ANALYSIS OF URBAN EXPANSION AND TRANSPORTATION CHARACTERISTICS

Draft_Thesis

Professor: Kian Y. Tajbakhsh

Student: Lina Yin

Uni: ly2357

Table of Contents

Abstract

Urban expansion and transportation are actually interrelated. Shanghai's rapid urban expansion was caused by the inflow of people and the relocation of employment, which increased people's travel demand, particularly for long-distance and motorized travel, greatly from 1990s onward. Dynamic travel purposes increased non-commute trips as well as people's travel rates. Thus, average daily trips rose sharply due to these combined effects. Based on results of statistical analyses, population and GDP are statistically significant factors that increase average daily trips, while the expansion of urban space is significantly related to the growth of private motorized car share in Shanghai.

People are working to increase transportation supply to fulfill travel demand by constructing more roads and promoting a well-designed public transportation system. However, the growth in demand has outpaced the increase in supply, as indicated by more congested roads, trains, and buses despite the significant increase in subway ridership.

The demand management strategy needs to be involved in the policy making process to manage not only the growth of motorization, but also the growth of urban spaces and population. More supply still induces new demand, and the demand will continue to grow unless it is managed.

Keywords: Urban transportation, urban expansion, Shanghai

1 Introduction

1.1 Overview

Topics about urban form and transportation seem to be separate, but in fact, they are interrelated. The transportation system shapes metropolitan form, while the form of the metropolis shapes the transportation system, as well ("Urban Form & Transportation," n.d.). The relationship between urban form and transportation is one of the most extensively studied subjects in urban planning research. With increased attention on sustainable development, the links between urban expansion and transportation demand greater scrutiny as a means of informing more effective public policy (Kashem, Irawan, & Wilson, 2014).

Since the 1980s, cities in China have experienced tremendous expansion under fast-paced economic growth and urbanization processes (Pan, Shen, & Zhang, 2009). Built along the Huangpu River in the lower Yangtze, Shanghai is one of the largest and most populous cities in China, which has recently witnessed rapid urban growth, spatial expansion, and social and economic changes. The level of urbanization increased significantly from 59% in 1978 to 88.6% in 2008 (Yue, Fan, Wei, & Qi, 2014). Han, Hayashi, Cao, and Imura (2009) concluded that population, economy, and transportation were the primary spatial determinants of the city's expansion in the late 20th century, and the spatial distribution of land use is mainly influenced by access to the transport network and city center.

However, the changes in urban spatiality, economy, and population also contribute to increased travel demand. There are several main forces of growth in travel demand, which can be categorized into three aspects: (1) rapid economic growth, (2) population de-concentration, and (3) spatial expansion. Because of economic development, the increasing demand for labor attracts migrants and thus drives drastic increases in population. Also, owing to economic growth, greater social activities increase people's travel rates and, in return, contribute to travel demand rise. The expansion of built-up areas and the de-concentration of population have slightly transformed the once-compact Chinese city into a more dispersed, and often polycentric, form (Wu & Gaubatz, 2012). Correspondingly, the overall transportation demand increased dramatically over larger areas and longer distances due to the extension and separation between work and living spaces. Longer travel distances and increased disposable income further facilitated the adoption of private motor vehicles, leading to rapid motorization (Zhao & Zhao, 2013), which increased the demand for road infrastructure.

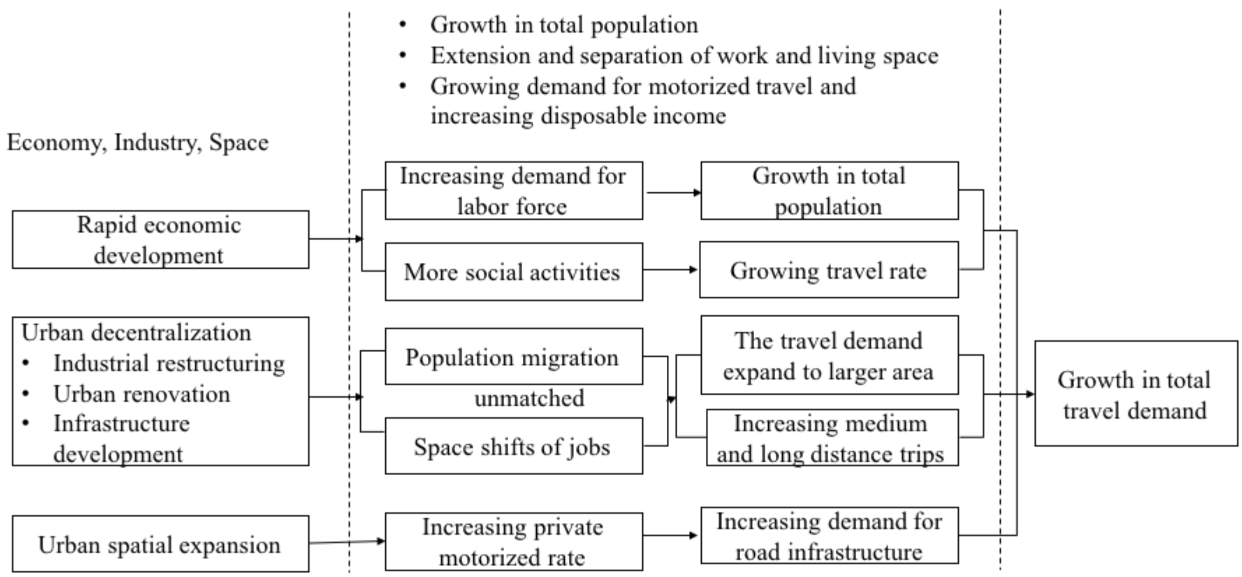


Figure 1: Mechanism of economy-population-infrastructure impact on travel demand

To deal with such huge demand, there is a need to invest more in transportation infrastructure, expanding transportation capacity by constructing more roads and public transit infrastructure. Since the land use in Shanghai for road construction is almost saturated, developing a well-planned public transit system has become the best, and probably only, way to deal with the increasing travel demand, which is the way that Shanghai's government is trying to promote. With high capacity and energy efficiency, public transportation is a good alternative for urban passenger transportation compared to private automobiles (Yang, Cheng, & Cheng, 2010). If it could be planned, operated, and managed in effectively and scientifically, the public transit system could serve as an environmental guard for conserving energy, enhancing communities' quality of life, and facilitating urban economic growth and development (Pucher & Koryattyswaroopam, 2004).

1.2 Research Questions

In regards to the interaction between the population, the economy, spatial expansion, and transportation, people tend to ask how they are actually related. What can people do to facilitate each part? Is Shanghai's transportation system adequate for people's travel demand? Since many traffic issues have appeared that never existed before, what has gone wrong? With the data from Shanghai's second, third, fourth, and fifth Comprehensive Travel Surveys conducted from 2005 to 2014 and the Annual Yearbook (Shanghai Government, 2015, 2016), this paper aims to offer insights into the relationship between urban expansion and transportation in Shanghai over the past 20 years by answering the following:

- How did Shanghai expand in the last few decades?
    - How did Shanghai's economy, population, spatiality, and employment expand?
- How did the travel demand change during the urban expansion process?
    - How did average daily trips, travel rates, travel purposes, travel periods, spatial distributions, mode splits, and average trip lengths change?
- What is the relationship between urban expansion and transportation?
- Has transportation infrastructure responded adequately to travel demand?
    - How did transportation infrastructure develop?
    - How is use of transportation infrastructure?
- What recommendations could be proposed for the transportation system in Shanghai?

1.3 Data and Methods

The empirical analysis in this thesis is based on data from multiple sources. The main source is the Shanghai Annual Yearbook, which is released to the public by the government of Shanghai every year and includes data on demographics, urban spaces, the domestic economy, agriculture, social development, etc. Another major source is the Comprehensive Travel Survey, which provides data on transportation involving residents' average trip lengths, travel times, mode splits, and so on.

The methodology is as follows:

1. To answer the question about Shanghai's expansion, the author collected data from the Shanghai Annual Yearbooks from 2002-2015,[1] examining economic development, population growth, urban spatial expansion, and employment distribution in Shanghai from 1995 to 2014.
2. Changes in transportation is researched with data from the Third, Fourth, and Fifth Comprehensive Travel Surveys, including changes in average daily trips, travel rates, travel purposes, travel periods, spatial distribution of trips, mode splits, and average travel distances from 1995 to 2014.
3. Urban expansion and changes in transportation are compared in a regression model to determine the relationship between them.
4. Analyses are conducted regarding the supply of Shanghai's transportation system and the usage of the system, answering the central question: Has the transportation supply in Shanghai responded adequately to travel demand?
5. Conclusions will be made, and recommendations will be proposed for future transportation development.

1.4 Research significance

Planning policies can influence transport supply as well as the distribution of land and, in return, can provide a way of influencing travel demand (Stead & Marshall, 2001). It is believed that proper transportation planning can contribute significantly to the mission of urban sustainable development (Yao & Chen, 2015), which has had a great impact on urban development patterns, serving as an efficient tool

[1] The earliest online version of the Shanghai Annual Yearbook is from 2002, which includes data from 1990 to 2001.

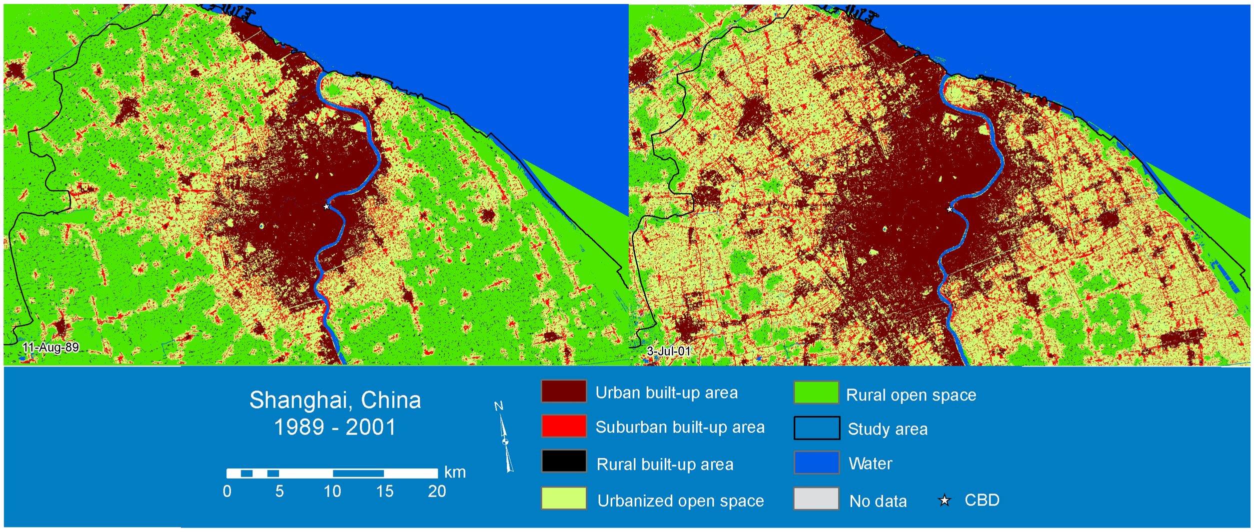
to guide people’s travel behaviors and living patterns. In this paper, a general overview is presented to measure how travel demand has increased with urban expansion and to assess whether the current infrastructure has met the demand for travel. From the perspective of urban planners, only through years of research and practice can we develop a theory of how to guide urban expansion through transportation planning, which is a more active way to manage and direct urban expansion.

Urban planning is a discipline that uses the scientific method to shape and lead urban development in a more sustainable way. Transportation planning, as a branch of urban planning, bears this responsibility, as well. The findings are expected to assist in the process of government policy-making and more or less narrow the gaps between the current travel demand and the current transportation supply.

2 Background

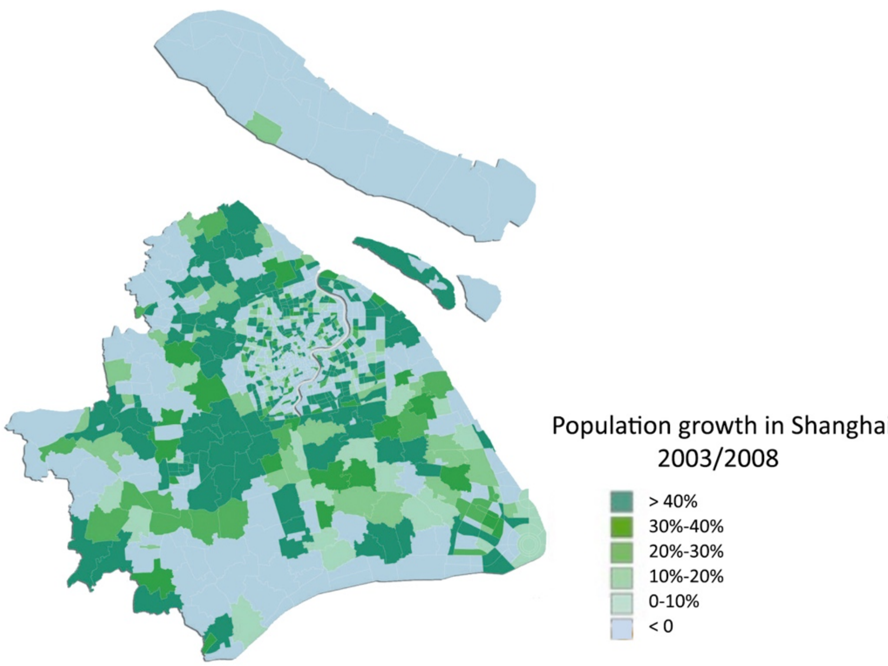
According to research from the Lincoln Institute of Land Policy, there are four key attributes of urban expansion: (1) urban land cover, measured by the total built-up area (or impervious surface) of cities; (2) density, measured as the ratio of the total population of the city to the total built-up area it occupies; (3) fragmentation, measured by the relative amount and spatial structure of open spaces that are fragmented by the noncontiguous expansion of cities into the surrounding countryside; and (4) compactness, measured by a set of compactness metrics ("Atlas of Urban Expansion," 2015).

Shanghai is one of four Chinese municipalities ranked at the highest-level classification and has witnessed great urban expansion in all of the above aspects. Constant inflows of people from other parts of the country increased Shanghai's population. At the very beginning, when it was turned into a city, Shanghai had a population of less than 100,000. By the end of 1949, the year Shanghai was liberated, that figure rose to 5.2 million. Until 2013, the city's number of permanent residents surged to 14.32 million—2.8 times of that in 1949. The number of long-term residents reached 24.15 million, including 14.25 million permanent residents and 9.9 million from other parts of the country. In terms of spatial features, Shanghai covered an area of only 636.18 km^2 in 1949, while in 2013 the city had a total area of 6,340.5 km^2, 0.06% of China's total area (Information Office of Shanghai Municipality; Shanghai Municipal Statistics Bureau, 2014).



Data sources: The fourth travel survey in Shanghai

Figure 2: Shanghai urban area in 1989 and 2001



Data sources: The fourth travel survey in Shanghai

Figure 3: Population growth in Shanghai 2003/2008

In addition to population and spatial expansion, Shanghai has experienced drastic social and economic changes in recent history, all of which could have led to changes in Shanghai's transportation demand. Market reform and the Open Door policy in 1978 marked China's re-entry to the global stage.

Five cities on the Pearl River Delta area were designated in to promote economic development in the early 1980s. Shanghai was bypassed in that process given its location on the Yangtze River Delta (Li & Wu, 2006). Nevertheless, in the beginning of the 1990s, Shanghai seized a decisive development opportunity when the central government announced its intention to develop the Pudong Area on the east side of the Huangpu River across from the historic city center of Shanghai in Puxi (Wu, 1999). With the establishment of China's special economic zones (SEZs), Pudong has grown rapidly since the 1990s and has turned out to be China's new financial and commercial hub. Its GDP was about 6 billion Yuan in 1990, but then exploded to roughly 2.16 trillion in 2013, increasing from one-twelfth of Shanghai's total economy to one-quarter. Driven by the development of Pudong, Shanghai entered a new era (Zhao & Zhao, 2013).

