit share dramatically, with a rapid increase of motorized trips, especially for individual motorized trips. An explosive increase of motorized trip placed great pressure on the road network and caused traffic congestion both in the city center and its outskirts.

2) The over-concentration of population and job in the city center produced two distinctive commuting peaks. In the process of population and job migrating from central district to periphery district, the traffic diffused to the whole city in the same way. Furthermore, changes of population and job did not go along in the same pace, which resulted in the increasing long-distance trip demand and extending traffic jam.

In summary, analysis of transportation system characteristics needs integrated and systematic consideration of urban economy, population, job, urban morphology, *etc*. In the process of urban development and expansion, a harmonious strategy for the city and transport is of great importance.

Acknowledgement

The paper is one of the fundamental work to support Guiding Research on Transportation Development of Shanghai funded by Shanghai Urban Planning Administration Department. The authors appreciate LI Junhao for his contribution to the provision of relevant materials.

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