Huge changes took place in Shanghai in the new era. With the efforts toward development, Shanghai managed a double-digit growth rate since the 1990s, regaining its pre-1949 leadership as an industrial, financial, and trading center in China and East Asia (Zhao & Zhao, 2013). Meanwhile, rapid urbanization led to dramatic spatial expansion. Overcrowding in the central area forced more and more people to move to the suburbs; meanwhile, the emergence of the labor market and the disappearance of enterprise-based housing provisions further contributed to the separation of residences and places of employment. What's more, due to rapid economic growth in Shanghai, workers' average annual income greatly increased from 5,619 Yuan (adjusted to the 2010 value) in 1980 to 46,757 Yuan in 2010. More Shanghai residents can afford the luxury of private automobiles, which increased automobile ownership as well as the share of motorized vehicles (Zhao & Zhao, 2013).

Along with rapid urbanization and economic development in Shanghai over the past three decades, travel demand in Shanghai has grown significantly, comprising longer trips, greater shares of motorized modes of transport, and a higher proportion of trips relying on personal vehicles (Shen, 1997). Shen (1997) also analyzed the increase in transportation demand from 1985 to 1994, and found the seven most important factors of the explosive growth of transportation demand, including population growth, economic and income growth, urban expansion, land use reconfiguration, the emergence of labor markets, the disappearance of enterprise-based housing provisions, and government decisions to nurture the auto industry.

Shanghai's local government developed various measures to meet rising travel demand and to mitigate the pace of motorization. In April 2002, the government of Shanghai issued the "Shanghai Metropolitan Transport White Paper" to address the transportation needs Shanghai would face with the expansion of their population and private automobile ownership. The paper was the first comprehensive transportation plan released nationwide. The master plan raised three goals of development: (1) public transit development; (2) hierarchical policies in different areas; and (3) cooperative vehicle infrastructure development, among which public transit development was the most important (Shanghai Government, 2002). Within ten years of development, the urban transportation system in Shanghai achieved relatively great success, leading China in transport management and services and successfully supporting transportation services at the 2010 Shanghai Expo. Faced with continuous increases in population and vehicles as well as new challenges in urban renovation and resource distribution, the government of Shanghai released a new version of the "Shanghai Metropolitan Transport White Paper" in August 2013 (Shanghai Government, 2013). The new paper was important in creating the new master city plan, strengthening Shanghai's leading role in Chinese urbanization and preparing Shanghai to be a new international city.

3 Literature Review

3.1 Urban expansion and urban transportation system

There is extensive literature on the relationship between urban form and travel characteristics. Many studies find that urban form characteristics have an influence on travel patterns ranging from the regional to the local scale (Stead & Marshall, 2001). Regarding the relationship between urban expansion and urban transportation systems, researchers analyzed theoretical models as well as management strategies. During the 1950s and 1960s, people were interested in building the quantification model. After the 1980s, there was a trend in the interaction of multi-field, multi-disciplinary study with the help of big data and spatial informative technology. The model became more simplified, while the theory became more optimized. From the perspective of planning management, people proposed theories including Transit-Oriented Development (TOD), Traditional Neighborhood Development (TND), and Smart Growth to coordinate transportation demand and land use (Li, Ye, Chen, Mohanmed, & Cen, 2010).

Gakenheimer (1999) pointed out the rapid decline in mobility and accessibility in most of the developing world due to the rapid development of motorization, the condition that local demand far exceeds the capacity of facilities to meet it, the incompatibility of urban structure with increased motorization, and limited cooperations among responsible officials. The developing world should learn from developed countries in regards to the roles of new technologies, the forms of institutional management, and the long-term consequences of effective automobile policies. Expanding the capacity of existing congested links or building new links are two methods that transportation engineers and planners are likely to adopt when considering growths in traffic demand, but this requires a balance between the outcomes and costs (Mathew & Sharma, 2009). To meet the needs of increasingly mobile populations, developing countries should focus on the following areas: (1) highway building, used as an opportunity to control access; (2) public transport management and improvements; (3) pricing improvements; (4) traffic management; and (5) an emphasis on rapid transit based on new revenue techniques.

Mao and Yan (2005) studied the mutual mechanism between urban transport systems and urban space patterns through the example of Guangzhou, China. Land use is the driving force of travel demand, determining its origin, destination, and spatial distribution. Different urban space patterns have different transportation features and greatly influence the transportation system. Also, the feedback effects from the transportation system on the urban space pattern must also be considered. In summary, the accessibility of transportation systems shapes urban development patterns.

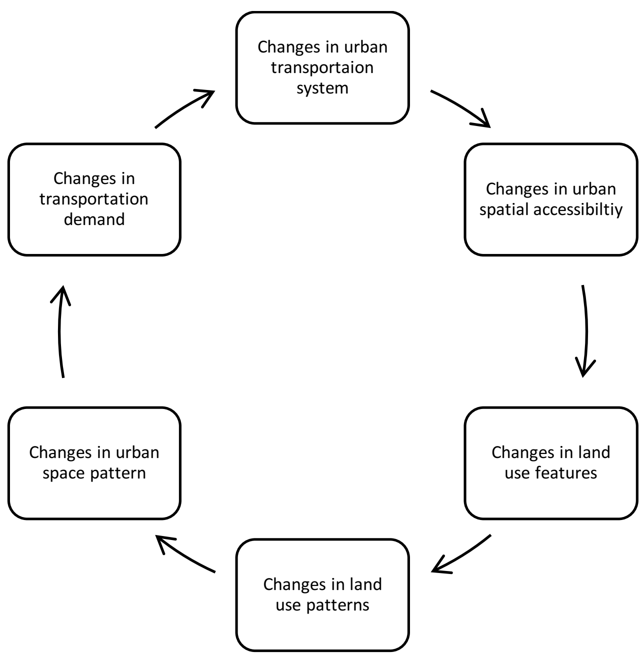


Figure 4: Mutual mechanism between urban transportation and urban space patterns

3.2 Model of transportation supply and travel demand

A transportation system is a collection of elements, and the interactions between those elements produce both the demand for travel in a given area and the provision of transportation services to satisfy that demand and consist of two main components: travel demand and transportation supply (Cascetta, 2009). Transportation supply is made up of facilities, services, regulations, and prices that produce travel opportunities, which is the maximum passenger-carrying capacity of the metropolitan transport system. Travel demand is derived from the need to access urban functions and services in different places and is determined by the distribution of households and activities within the area; it is the movement requirements for using public transport facilities from one functional area to another.

Travel demand and transportation supply analysis is considered through analysis of traffic phenomena to shed light on the theories and techniques related to high-efficiency transportation systems. Wu, Pei, and Gao (2015) analyze the transportation system using the methods of system dynamics and estimate the transportation supply-demand ratio using VENIM, an industrial-strength simulation software program for improving real system performance that has rich features emphasizing model quality, connections to data, flexible distribution, and advanced algorithms. They selected cities with dense populations and relatively well-developed economies so that massive public transportation systems were provided. The other scenario is that there must be significant transportation events that have occurred in recent years, since the before-and-after data comparison can reveal the events' impacts on the balance of the transportation system. If the demand-to-supply ratio (w) is less than 0.80, the conclusion could be made that the urban system in that city cannot meet its residents' travel demands. When w falls between 0.90-0.95, it indicates a short supply of traffic. If w is between 0.95-1.10, the transportation system is supply-demand balanced. Excess supply occurs when w is larger than 1.10.

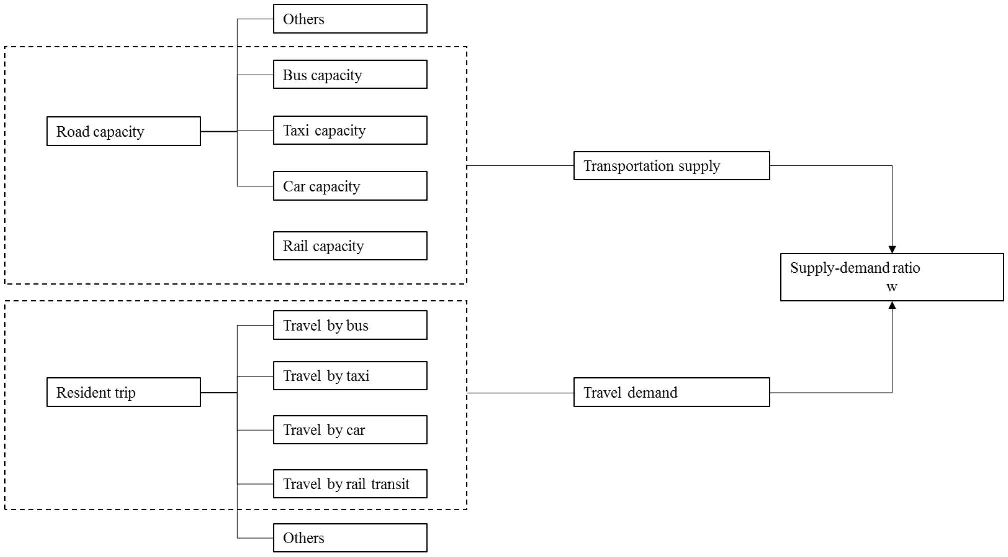


Figure 5: Idealized system of urban transport system

The transportation supply-demand ratio (w) equals the transportation supply (S) divided by the travel demand (D):

$$w = S / D$$

$$S = S_{\text{bus}} + S_{\text{rail}} + S_{\text{taxi}} + S_{\text{car}}$$

$$D = D_{\text{bus}} + D_{\text{rail}} + D_{\text{taxi}} + D_{\text{car}}$$

$$S = C_{\text{road}} \times D_{\text{max per unit}}$$

$$D = PAR$$

The supply of each transport vehicle equals the product of the capacity of the road (C_{road}) and the number of people each unit could support ($D_{\text{max per unit}}$). Demand (D) is expressed as the product of the total population (P), average trips (A), and the proportion of the transit service share (R) of the average daily trips.

3.3 Research about Shanghai

Regarding Shanghai's transportation demand in response to urban expansion, Li et al. (2010) found that during Shanghai's nearly 20-year urban expansion, urban sprawl around the central district dramatically changed the transit mode share, with a significant increase in motorized trip share, especially in the private form. The over-concentration of people and jobs in the city center produced two distinct commuting peaks in the mornings and evenings. Zhao and Zhao (2013) point out that vehicle travel is growing at a much faster pace than person travel is. In terms of growth, travel demand in Shanghai has passed its peak growth in 2004 for both person and vehicle travel. With regard to the absolute figures, person trip growth has peaked, but vehicle trip growth has not.

Guo and Sun (2009) examine the transportation supply from the perspective of road capacity. In the central area, 17% of the land was used for road development. This number around the world falls between 15-20%, and this indicates that the land use for transportation in the central area has become almost saturated. On the one hand, the government needs to find a new way to fulfill increasing travel demand by promoting massive public transit development. On the other hand, the government needs to manage transportation demand by restructuring the urban space; decentralizing the travel demand; and encouraging mixed land use to balance jobs, residences, and public services.

In terms of the path and strategy Shanghai should adopt for future transportation development, Chen, Ye, Shang, and Wu (2015) argue shifts should be made from simple mobility to efficiency, sustainability, safety, and social equity, improving the service levels of transportation services while decreasing the total costs including expenses for travel, management, and external operations. To realize the goals of safety, efficiency, accessibility, sustainability, and equity, Chen et al. (2015) describe six crucial strategies: (1) utilizing resource and environmental constraints: control urban growth and reduce the emissions per capita from transportation activities; (2) promoting transit-oriented development: directing population and economic growth through mass transit system corridors; (3) improving the overall public transport system: set different hierarchies for railway and bus services; (4) developing an integrated transit system; (5) setting different developing zones; and (6) enhancing information technology development.

3.4 Summary

Past and present research has proven that urban expansion and urban transportation systems are interrelated. Urban expansion will increase people's travel demand, especially their demand for motorized trips; meanwhile, transportation systems can lead the direction of urban expansion. Indices of socioeconomics, population, and employment should be included to evaluate urban expansion, since they are related to a city's development.

In terms of urban expansion and changes in transportation characteristics in Shanghai, although the travel demand in Shanghai has passed its peak growth for both person trips and vehicle trips, the absolute number of vehicle trips has not passed its peak growth. Scholars propose that the development of an urban public transit system in the inner city is a better way to fulfill the growing travel demand due to the paucity of land. However, hierarchies need to be cleared along the main transportation corridors, and an integrated transit system is encouraged to facilitate urban development because Shanghai's road construction is nearly saturated.

Faced with increasing travel demand, more transportation infrastructure should be constructed. Wu et al. (2015) proposed an estimation model of the urban transportation supply-demand ratio to quantitatively describe the condition of an urban transport system, providing theoretical support for transport policy-making. Shanghai has prioritized the development of a public transportation system, but there are few studies really examining the supply-demand situation. In this way, the author would like to refer to the above model of transportation supply and travel demand to evaluate the transportation system, especially the public transit system, in Shanghai from 1995-2014 to answer questions related to transportation supply and demand during that period. Recommendations will be made as a reference for the construction of future strategic transportation plans.

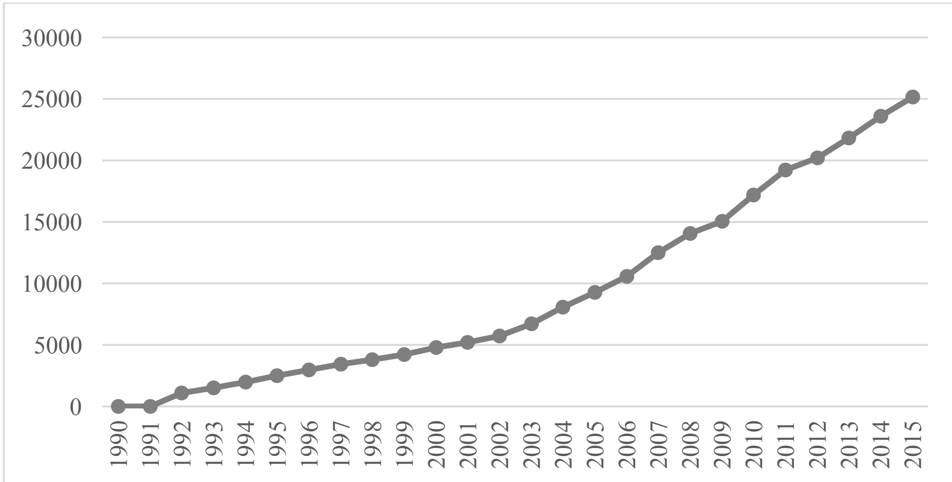
4 Urban Development in Shanghai

Many indicators can be used to evaluate the development of a city, including housing prices, price levels, foreign investments, total construction, etc. In this paper, economic development, population, spatial expansion, and employment distribution area have been selected to describe Shanghai's urban development from 1995-2014.

4.1 Economic development

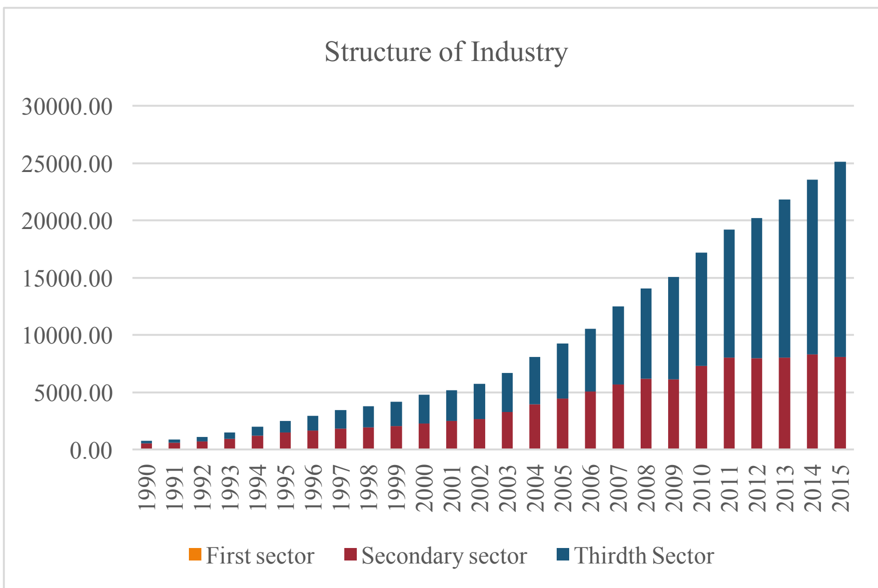
The Chinese economy as a whole has made great progress in the past 30 years. Shanghai, as an important economic, financial, trade, and shipping center, achieved the most progress among all provinces, metropolitan areas, and autonomous districts. As one of the major indicators for economic development, the gross domestic product (GDP) in Shanghai increased drastically from 1990 to 2015. In 1990, Shanghai's GDP per capita broke $1,000 for the first time, and in 1995, this number doubled to $2,000. In 2015, Shanghai's total GDP reached 2.53 trillion Yuan ($356 billion), with an increase of 6.8%, ranking first among all cities in mainland China (Shanghai Government, 2016).

Parallel to the growth in GDP, the structure of Shanghai's industry shifted from the primary and secondary sectors to the tertiary sector. The government of Shanghai has set a goal of driving service sector development and making the city an international financial center (IFC) and shipping hub by 2020 (Chinese Government, 2001). The Shanghai Free Trade Zone (FTZ) established in 2013 also works as a step to increase services and attract foreign investors. In 2015, the service sector in Shanghai accounted for two-thirds of the city's overall economy. The industrial upgrades together with globalization processes helped Shanghai's modern industry prosper. A large number of factories and firms established headquarters or branches in Shanghai and transformed Shanghai into China's industrial center in many fields through advanced technology, equipment, and systematic management.



Source: Shanghai Annual Yearbook

Figure 6: GDP growth in Shanghai 1990-2015(unit: 100 million yuan)



Source: Shanghai Annual Yearbook

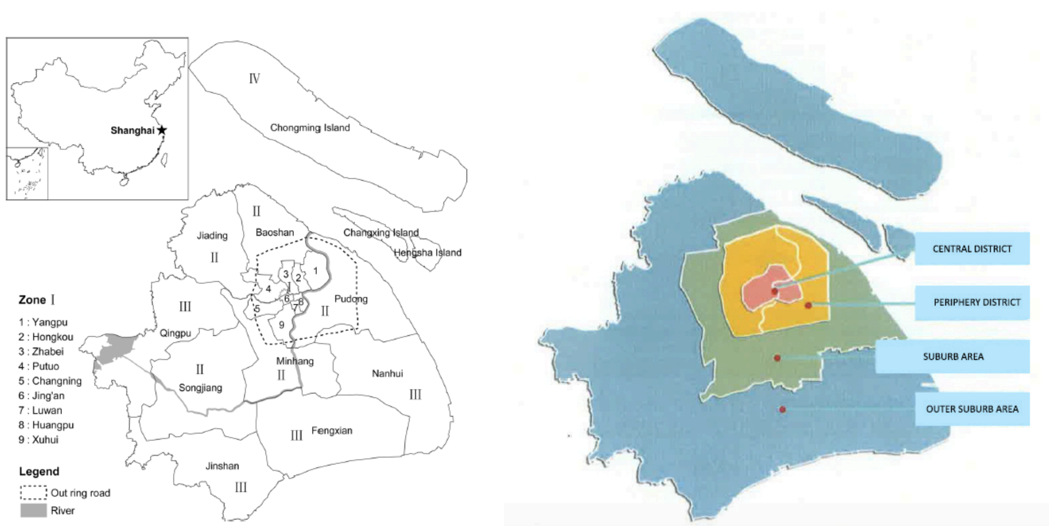
Figure 7: Structure of Industry in Shanghai 1990-2015(unit: 100 million yuan)

Economic activities have been recognized as exogenous drivers of personal travel in China (Shen, 1997), especially when the structure of industry gradually shifts to the tertiary sector. The extra available income and diversified leisure activities significantly encourage people's travel rates. This may also affect the modes of travel that people select.

4.2 Spatial expansion

The city of Shanghai experienced rapid growth and spatial expansion from 1990 to 2015 relative to what had previously taken place. The 1937 Japanese occupation of Shanghai, World War II, and the 1949 revolution dramatically changed the processes and patterns of its growth. Shanghai was transformed from what could be largely described as a capitalist colonial city to a centrally planned, socialist city. During the period from the early 1950s to the early 1990s, Shanghai did not significantly expand, except for the urban–rural fringe industrial development during the 1970s and 1980s. However, Shanghai has experienced great urban expansion in the last two decades. In 1991, the total urban built-up area covered 45,678 hectares and increased to 126,666 hectares in 2000. In 2015, this number rose to 269,340 hectares at an average annual rate of 1.6% ("Atlas of Urban Expansion," 2015).

By the end of 2001, Shanghai was divided into 18 districts and one county, with nine core districts in Zone I. Shanghai can be divided into four zones within its built-up areas: the central district, the peripheral district, the suburbs, and the outer suburbs. The central district is the area within the Inner Ring Expressway. The central and peripheral districts compose the central city, the 660 km^2 inner area surrounded by the Outer Ring Expressway.

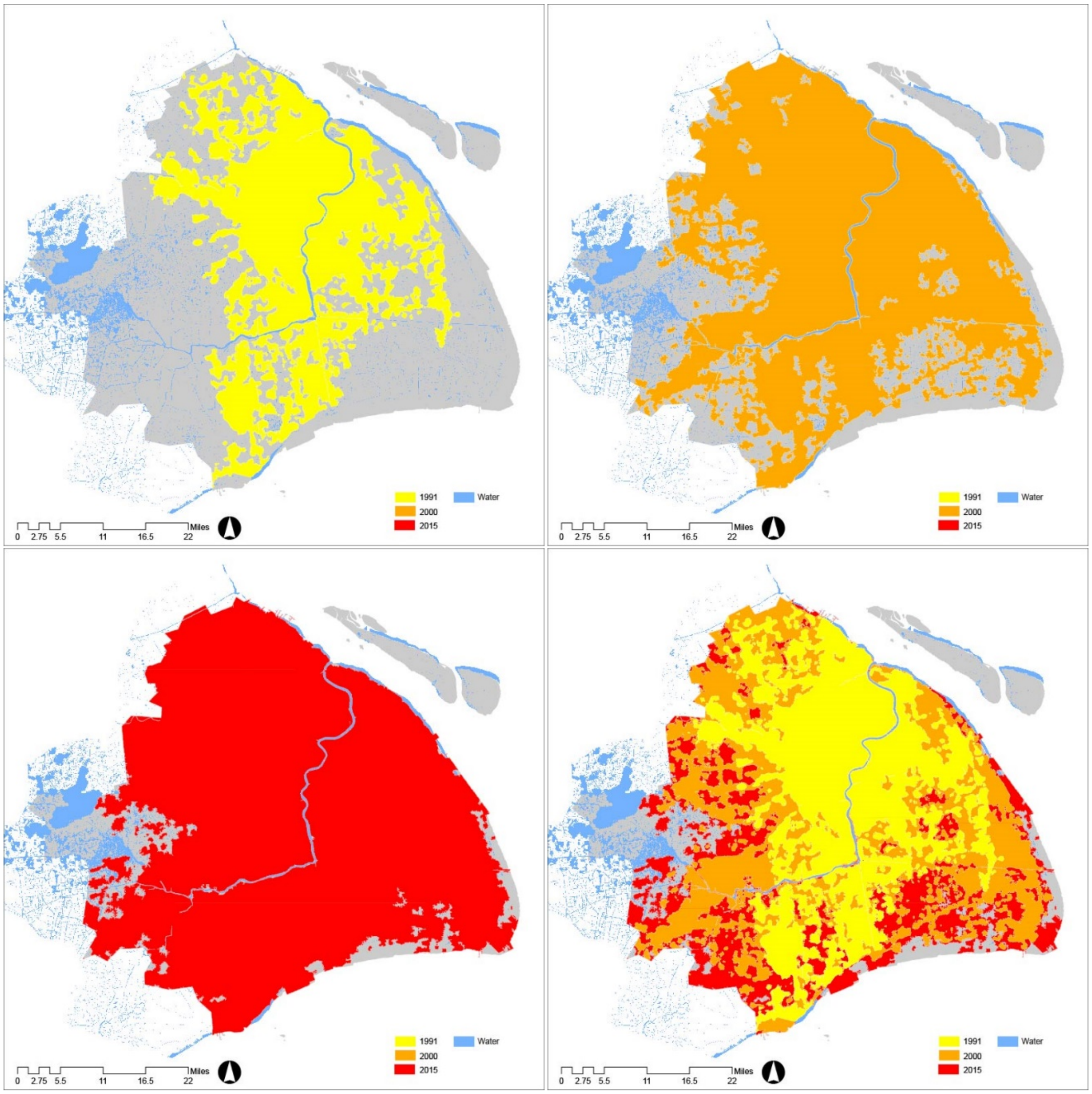


Source: Shanghai Government (2015)

Figure 8: Shanghai urban area

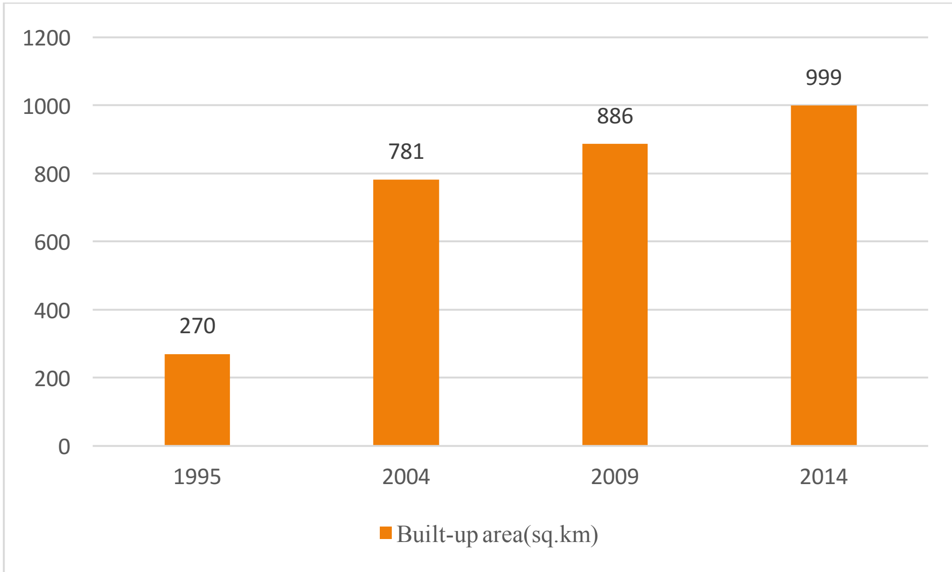
Lacking in effective scientific guidance and control for urban expansion, the sprawl mainly existed around the central district (Li et al., 2010). The map below shows the spatial pattern of Shanghai's expansion in the last 25 years. The built-up area expanded from 270 km^2 in 1995 to 999 km^2 in 2014. This kind of spatial expansion took place in many other Chinese cities in the past two decades; for example, in Guangzhou, the built-up area increased from 187 km^2 in 1990 to 297 km^2 in 2000, and in Chengdu, the built-up area increased from 144 km^2 in 1997 to 383 km^2 2003 (Xu, Liao, & Shen, 2007).

Through the process of urban sprawl, lands in the suburban district gradually became a part of the central city. It is likely that Shanghai's urbanization will continue to expand into areas in Jiangsu Province. Also, there is the possibility that it will meet the province of Zhejiang. Development is spreading east and southeast in Pudong, including Lingang, which is a designated residential area that could attract 1 million residents. But, the ocean will prevent further expansion in this direction (Cox, 2011). Consequently, the outer ring of the city is no longer the boundary between the central city and suburbs, as it once was (Li et al. 2010).



Source: "Atlas Urban Expansion"

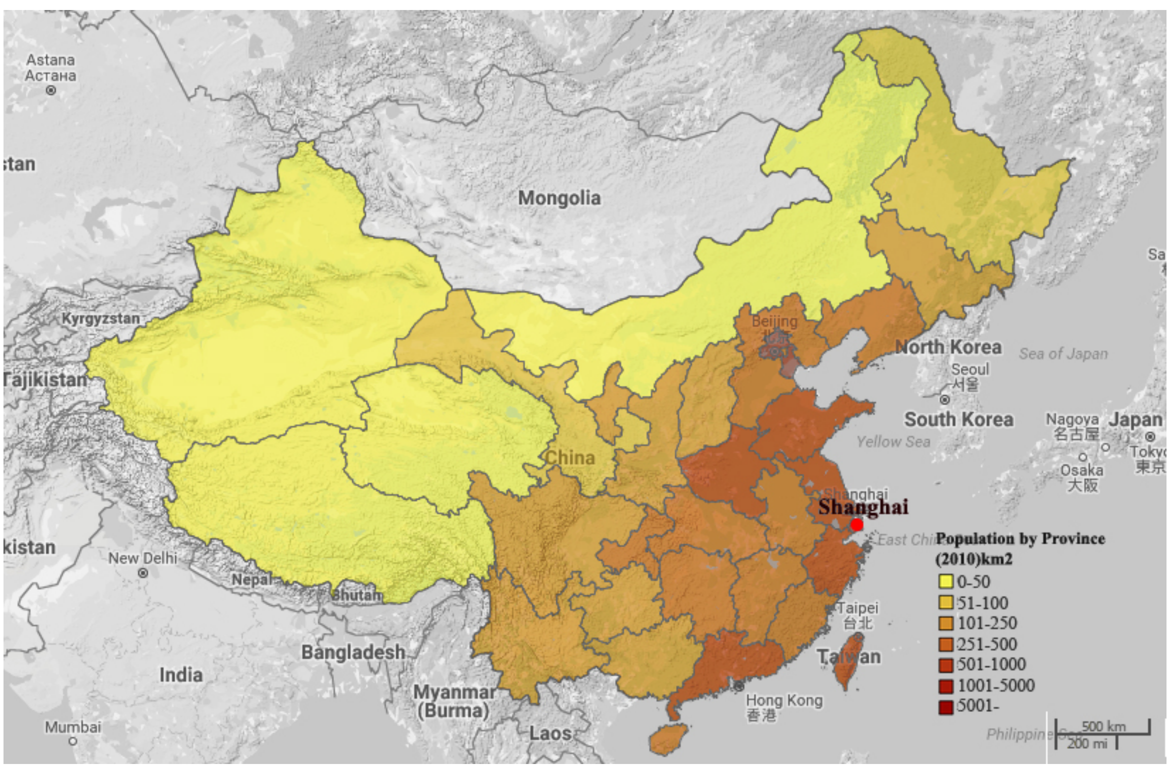
Figure 9: Map of Urban Expansion in Shanghai 1991-2015



Source: Shanghai Annual Yearbook

Figure 10: Urban Built-up Area 1995-2014

4.3 Population growth



Source: Harvard University GIS Information Center

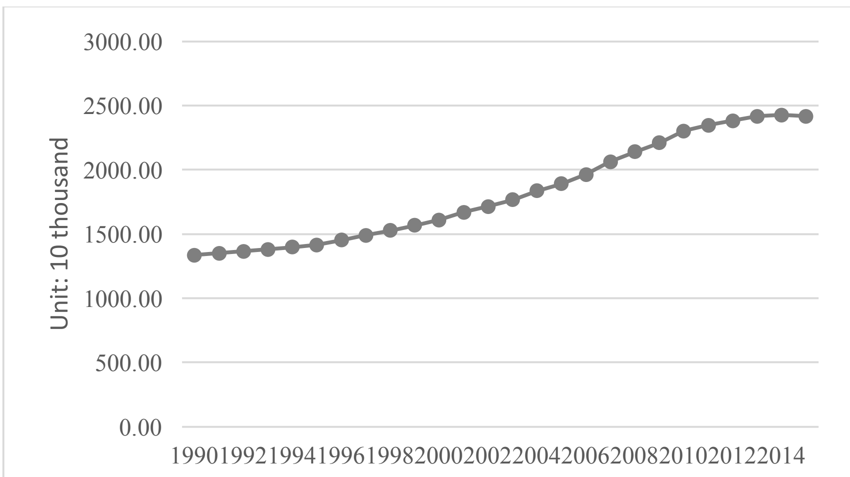
Figure 11: Population distribution in China

The expansion of the economy, especially with the development of the tertiary sector, greatly increased the demand for labor and attractions for migrants. Many people from less developed or rural areas came to Shanghai with a desire to find better jobs and an overall better quality of life ("Shanghai Population Growth," 2014).

With more and more people flooding into Shanghai, it is now one of the most populous cities in China. In 1990, the total population was 13.34 million, which increased year to year, and in 2014, the number rose to 24.25 million (Shanghai Government, 2016). The population mentioned here is the number of residents with or without the local Shanghai *hukou*. Due to restrictions on obtaining a local Shanghai *hukou*, there are only 14.26 million registered Shanghai residents, composing 59% of the total population. The rest of population is called the "floating population," which refers to individuals who do not live at their *hukou* location (Chan, 2009).

The rapidly increasing population poses risks for Shanghai, which lead to inadequate land resources, air pollution, insufficient public facilities and services, higher living costs, and fierce competition for employment. The government has to take action to manage population growth, one major way of which is the *hukou* system, which works as a tool to regulate migration activities. *Hukou* is a record of household registration in mainland China ("Hukou System," n.d.). It is hard for people from other provinces to obtain a Shanghai *hukou*; although, they have the freedom to find a job in Shanghai and live there. However, migrants cannot acquire ownership of municipal/work units or public housing—only people with local *hukou* can do that. Public programs for affordable housing—either for sale or for rent—only target local urban residents. Commercial housing is the only real property available to migrants, but most of them cannot afford it (Wu, 2008). Thus, the vast majority of new migrants rent or share accommodations in Shanghai. Frequently, they rent in suburban areas within the metropolis because of lower rent costs, which results in a higher proportion of rentals among migrants in the suburbs than in the central city.

In addition to the limitations created by the *hukou* system, increasingly high costs of living in Shanghai are now holding back more and more migrants. There is an obvious decline in the growth rate of the population after 2010 (see Figure 12). From 2014 to 2015, the total population in Shanghai decreased by about 0.4%, the first decrease in 25 years.



Source: Shanghai Annual Yearbook

Figure 12: Population Growth in Shanghai 1990-2015

After breaking down the population growth in different areas of Shanghai, the growth in the suburbs outpaced all other areas. In the central district, population increased by 1% from 2000 to 2014, while the rates of increase in the suburbs and outer suburbs were 120% and 70%, respectively. However, the absolute number of people in the central city composed about 48.47% of the total population in 2014, dropping from 67.8% in 2000. The decreasing proportion of people living in the central city reveals that people are more likely to live outside of the central city, which may due to the saturation of land.

Table 1: Population growth in different areas (1:10,000)

Source: Shanghai Government *(2015)*

Area		2000	2009	2014	Change
Central city	Central district	347	380	351	1%
	Periphery district	766	594	825	8%
	Total	1113	975	1176	6%
	Suburb area	239	453	525	120%
	Outer suburb area	427	63	725	70%
Total		1641	2210	2426	48%

4.4 Population Density

Population density is the ratio of the total population of a city and the total built-up area the city occupies ("Atlas of Urban Expansion," 2015). It is believed that urban population density has a significant impact on mode splits, especially on vehicle shares, since higher density can reduce vehicles per kilometer travelled and increase the proportion of walking and public transit use (National Research Council, 2009). Low-density cities have fewer metro passenger miles per year than high-density cities, since the residents are more likely to rely on automobiles (Bertaud & Richardson, 2004).

From 1995 to 2014, the urban population density of Shanghai decreased from 52,300 people/km^2 to 24, 300 people/km^2, indicating a faster rate of spatial expansion than population growth in Shanghai, but the decreasing rate ended after 2004 and maintained a relatively stable level of 24,000 people/km^2.

The changes in population density varied among different areas. In the central city, the population density was around 50,000 people/ km^2 in 2011, down from 60,000/km^2 in 2000. Even so, the central city still has a relatively high population density compared to Manhattan or Paris. In the suburban areas, the average population density grew about 0.8% from 2000 to 2011, which was approximately 25,000 per km^2 (Cox, 2011).

Table 2: Population density of Shanghai 1995-2014

	1995	2004	2009	2014
Population (in 10,000s)	1414	1834.98	2210.28	2425.68
Built-up Area (km^2)	270	781	886	999
Density	5.23	2.35	2.49	2.43

Source: Shanghai Annual Yearbook

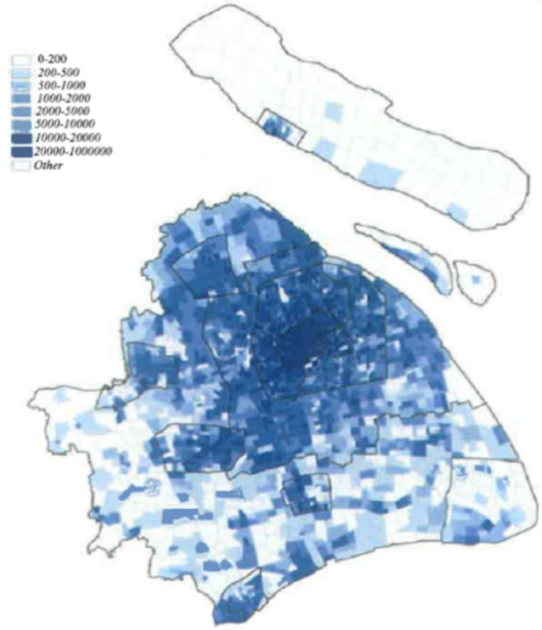
4.5 Employment Distribution

Shanghai is like a job magnet that attracts people from all over the country. In 2013, the total employed population was 12.24 million, composing 50.6% of total Shanghai residents. This number increased by 1.82 million from 2008. Consistent with the industrial distribution shift to the tertiary sector, employment in the tertiary sector increased from 7.44 million in 2008 to 9.38 million in 2013, constituting 61% of the total employment. The proportion of GDP in the tertiary sector was 63%, a great match that reveals the interim success of the industry upgrade process.

It is worth mentioning that employment was unevenly distributed in different areas, more than half of which were located in the central city. However, migrants and low-income groups are more likely to reside in the suburbs of Shanghai due to its relatively low living costs, and this triggered a huge commute demand from the outer areas to the central area of Shanghai.

Table 3: 2013 Distribution of employment *Source: Shanghai Annual Yearbook*

	Employment (ten thousand)
Central City	622
Suburb area	229
Outer suburb area	373
Total	1224



Source: Shanghai Government *(2015)*

Figure 13: 2013 Distribution of Employment

5 Changes of Transportation Characteristics

Together with economic, population, spatiality, and employment increases, the travel demand—including average daily trips, travel rates, travel purposes, travel periods, the spatial distributions of travel demand, mode splits, and average trip lengths—increased tremendously over two decades in Shanghai.

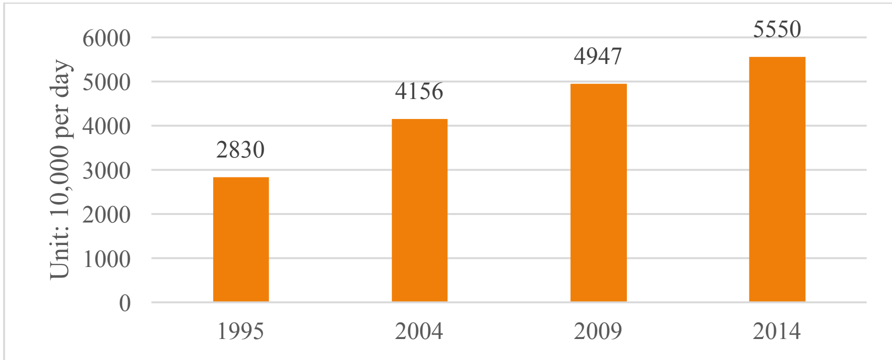
5.1 Average daily trips

"Average daily trips" refers to the annual average number of daily trips. The number of average daily trips doubled from 1995 to 2004 due to the combined effects of several factors. "Travel" refers to the completion of a purposeful activity from one place to another, which includes three criteria: the completion of the activity, the use of existing roads and streets, and trips no less than 400 meters or five minutes' walk (Shanghai Government, 2015). There were 55.55 million trips per day in 2014, up 12% from 2009. Among the trips, those generated by local residents was 52.12 million, a 24% increase in the past five years.

Table 4: Selected transportation features in Shanghai from 1995-2014

Year	Population (10,000)	Average trips (once per person per day)	Average daily trips (10,000)	Average trip length (km per trip)
1995	1266.7	1.87	2830	4.5
2004	1712	2.15	4156	6.9
2009	2210	2.16	4947	7.4
2014	2426	2.16	5550	8.2

Data source: The second, third, and fourth comprehensive travel surveys in Shanghai

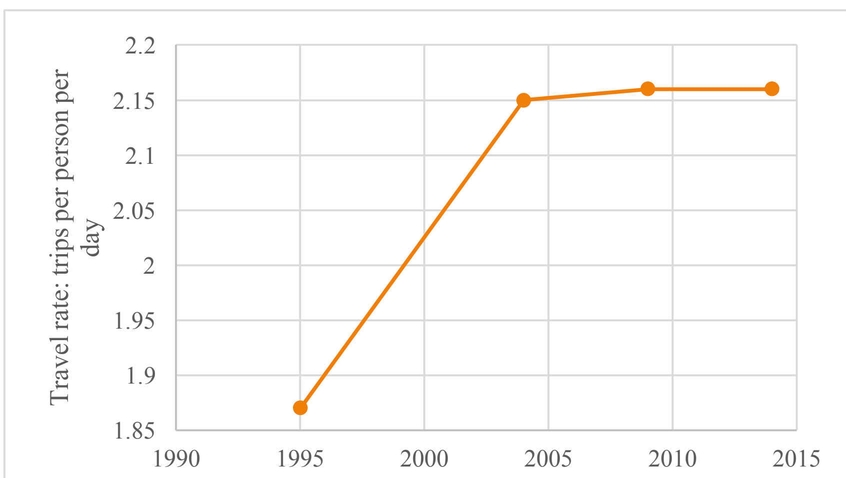


Data source: Shanghai Government (2015)

Figure 14: Average daily trips change (1995/2004/2009/2014)

5.2 Travel rate

"Travel rate" refers the number of trips one person generates per day, which increased largely in Shanghai from 1995 to 2004. However, since 2004 the travel rate remained stable at about 2.16 times per person per day (Shanghai Government, 2015).



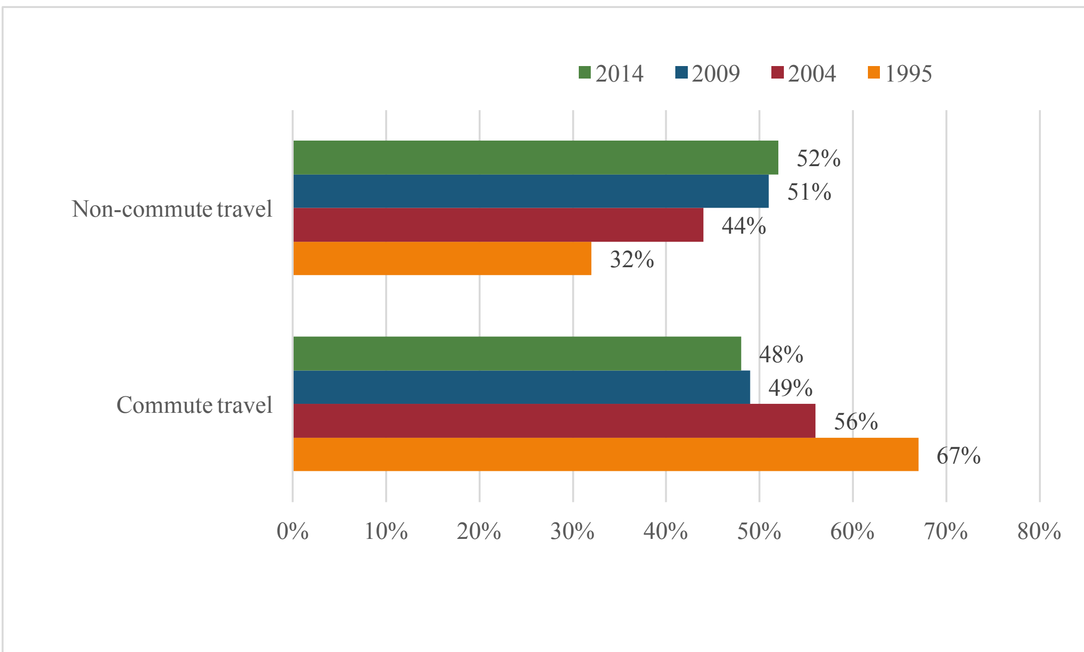
Data source: The fifth comprehensive travel survey in Shanghai

Figure 15: Travel rate changes in Shanghai 1995-2014

5.3 Travel purpose

Along with improvements in quality of life, people's travel purposes became more diversified. The proportion of non-commute travel greatly increased from 1995 to 2014, with rates of 48%, 49%, 56%, and 67% in the years 1995, 2004, 2009, and 2014, respectively. Accordingly, the share of commute travel decreased from 67% to 48% over these twenty years.

Although the share of commute trips went down, actual trips increased with travel demand growth, which was 25.11 million in 2014, a 7% increase from 2009. Non-commute travel including shopping and leisure rose more rapidly with the expansion of economic activities, with 27.02 million trips—an 11% increase since 2009 (Shanghai Government, 2015).



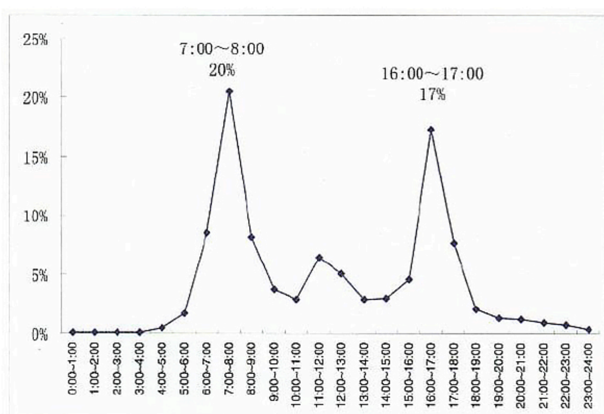
Data source: Shanghai Government (2015)

Figure 16: Travel purpose composition

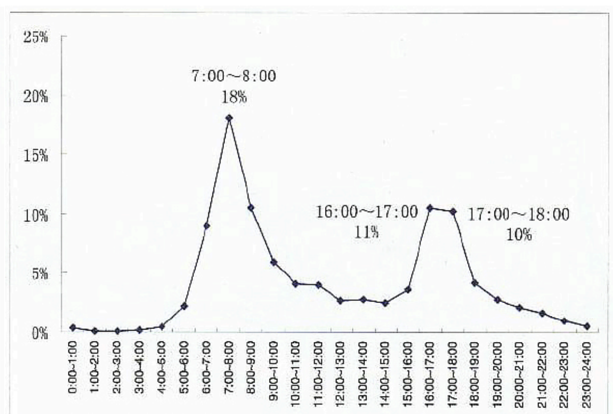
5.4 Travel period

With the increase of commute travel demand, trips during rush hour kept increasing in Shanghai but with more flexibility during rush hour, as indicated by the drop in the travel during rush hour. Accompanied with more active, non-commute travel, rush hour in the evening had a tendency to be earlier and less concentrated. Another interesting phenomenon is that the increase in travel demand disappeared at noon compared to 1995, which was related to the changes in people's work schedules. In the past, people tended to go home at noon, since they did not live far from work. But nowadays, they are more who are willing to have lunch near their workplaces.

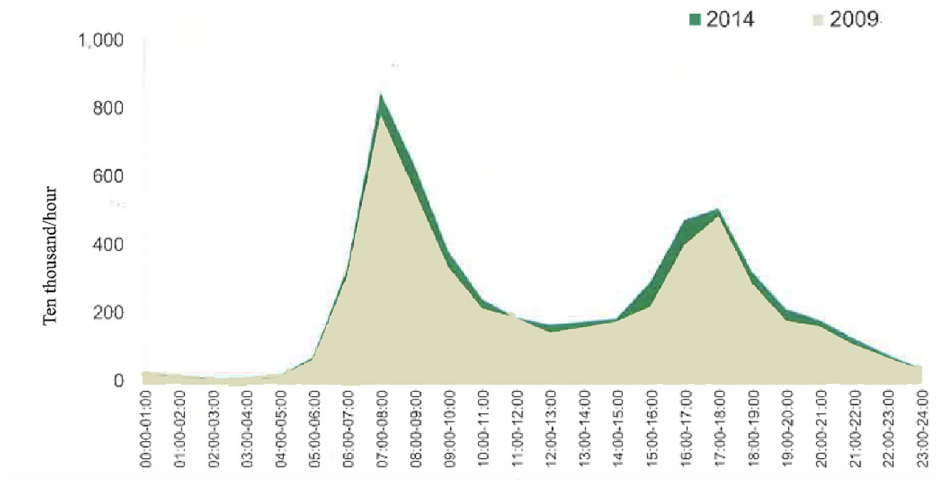
In 1995, 20% of total travel occurred between 7 a.m. and 8 a.m., and in 2004, this number fell to 18% and kept falling to 15.2% in 2014. During evening rush hour, 17% of total travel occurred between 4 p.m. and 5 p.m., but in 2004, 11% of travel occurred between 4 p.m. and 5 p.m., and travel between 5 p.m. and 6 p.m. composed 10% of the total. In 2014, the evening rush hour was postponed to between 5 p.m. and 6 p.m., which constituted 9.1% of average daily trips, and witnessed a slight decrease over twenty years. During regular hours in 2014, the growing rate of trips was higher than it was in 2009. There was a 10% increase in morning rush hour trips and a 15% growth in evening trips between 3 p.m. and 5 p.m. People traveled 11% more often between 10 a.m. and 3 p.m., and night trips increased to 15% between 7 p.m. and 9 p.m. (Shanghai Government, 2010, 2015).



1995



2004



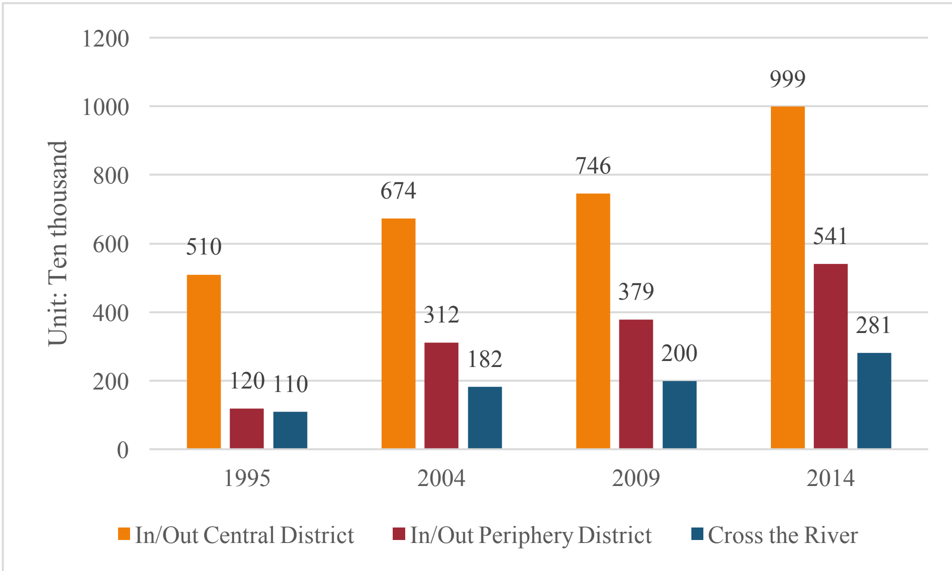
Data source: Shanghai Government (2015)

Figure 17: Travel in different time periods

5.5 Spatial distribution of trips

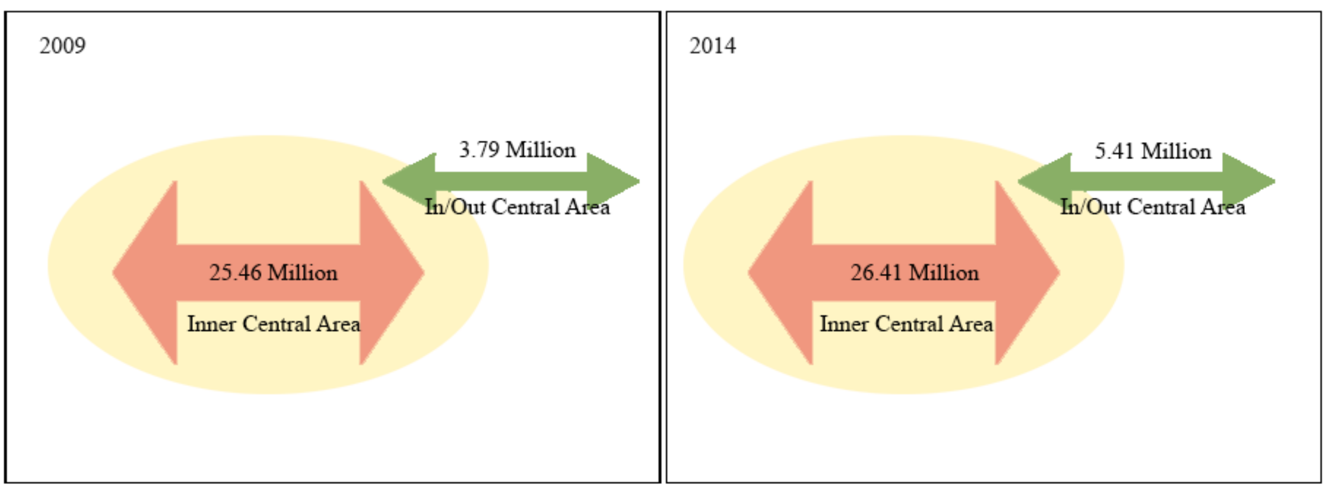
With the expansion of urban space and the longstanding resource concentration in the central city, the transportation connections between different areas are closer and lead to the growing travel demand from the central city to the peripheral spaces. Also, an internal spatial restructuring of the city took place along with the outward expansion of its urbanized area (Zhao & Zhao, 2013). Land use in the urban core was reconfigured, and a significant amount of residential and industrial land was converted into commercial land after 1988 (Xu et al., 2007). As a result, residents were forced to move from the high-density central district to the periphery, which increased travel demand in the same direction.

Overall, travel demand is still concentrated in the central city (Zhao & Zhao, 2013). There were 31.83 million daily trips related to the central area in 2014, of which inner central area trips composed 26.41 million, a 4% increase from 2009. The number of commutes in and out of the central district (the area between the Inner and Outer Rings) increased from 1995-2014. In 2014, there were 9.99 million daily commutes on average to the central districts, a 37% increase from 2009 almost double the rate from 1995. There was a 44% increase in commutes in and out central area from 2009 to 2014, more than four times that of 1995 and almost double that of 2004. Cross-river travel composed 2.81 million inner city trips, with a growth of 53% compared to 2009, which revealed a closer connection between Pudong and Puxi. The 9.99 million trips in and out of the central districts composed 18% of all daily trips in 2014.



Data source: Shanghai Government (2015)

Figure 18: Spatial distribution of trips



Data source: Shanghai Government (2015)

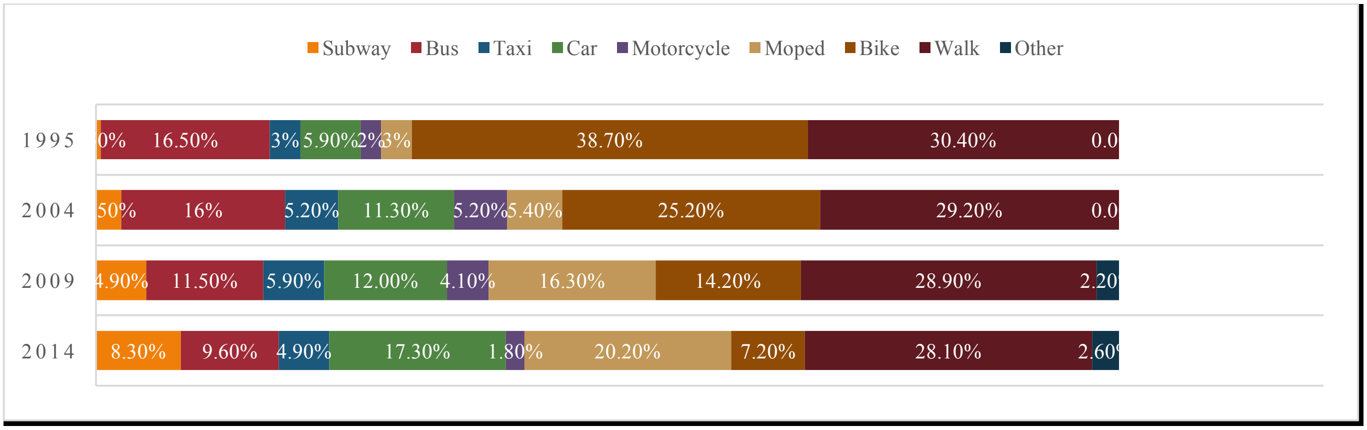
Figure 19: Trips related to central area

5.6 Mode Split

Mode split refers to the proportion of each travel mode in all trips. Urban expansion from the central city is the fundamental change influencing the structure of mode split. When urban space was limited, walking and cycling were the primary modes of transportation. Along with urban expansion, buses were more important, and there was a trend to shift from non-motorized trips to bus trips. With further urban expansion processes, private motorized trips dominated due to increased travel lengths and a lack of mass public transit. On the other hand, it is relatively costly and difficult to construct an efficient transit system under the dispersed urban development pattern, which in turn aggregates the reliance on private motorized vehicles. (Li et al., 2010).

Shanghai has an extensive public transportation system with subway, bus, and ferry networks (Zhao & Zhao, 2013). Overall, public transit did not experience any huge changes between 1995 and 2014, staying around 17% of the total mode split. However, the components of the transit system changed. From 1995 to 2014, the share of subway trips increased sharply from 0.5% to 8.3%, and ridership increased 176% from 2004 to 2009. On the contrary, the proportion of bus trips went down slightly from 1995 to 2004 to below 10%, primarily because of the expansion of the subway network.

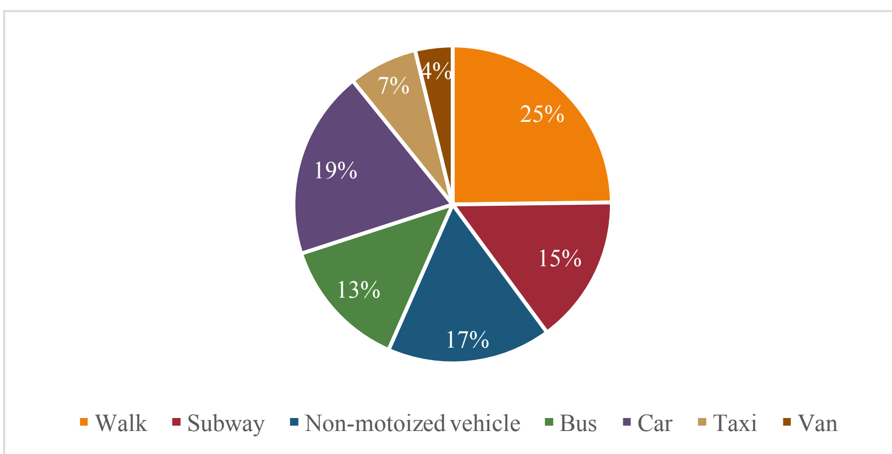
The growth in motorized travel outpaced all other modes. The share of private cars increased dramatically from 5.9% to 17.3% over the two decades. The dual amplification of the total volume of trip demand and motorized trip share increased the vehicle trip volume, posing great pressure on the road system and resulting in more frequent traffic congestion. Motorization may lead to a shift from non-motorized to private motorized modes of transit. From 1995 to 2014, the proportion of bike trips shrank significantly, and the proportion of walking trips decreased from 30.4% to 28.1%.



Data source: Shanghai Government (2015)

Figure 20 Mode Split in Shanghai 1995-2014

Population density and employment opportunities are still concentrated in the central city despite urban expansion. Because of the limited capacity of current transportation infrastructure in the central area, public transit became the primary mode in Shanghai. On weekdays in 2014, 32.8% of travel was completed via public transit, including subways, buses, shuttles, and ferries, among which subways contributed most with about 15.1%.



Data source: Shanghai Government (2015)

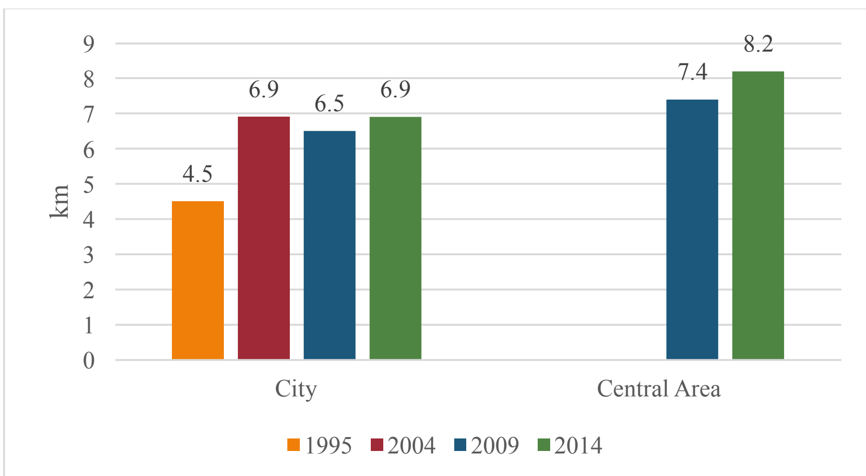
Figure 21 Mode Split in the central area in 2014

Different transit modes take responsibility for different average trip lengths. The subway takes mid- to long-distance travel, 82% of which is greater than 7 km with an average distance of 18.3 km.

Buses mostly take responsibility for mid-distance travel, of which the average distance is 8.7 km. The average trip length for cars is 13.2 km. Mopeds and bikes take care of the short-distance travel with average distances of 4.1 km and 2.6 km, respectively. A more detailed analysis of average trip length at the city level will be presented next.

5.7 Average trip length

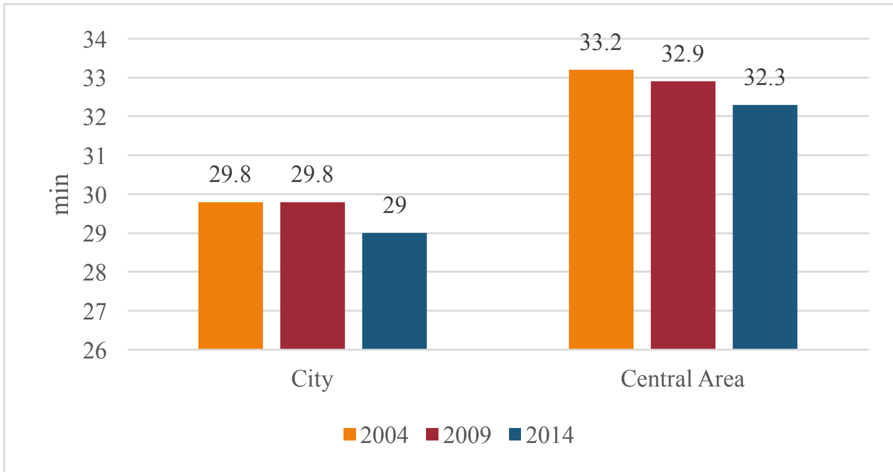
Another feature that the expansion of urban space brought was longer average trip lengths, which increased to 6.9 km per trip in 2004 from 4.5 km per trip in 1995. However, this number fell to 6.5 km in 2009 and went back to 6.9 km in 2014. Due to data accessibility issues, the average trip lengths in the central area in 1995 and 2004 are missing. Compared with 2009, the average distance of trips in and out of the central area increased to 8.2 km per trip in 2014, which could be considered a good indicator of the expansion of urban space and people's living and activity radiuses.



Data source: Shanghai Government (2015)

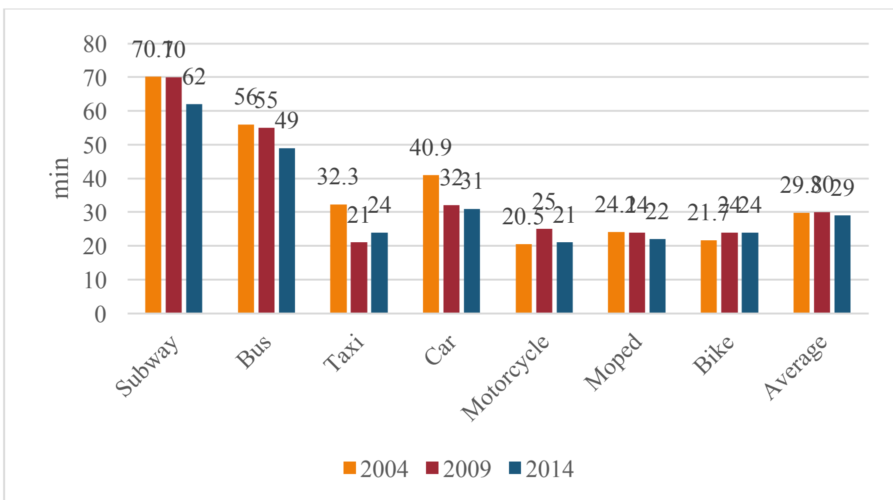
Figure 22: Average trip length in Shanghai 1995-2014

With the improvement of public transit services, especially the development of subways, the average travel speed actually increased in the last ten years. The average time people traveled slightly decreased from year to year. For the whole city, this number went down from 29.8 min to 29 min, while the commuting time in and out the central area decreased from 33.2 min to 32.3 min. Although the data from 1995 was unable to be retreived, we could conclude that travel speeds increased since the average average trip length increased while the average travel times dropped.



Data source: Shanghai Government (2015)

Figure 23 Travel time in Shanghai 2004-2014

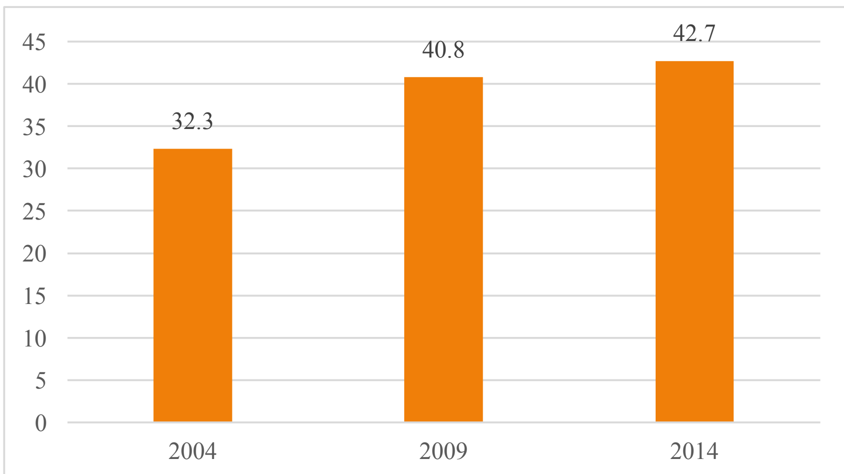


Data source: Shanghai Government (2015)

Figure 24 Travel time for different modes 2004-2014

Both the capacity and speed of public transit improved from 2004 to 2014. The overall travel time for public transit decreased, as shown in Figure 24. The average time for the subway went down from 70.7 min to 62 min and the average time buses took fell from 56 min to 49 min. These are attributed to the improvements made to public transit services and infrastructure, especially in the context of longer distance travel demand and increased public transit share.

However, the time for commutes increased to 42.7 min in 2014; the average time for commutes in 2009 was 40.8 min. With better public transit services and higher speed travel, the extended commute time may be attributed to urban expansion. People are living further away from the city center for multiple reasons, and they may need more time to commute.



Data source: Shanghai Government (2015)

Figure 25 Average commute time in Shanghai 2004-2014

6 Urban Expansion and Transportation

In order to quantitatively examine whether there is a statistically significant relationship between changes in transportation features and urban expansion factors, regressions were conducted based on travel surveys and annual yearbook data (Shanghai Government, 2015, 2016). However, all the regressions below have limitations of data. If more data were available, the results would be more precise.

6.1 Urban expansion and average daily trips

Population and GDP were selected as indicators for urban expansion to investigate the impacts of urban expansion on average daily trips in Shanghai. Population growth is believed to increase total travel demand, while the increase of economic activity can increase travel rates and lead to higher travel demand, as well. However, since population and GDP are related, to avoid the correlation effect caused by their coexistence, the regression was conducted separately.

Table 5 Population, GDP and average daily trips (1995/2004/2009/2014)

Data source: Shanghai Government (2015, 2016)

Year	Population (10 thousand)	GDP (100 million)	Average daily trips (10,000)
1995	1414	2499.43	2830
2004	1834.98	8072.83	4156
2009	2210.28	15046.45	4947
2014	2425.68	23567.7	5550

6.1.1 Population and average daily trips

The null hypothesis for this test is that there is no relationship between population and average daily trips. If $P < 0.05$, we can reject the null hypothesis. In other words, the regression investigates the change in average daily trips from 1995 to 2014 significantly related to population growth under a 95% confidence interval. The R-square value is 0.99, meaning that 99% of variation in average daily trips can be explained by population growth. The coefficient for population is 2.63 trips per person, indicating that for every additional person in Shanghai, trips are expected to increase by 2.63 per day. Increased population will increase the average daily trips.

Table 6: Regression result of population and average daily trips

Regression Statistics	
Multiple R	0.996460769
R Square	0.992934064
Adjusted R Square	0.989401096
Standard Error	120.9797778
Observations	4

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-822.1477944	315.6068273	-2.604974682	0.121158515
Population	2.634337253	0.157137926	16.76449042	0.003539231

6.1.2 GDP and average daily trips

Similar to population, as the results show, GDP is significantly related to the change in average daily trips change over two decades at a 95% confidence interval. One hundred million additional GDP will increase the total number by 1,242 trips per day. With more disposable income and available services, people can enjoy social activities, which will increase travel rates and contribute to average daily trips.

Table 7: Regression result of GDP and average daily trips

Regression Statistics	
Multiple R	0.962521843
R Square	0.926448298
Adjusted R Square	0.889672448
Standard Error	390.32314
Observations	4

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2842.333341	361.6891822	7.858496967	0.015809779
GDP	0.12429585	0.024764377	5.019139076	0.037478157

6.2 Urban expansion and mode split

To accommodate the demand for dynamic economic activities and the rapidly increasing population, spatial expansion is inevitable (Zhao & Zhao, 2013). It was considered that the spatial expansion of built-up area would increase people's reliance on motorized vehicles and thus lead to increased shares of cars and subways, since both are primary transport modes for long-distance trips. Also, population density is believed to be connected with mode split, especially in car and subway share (National Research Council, 2009).

Table 8: Built-up area, share of car, share of subway (1995/2004/2009/2014)

Data source: Shanghai Government (2015, 2016)

Year	**Built-up area (km^2)**	**Population density(10,000/ km^2)**	**Share of car**	**Share of subway**
1995	270	5.23	0.059	0.005
2004	781	2.35	0.113	0.025
2009	886	2.49	0.12	0.049
2014	999	2.43	0.173	0.083

6.2.1 Urban built-up area and car share

As the results show, the increase in built-up area does not have a significant relationship with the changes in car share under a 95% confidence interval. However, since $P = 0.06$, it is at the margin of statistical significance, and the relationship would be significant if the confidence interval were set at 90%. In other words, we are 90% confident that the expansion of urban built-area will lead to increased car share. Every additional square-kilometer increase in urban built-up area will increase care share by 0.014%.

Table 9: Regression result of urban built-up area and share of car

Regression Statistics	
Multiple R	0.9332
R Square	0.87087
Adjusted R Square	0.8063
Standard Error	0.02052
Observations	4

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.01702	0.0289	0.58907	0.61549
Built-up area	0.00014	3.7E-05	3.67262	0.0668

6.2.2 Urban built-up area and subway share

The relationship between urban built-up areas and subway share area not significant, which reveals that the expansion of urban space cannot be a primary factor that influences subway share. There must be reasons other than urban expansion attracting people to subways .

Table 10: Regression result of urban built-up area and share of subway

Regression Statistics	
Multiple R	0.87317
R Square	0.76242
Adjusted R Square	0.64363
Standard Error	0.02003
Observations	4

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.0263	0.02821	-0.9329	0.44934
Built-up area	9.1E-05	3.6E-05	2.53343	0.12683

6.2.3 Population density and car share

Different from studies in the literature review, the change in car share in Shanghai does not significantly relate to the decrease in population density, meaning that the decrease in population density will not interfere with the car share. Apart from differences in data volume, other studies compare the population densities of different cities, while the regression here focuses on one city. The increase in car share may due to interactions between many other factors.

Table 11: Regression result of population density and car share

Regression Statistics	
Multiple R	0.813426583
R Square	0.661662806
Adjusted R Square	0.492494209
Standard Error	0.033218135
Observations	4

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.200641739	0.045790258	4.381756042	0.048338597
Population Density	-0.027005357	0.013654991	-1.97769123	0.186573417

6.2.4 Population density and subway share

As the results show below, population density does not have a significant relationship with subway share. Although an empirical study has established an association between high-density environments and greater transit use (Bertaud & Richardson, 2004), population density now is not a significant factor that increases subway ridership. This can be explained by the differences in the developing stages. In Bertaud and Richardson's study (2004), the object was based on cities with well-developed public transit systems.

For Shanghai, as a developing city, increased subway share may be more attributable to the development of subway infrastructure, which I will analyze in the next chapter.

Table 12: Regression result of population density and subway share

Regression Statistics	
Multiple R	0.690548745
R Square	0.47685757
Adjusted R Square	0.215286355
Standard Error	0.0297296
Observations	4

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.092064955	0.040981412	2.246505193	0.153724246
Population Density	-0.016500786	0.012220958	-1.350203924	0.309451255

6.3 Urban expansion and average trip length

From empirical suspension, the average trip length will increase with urban expansion processes, since people are decentralizing while employment and commercial places are still concentrated in the city center.

The results of a regression of built-up area and average trip length show that their relationship is not significant at a 95% confidence level, since the P-value is slightly higher than 0.05. But, if the degree of confidence increases by 0.1, they are significantly related. We have 90% confidence that the expansion of urban built-up areas will increase the average trip lengths in Shanghai. Every additional square kilometer in the built-up area will add 3.39 meters per trip on average.

Table 13: Built-up area and average trip length (1995/2004/2009/2014)

Year	Built-up area(sq.km)	Average trip length(km)
1995	270	4.5
2004	781	6.9
2009	886	6.5
2014	999	6.9

Table 14: Regression result of urban built-up area and average trip length

Regression Statistics	
Multiple R	0.94893
R Square	0.90047
Adjusted R Square	0.8507
Standard Error	0.44393
Observations	4

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	3.71393	0.62518	5.94058	0.02719
Built-up area	0.00339	0.0008	4.2537	0.05107

7 Supply-demand analysis of transportation system

On the supply side, the infrastructure of the public transit system is taken into account, including the number of vehicles and the lengths of operating lines, as they are the primary public transit compositions in Shanghai. With fast-paced motorization growth, the development of road infrastructure is also remarkable. Compared with the use of transportation infrastructure, we can gain an overview of the supply-demand status of Shanghai's transportation system to try to answer the central question: has the transportation supply in Shanghai been adequate for its travel demand?

7.1 Infrastructure development

7.1.1 Bus Service

The bus service in Shanghai has long played an important role. The length of bus lines increased unexpectedly from 1995 to 1998, but the overall bus service length has remained stable since, which proved the Shanghai government's longstanding efforts for public transit development. The overall number of bus lines increased from around 1,000 to 1,500 from 1995-2015; however, the passenger volume dropped from 5.4 billion to 2.5 billion due to the development of the subway system and the diversity of modern vehicles. This number also echoes the drop in bus share over the past twenty years.

The rate of bus service coverage increased largely in the suburban and outer suburban areas. In 2014, 100% of the population had access to bus stations in the central district within 500 meters, 97% of residents could get to bus station within 500 meters in the central area, and the overall coverage rate for a 500-meter radius was 81% (Shanghai Government, 2015).

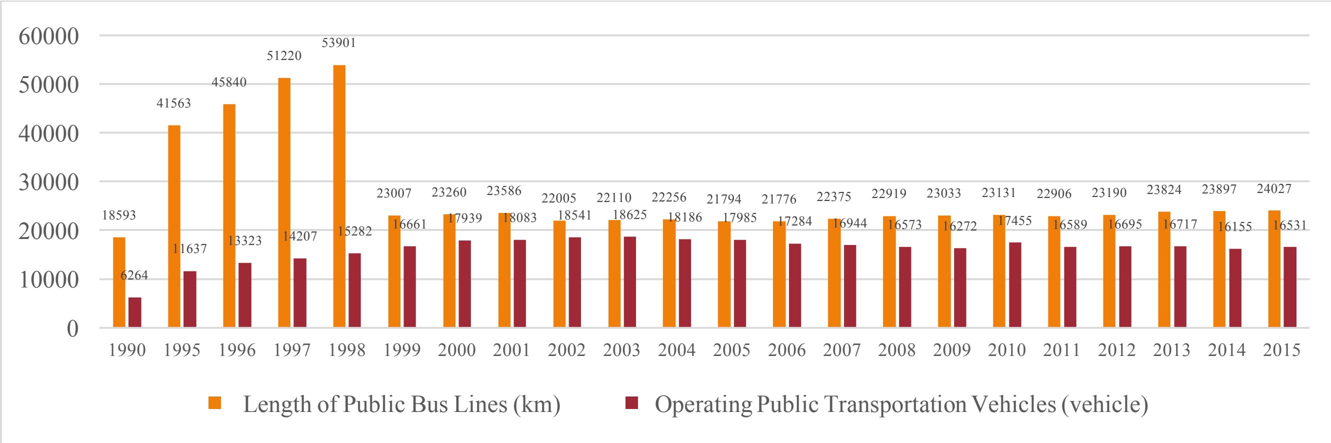


Figure 26: Length and vehicles of buses in Shanghai 1990-2015

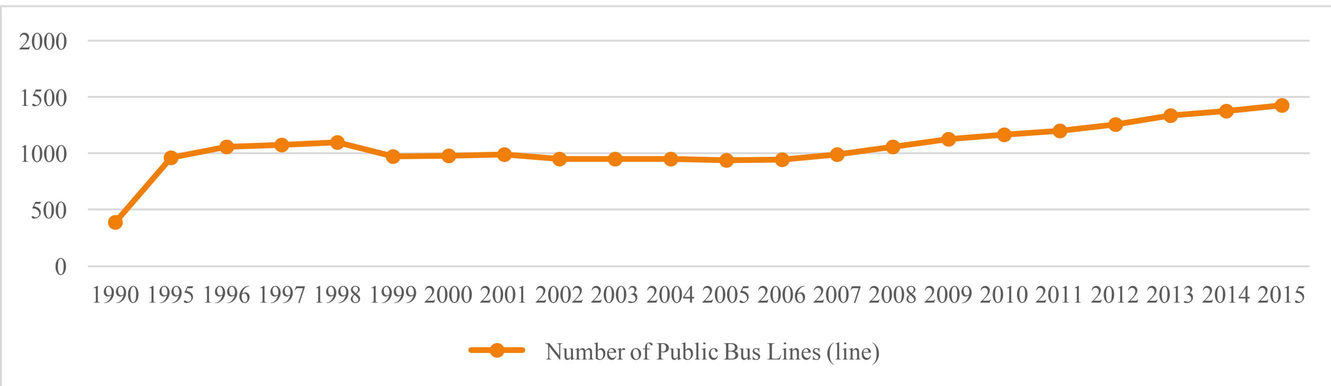


Figure 27: Number of bus lines in Shanghai 1990-2015

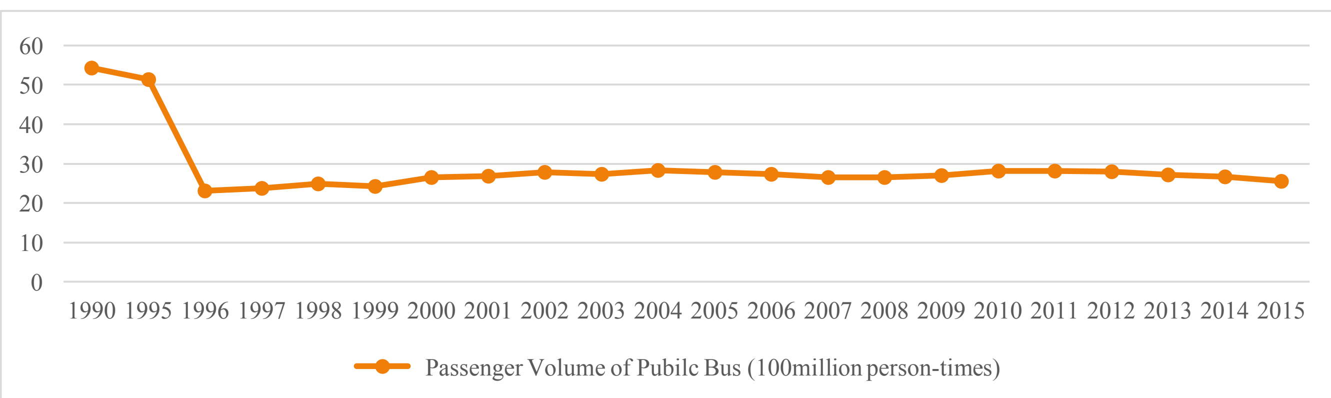


Figure 28: Passenger Volume of bus in Shanghai 1990-2015

7.1.2 Subway Service

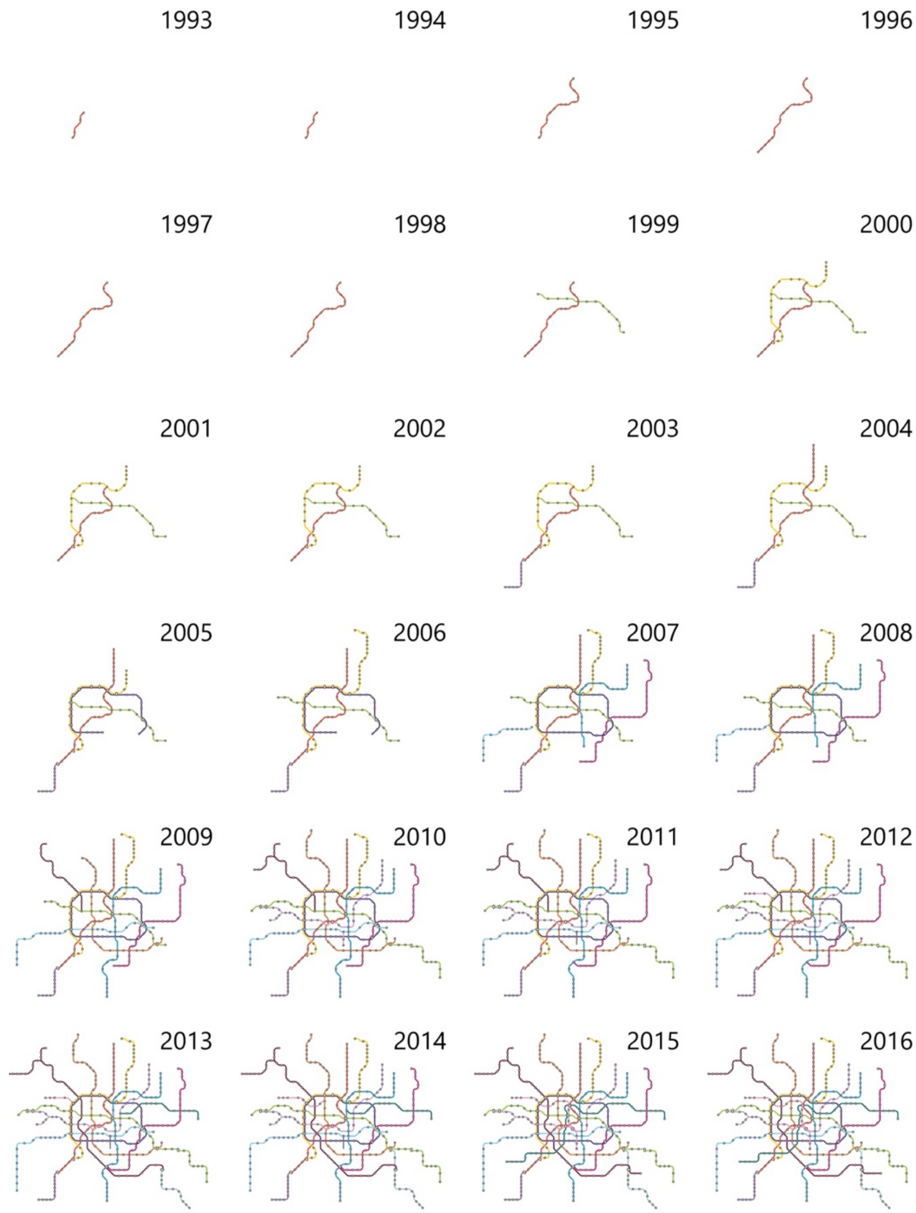
The subway network expanded dramatically from 1995-2014. The total number of subway lines increased to 15 (including maglev trains) with a total service range of 617.53 km in 2014. Shanghai has 339 subway stations, 41 of which are terminals providing transfer services with more than two subway lines, bus lines, and other transit systems. Shanghai's subway service is the largest rapid transit system by route length in the world (Railway Gazette, 2010). In the central area, 47% of the employed population can access subway transit within a 600-meter radius.

Table 15: Shanghai subway system development 1996-2015

	Number of Operation Lines (line)	Length of Operation Lines (km)	Volume of Passenger Traffic (10,000 person-times)
1996	1	15.21	8,944
1997	1	20.06	11,174
1998	1	20.06	12,606
1999	2	20.06	10,921
2000	3	62.92	13,556
2001	3	62.92	28,270
2002	3	62.92	35,739
2003	4	108.65	40,604
2004	4	121.23	48,007
2005	5	147.8	59,406
2006	6	169.4	65,569
2007	9	262.83	81,395
2008	9	264.3	112,798
2009	11	355.05	131,837
2010	12	452.57	188,407
2011	12	454.1	210,105
2012	13	468.19	227,573
2013	15	567.42	250,628
2014	15	577.55	282,727
2015	15	617.53	306,798

Data source: Shanghai Annual Yearbook

The map below shows the development of the Shanghai subway service since 1993. The extension of existing lines and the completion of new lines contributed to the increased operation area. The route originated in the central area and then gradually expanded to the outer spaces in a radial pattern.



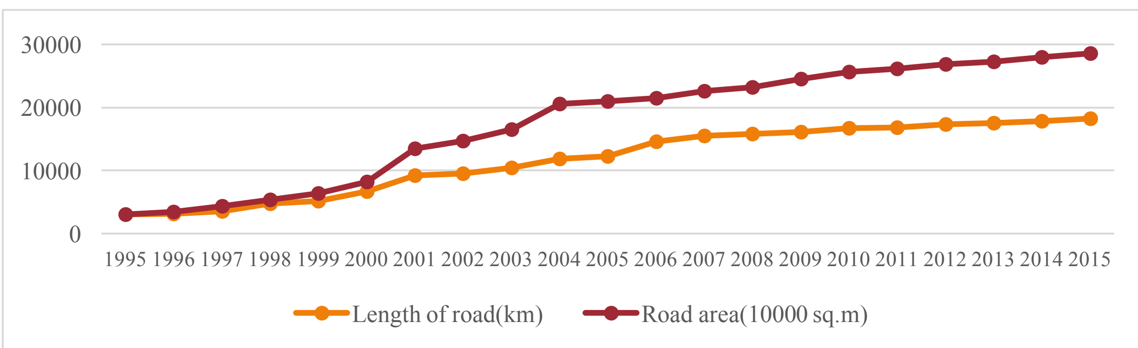
Data source: Wikimedia Commons

Figure 29 Shanghai subway routes 1993-2016

7.1.3 Road System

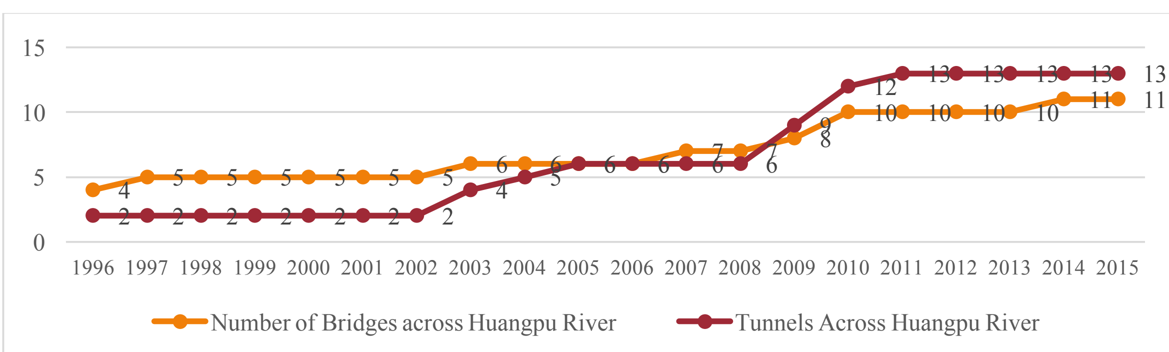
Both road length and road area in Shanghai grew steadily from 1995 to 2015, but the growth rate declined slightly after 2005. By the end of 2014, the total road length was 1.8 million km, and the total road area was 2.8 million m^2. The length in 2014 was three times that of 1995, while the road area increased five-fold.

To better connect Pudong and Puxi, many invested in bridge and tunnel construction. In 1995, there were only four bridges and two tunnels across Huangpu River. From 2008 to 2010, six new bridges and three new tunnels were constructed as part of the government's efforts to host the Shanghai 2010 EXPO. By 2014, there were 13 tunnels and 11 bridges linking the two areas, satisfying people's demand for crossing the river.



Data source: Shanghai Annual Yearbook

Figure 30: Road infrastructure development 1995-2015



Data source: Shanghai Annual Yearbook

Figure 31: Bridges and tunnels across Huangpu River 1995-2015

7.2 Infrastructure Usage

7.2.1 Public Transit System

The number of public transit passengers kept increasing. In 2014, there was, on average, 15.21 million trips covered by the public transit system daily, a 34% increase from 2009. Among all the trips, the subway system served 7.74 million riders, a growth of 114%. The bus service served 7.3 million riders.

Table 16: Ridership of public transit system (Unit:10,000 riders)

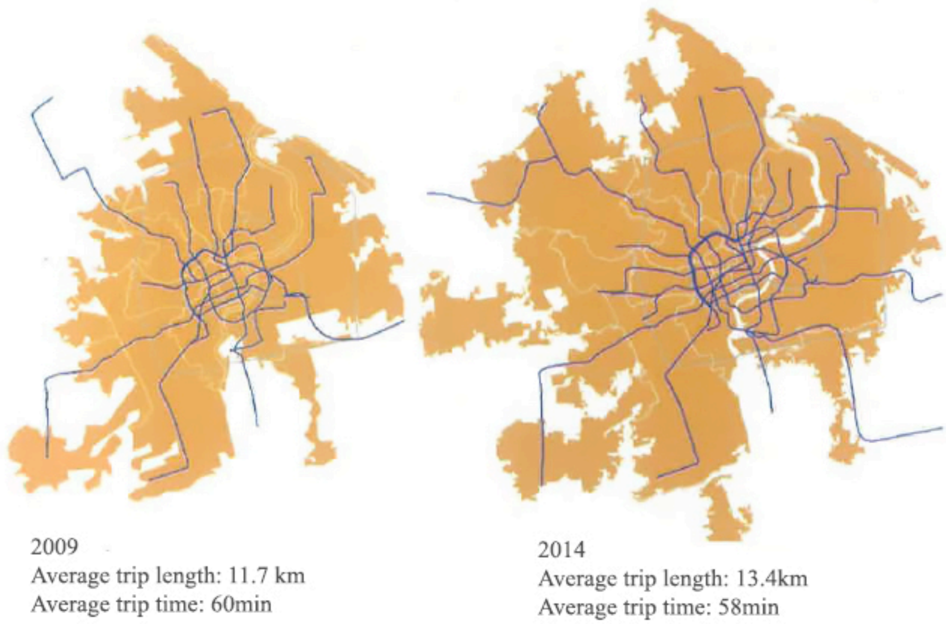
	2004	2009	2014
Subway	131	361	774
Bus	775	741	730
Ferry and others	40	30	17
Total	946	1132	1521

Among all public transit services, the subway system played an increasingly important role. From 2009 to 2014, the subway share of public transit increased from 32% to 51%; at the same time, the bus share declined from 65% to 48%. Other transit, including ferries, dropped from 3% to 1%.

The improvement of public transit services is one of the reasons for the increase in ridership. The subway's coverage area expanded, and efforts were made to enhance the connections between different transit modes, including subways and buses. The average trip length for public transit increased from 11.7 km in 2009 to 13.4 km in 2014, and the average travel time decreased from 60 min to 58 min.

Table 17: Mode split of public transit system

	2004	2009	2014
Subway	14%	32%	51%
Bus	82%	65%	48%
Ferry and others	4%	3%	1%
Total	100%	100%	100%

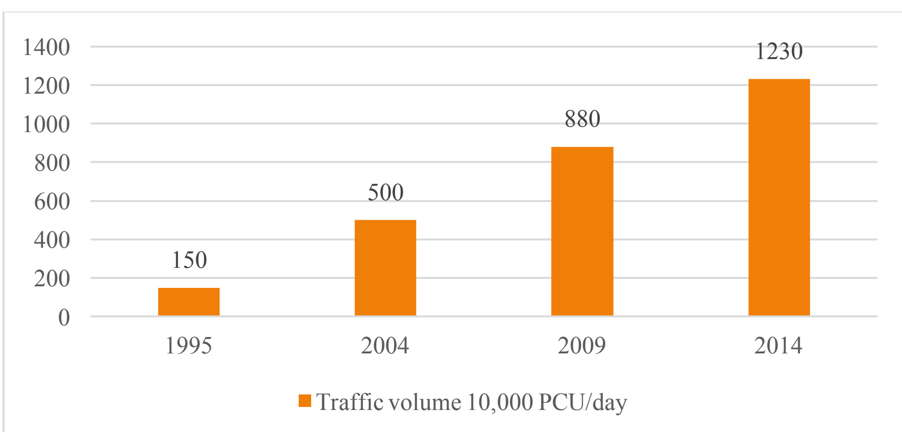


Source: The fifth comprehensive travel survey

Figure 32: Improvement of public transit service level

7.2.2 Road System

Together with the increase in the share of car trips, traffic volume rose quickly from 1995 to 2014, which put pressure on the road system in Shanghai. In 1995, there were 150,000 passenger car units (PCU) every day; in 2014, this number rose to 12.3 million. All traffic volume values were converted to PCU with different coefficients in the calculation.



Data source: Shanghai Government (2015)

Figure 33: Traffic volume (1995/2004/2009/2014)

7.3 Supply-Demand Analysis

7.3.1 Public Transit System

Although both the development of public transit infrastructure and its mode share increased largely, it was found that the subway share is growing relatively slowly. Also, compared with the car share, which increased from 5.9% to 17.3%, the increase in public transit share was not significant. This indicates that increasing the supply alone may not efficiently increase ridership. Other implementations shall be considered to promote the use of public transit (Zhao & Zhao, 2013).

The rapid and convenient subway service is a viable alternative to private motor vehicles and buses, which magnifies people's reliance on the subway system and causes crowding phenomena at peak hours, especially from the peripheral area to the central area. During peak hours on weekdays, the rate of loading exceeds 100% on some lines, and the metro's management has to limit the passenger flow by skipping some stations (Shanghai Shentong Metro Group, n.d.).

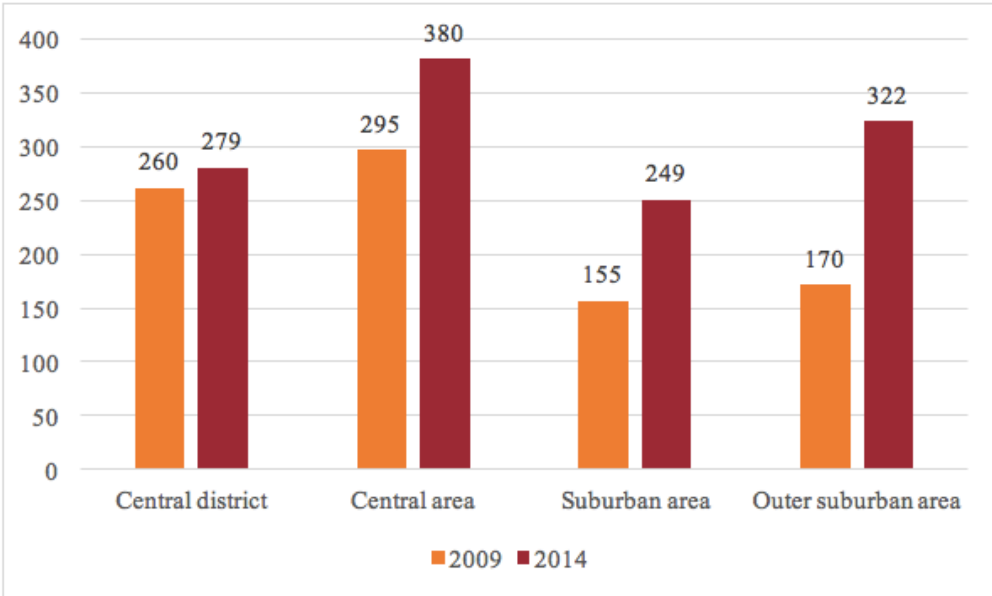
Table 18: Supply-demand analysis of public transit system

	Subway				Bus			
	2004	2009	2014	Change	2004	2009	2014	Change
Operating length (km)	121.23	355.05	577.55	376%	22256	23033	23897	7.3%
# of vehicle trips (10,000)	48007	131837	282727	489%	283800	270600	266500	-6%
Mode share	2.50%	4.90%	8.30%	232%	16.00%	12%	11%	-3%

Data source: The third and fifth comprehensive travel survey, Shanghai Annual Yearbook

7.3.2 Road System

Pacing with urban expansion and people's favor for motorized trips, increased traffic in suburban areas outpaced all areas in 2014, almost doubled since 2009, and contributed to 43% of the entire increase. However, despite the remarkable increase in traffic in the periphery, the traffic volume still centralized in the city, increasing 39.7% in five years. The over-concentration of traffic in the central districts creates distinct peak hours and spreads traffic congestion outward due to the diffusion of traffic demand from the central district to the periphery and suburbs.



Data source: Shanghai Government (2015)

Figure 34: Traffic volume in different area 2009/2014(10,000 PCU/day)

In road transportation, various modes coexist and share resources (Zhao & Zhao, 2013). The average annual growth rate for traffic volume is 58%, while road length only increased by 26% every year. The total road traffic volume increased faster than road infrastructure grew, and that is the main reason why roads are more congested. People travel more, but more importantly, they use motorized vehicles more.

Table 19: Supply-demand analysis of road infrastructure (1995/2004/2009/2014))

	1995	2004	2009	2014	Annual growth rate
Traffic volume (10,000 PCU.km/day)	675	3450	5720	8780	58%
Length of road (km)	3008	11825	16071	17797	26%

8 Conclusion and Recommendation

8.1 Conclusion

A significant spatial expansion in Shanghai's urban space resulted from urban decentralization and population relocation in the past twenty years. With economic development and population growth, average daily trips witnessed a huge increase, which also increased people's travel rates because of dynamic traveling habits purposes—non-commute travel increased remarkably.

There is an imbalance between resource distribution and population distribution. Large numbers of people live outside of the central city, but jobs are over-concentrated in the city center, which increases the demand for mid- and long-distance travel from the periphery to the central area and creates morning and evening congestion hours on weekdays. However, people's travel periods are more flexible than before, as indicated by the diffusion of peak hours.

Urban expansion around the central district dramatically changed transit share. The share of motorized trips increased rapidly, especially for private cars, which put great pressure on the road system, causing traffic and increasing management costs. Because of the rapid development of the subway system, the subway share increased significantly, especially after 2004.

There have been great improvements in Shanghai's transportation services, with increased average trip length and decreased time spent per trip, especially for subway, bus, and private motorized car trips.

From the statistical analysis of urban expansion and transportation, we found that population and GDP are significantly related to average daily trips, which means increasing population and GDP are factors that increase average daily trips. Urban built-up areas are also significantly related to motorized car share but is not significantly related to subway share. The results reveal that the expansion of urban built-up areas is one reason a larger proportion of people choose motorized cars for travel, but it is not a significant factor in increased subway share. Under this development stage, population density does not show any significant relationship with either car or subway share.

In order to meet travel demand, heavy investments have been made to improve transportation infrastructure and services (Zhao & Zhao, 2013). The bus service developed early but did not expand much in either service or ridership. Under the context of growing travel demand, bus share is dropping. However, the subway system was rapidly developed. The operation lines became longer and more widespread throughout the city. Its convenient and efficient service attracted more and more riders. However, public transportation share is growing relatively slowly compared to the share of private motorized vehicles. This indicates that increasing the supply alone may not be sufficient to increase ridership. Other implementations shall be considered to promote public transit. Also, the number of trips increased faster than the subway grew, revealing an increasing unmatched reliance on the subway system causing crowding phenomena during peak hours.

Although efforts have been made to increase road capacity and enhance the connections between different areas of the city, traffic congestion worsened. Motorization, rather than the natural growth of travel demand, was found to be the major causal factor of the drastic increase in road traffic volume due to the shift from non-motorized to motorized modes of transport and the need for mid- and long-distance trips, especially out of the central city. Consequently, vehicle travel demand is growing much faster than road infrastructure development.

8.2 Recommendation

Demand management is an important strategy Shanghai should adopt when it is too large and crowded to develop. Efforts has been made to accommodate increasing travel demand by investing in developing more transportation systems, but it is far from enough if the population and urban space are to keep growing. More supply induces new demand. Thus, supply-side improvements alone cannot completely solve the transportation problem.

As early as 1992, the Shanghai government stated that automobiles should be controlled in the central area through regulations and price management in the first comprehensive transportation plan, with the license plate auction policy being implemented two years later (Gu & Xue, 2011). However, automobile ownership growth is accelerating since people are willing to pay for motorized vehicles, and once they have a licensed car, they tend to use their vehicles more to compensate. The policy's effects on vehicle ownership control failed to fully translate to traffic volume. Thus, further measures need to be adopted (Zhao & Zhao, 2013).

In addition to motorization control, population and urban expansion must be limited. Shanghai cannot afford unlimited population growth and spatial expansion. In the context of China, the state and the market are the primary driving forces of urban expansion, and supply-driven land development has been a major feature of Chinese cities (Tian & Ma, 2009). Although the control of land has been decentralized to some extent, land leasing in Shanghai is still under the strict control of the municipal government. In this way, the role of government is important in managing urban growth. The government could use strategies from urban growth management plans around the world, including high-density residential uses, mixed-use development, urban growth containment boundaries, etc. (OECD Green Growth Studies, 2012). More importantly, efforts need to be made not only in policy-making but in implementation, as well.

On the other hand, the optimization of the transportation network should be accounted for, which may not simply involve improving road capacity. We should maximize the efficiency of usage by enhancing the real-time information and estimation systems. People could find the best routes and modes for travel to not only save time but make travel more comfortable, as well. A good transportation system must be efficient and integrated to satisfy travel demand.

9 References

1. Atlas of Urban Expansion. (2015). Shanghai, Shanghai. Retrieved from http://www.atlasofurbanexpansion.org/cities/view/Shanghai_Shanghai

2. Bertaud, A., & Richardson, H. W. (2004). Transit and density: Atlanta, the United States and Western Europe. In H. W. Richardson & C. C. Bae (eds.), *Urban sprawl in Western europe and the United States* (pp. 293-310). Ashgate.

3. Cascetta, E. (2009). *Transportation Systems Analysis.* New York: Springer.

4. Chan, K. (2009). The Chinese Hukou system at 50. *Eurasian Geography and Economics*, *50*(2), 157-221.

5. Chen, X., Ye, J., Zhang, H., & Wu, J. (2015). The path to reshape Shanghai transportation system. *Journal of Urban Planning and Development*, *141*, 86-93.

6. Government of China. (2001). *Tenth National Plan.* Beijing.

7. Cox, W. (2011). The evolving urban form: Shanghai. *Newgergraphy*. Retrieved from http://www.newgeography.com/content/002283-the-evolving-urban-form-shanghai

8. Gakenheimer, R. (1999). Urban mobility in the development world. *Transportation Research Part A*, *3*(7-8), 671-689.

9. Gu, Y., & Xue, M. (2011). Thirty years of comprehensive transportation planning in Shanghai. *Urban Transport of China*, *2*, 47-52.

10. Guo, & Sun. (2009). Analysis of effects and the future trends of Shanghai transport supply policy. *Shanghai Urban Planning Review*, (6), 69-72.

11. Han, J., Hayashi, Y., Cao, X., & Imura, H. (2009). Evaluating land-use change in rapidly urbanizing China: case study of Shanghai. *Journal of Urban Planning and Development*, *135*(4), 166-171.

12. Hukou system. (n.d.). In *Wikipedia*. Retrieved from https://en.wikipedia.org/wiki/Hukou_system

13. Information Office of Shanghai Municipality. (2014). Shanghai basic facts*. Shanghai Municipal Statistics Bureau.* Shanghai.

14. Pucher, J. & Korattyswaroopam, N. (2004). The crisis of public transport in India: Overwhelming needs but limited resources. *Journal of Public Transportation , 7*(3), 1-20.

15. Kashem, S. B., Irawan, A., & Wilson, B. (2014). Evaluating the dynamic impacts of urban form on transportation and environmental outcomes in US cities. *International Journal of Environmental Science and Technology*, *11*, 2233-2244.

16. Li, Y., Ye, J., Chen, X., Mohanmed, A. A., & Cen, M. (2010). Transportation characteristics change under rapid urban expansion: A case study of Shanghai. *Chinese Geographical Science*, *20*(6), 554-561.

17. Li, Z., & Wu, F. (2006). Socioeconomic transformations in Shanghai 1990-2000. *Cities*, *23*(4), 250-268.

18. Mao, J., & Yan, X. (2005). Study on mutual mechanism between urban transport system and urban space pattern: A case study of Guangzhou*.* *City Planning Review*, (5).

19. Mathew, T. V., & Sharma, S. (2009). Capacity expansion problem for large urban transportation networks. journal of transportation engineering. *Journal of Transportation Engineering*, *135*(7), 406-415.

20. National Research Council. (2009). *Driving and the built environment:The effects of compact development on motorized travel, energy use, and CO2 emissions -- special report.* The National Academies Press.

21. OECD Green Growth Studies. (2012). *Compact city policies: A comparative assessment.* OECD.

22. Pan, H., Shen, Q., & Zhang, M. (2009). Influence of urban form on travel behaviour in four neighbourhoods of Shanghai. *Urban Studies*, *46*(2), 275-294.

23. Shanghai Government . (2013). *Shanghai Metropolitan Transport White Paper.* Shanghai.

24. Shanghai Government. (2016). *Shanghai Annual Yearbook.* Shanghai.

25. Shanghai Government. (2002). *Shanghai Metropolitan Transport White Paper.* Shanghai.

26. Shanghai Government. (2015). *The fifth comprehensive travel survey.* Shanghai.

27. Shanghai Shentong Metro Group Co., Ltd. (n.d.). *Shanghai Metro*. Retrieved from http://service.shmetro.com/en/

28. Railway Gazette. (2010). *Shanghai now the world's longest metro*. Retrieved from: http://www.railwaygazette.com/news/single-view/view/shanghai-now-the-worlds-longest-metro.html

29. Shanghai population growth. (2014). In *Understanding urban China*. Retrieved from: https://uosm2018.wordpress.com/2014/02/28/shanghais-population-growth/

30. Shen, Q. (1997). Urban transportation planning in Shanghai, China: Problems and planning implications. *International Journal of Urban and Regional Research*, *21*(4) , 589-606.

31. Stead, D., & Marshall, S. (2001). The relationships between urban form and travel patterns: An international review and evaluation. *EJTIR*, *1*(2), 113-141.

32. Tian, L., & Ma, W. (2009). Government intervention in city development of China: A tool of land supply. *Land Use Policy* (26), 599-609.

33. Urban form & transportation. (n.d.). In *CityObservatory.* Retrieved from http://cityobservatory.org/urban-form-and-trans/#0

34. Wu, C., Pei, Y., & Gao, J. (2015). Model for estimation of urban transportation supply-demand ratio. *Mathematical Problems in Engineering*, 1-12.

35. Wu, W., & Gaubatz, P. (2012). *The Chinese city*. Routledge. pp. 152-172.

36. Wu, W. (1999). City profile: Shanghai. *Cities*, *16*(3), 207-216.

37. Wu, W. (2008). Migrant settlement and spatial distribution in metropolitan Shanghai. *The Professional Geographer, 60*, 101-120.

38. Xu, J., Liao, B., & Shen, Q. (2007). Urban spatial restructuring in transitional economy-Changing land use pattern in Shanghai. *Chinese Geographical Science*, *17*, 19-27.

39. Yang, Y., Chen, H., & Chen, L. (2010). Evaluation of public transportation system in Shanghai, China. *2010 International Conference on Computer and Communication Technologies in Agriculture Engineering*, 197-199.

40. Yao, H., & Chen, D. (2015). A system dynamics model for urban sustainable. *2015 23rd International Conference on Geoinformatics*, 1-5. Wuhan.

41. Yue, W., Fan, P., Wei, D., & Qi, J. (2014). Economic development, urban expansion, and sustainable development in Shanghai. *Stochastic Environmental Research and Risk Assessment*, *28*(4), 783-799.

42. Zhao, Z., & Zhao , J. (2013). Has transportation demand of Shanghai, China, passed its peak growth? *Transportation Research Record: Journal of the Transportation Research Board*, *2394*.