sustainability

MDPI

Article

Impact of Megacity Jobs-Housing Spatial Mismatch on Commuting Behaviors: A Case Study on Central Districts of Shanghai, China

Xiang Zhou [1,2,*], Xiaohong Chen [1] and Tianran Zhang [2]

1 The Key Laboratory of Road and Traffic Engineering, Ministry of Education, Tongji University, 4800 Cao'an Road, Shanghai 201804, China; chenxh@tongji.edu.cn
2 Centre of Comprehensive Transportation Research, Shanghai Urban Planning and Design Research Institute, 331 Tongren Road, Shanghai 200040, China; zhantr@supdri.com
* Correspondence: zhouxiang@supdri.com; Tel.: +86-21-6247-3288-2404; Fax: +86-21-6247-7739

Academic Editor: Marc A. Rosen
Received: 7 November 2015; Accepted: 22 January 2016; Published: 28 January 2016

Abstract: This study utilized the mobile signaling data to conduct the impact analysis of jobs-housing spatial mismatch on commuting behavior, with eight typical employment centers of three categories selected as the research subjects. Based on the analysis of the characteristics and indictors including commuting distance, accessibilities from cumulative opportunity model *etc.*, this study demonstrates that (a) cumulative percentage of short commuting distance (e.g., less than 3 km) reflects the jobs-housing spatial match between employment centers and their peripheral areas; and (b) combining the indicators of employed population and area covered within a certain space-time range among indictors of accessibility, it is possible to identify the degree of jobs-housing balance and efficiency of the transport system. According to the evaluation radar maps, the authors believe that employment centers could be divided into three categories: those with a gathering power, those with improvable functions, and those with local adjustment potentials. Possible measures including controlling the gathering power of the city centers, improving the function mix and transport facilities, and optimizing the overall local environment, *etc.* could be made to achieve jobs-housing balance in central districts and their peripheral areas as a whole. Besides, the study, proceeding from the perspective of commuters, suggests that optimization of jobs-housing distribution along banded corridors would be more efficient than those within the traditional region so as to reduce commuting traffic load.

Keywords: jobs-housing balance; spatial mismatch; employment centers; commuting transport; mobile signaling data; accessibility

1. Introduction

To solve the problem of traffic congestion during peak commuting hours caused by the time-spatial shortage of transport resources is the current focus of multidisciplinary research. Rewarding attempts and progress have been made to address the jobs-housing spatial mismatch and easing the commuting traffic load since early days. For example, the concept of "garden cities" developed by Howard, "organic decentralization" brought forth by Saarinen in the 1940s and, in later generations, the planning and development of satellite cities and new cities, *etc.*

In the 1960s, spatial mismatch hypothesis was put forth by Kain (1968) [1] and Mooney (1969) [2] to establish the spatial relationship between jobs and housing in cities. Empirical studies on housing and employment spatial opportunities of the disadvantaged have mushroomed since by Wilson (1987) [3], Taylor *et al.* (1995) [4], Holzer and Ihlanfeldt (1994) [5], and Thompson (1997) [6]. Jobs-housing balance or spatial match can be gauged from two perspectives: balance of quantity and match of quality [7,8]. The latter is also known as the degree of self-containedness and is largely reflected by an "Independence Index" [9], namely the ratio of the population among residents of a specific area who also work locally to those seeking employment outside it. Several derivative indicators have been established, including the jobs-housing Gini-coefficient [10], number of jobs within a radius of 30-min traveling distance (or a certain distance) of a specific area [11], *etc.* Levingston (1989) [12], Deakin *et al.* (1989) [13], discussed the geographical scope for the gauge of the jobs-housing match; Peng (1997) [14] suggested that it would be more relevant to focus on an area or a floating measurement unit covering a radius of a reasonable commuting distance of a residential area or an employment center. Cervero (1989 [8], 1996 [9]) analyzed the housing and employment situation of Chicago and San Francisco suburbs, pointing out that jobs-housing spatial mismatch was not the main contributor to the traffic congestion in cities. Nowlan *et al.* (1991) [15] conducted research into Toronto CBD, Canada; Ewing (1995) [16] made regression analysis on statistics of the State of Florida, U.S; Weitz *et al.* (1997) [17] compared data of two cities in Oregon, U.S and Lobyaem (2006) [18] took Bangkok as an example, all presenting evidence that a higher degree of jobs-housing spatial match helped ease the commuting traffic load. Becky P.Y. Loo (2011) [19] analyzed related data of Hongkong between 1992 and 2002, stating that the government could address issues regarding the commuting traffic and lowering their impact on the environment by implementing the strategy of decentralized employment centers in a synchronous manner. This kind of research works revealed two facts: one is that the issues of jobs-housing imbalance and spatial mismatch are commonly faced by megacities; the other is that the degree of jobs-housing mismatch is positively correlated with the commuting traffic intensity.

At the stage of fast development, large cities and megacities in China witnessed a prevailing suburbanization trend and the phenomenon of jobs-housing separation induced by urban spatial restructuring. Commuting problems that emerged against this background have increasingly riveted the attention of urban and transport studies. In recent years, as urban spatial restructuring spurred on, jobs-housing spatial separation and the increase of commuting distance and time resulted from land and housing reforms as well as the suburban building boom have come under the spotlight of areas such as urban geography, planning science, and sociology, among others. Studies have been conducted around commuting space, distance and time. Analyses were made mainly based on micro-statistics regarding big cities such as Beijing by Li (2007) [20], Wang and Chai (2009) [21], Liu *et al.* (2009) [22], Zhou *et al.* (2014) [23], Guangzhou by Zhou and Yan (2006) [24], Shanghai by Sun *et al.* (2010) [25], and Xi'an by Zhou *et al.* (2014) [26]. In particular, the advantage and positive impact of *Danwei* on jobs-housing balance and urban commuting was mostly discussed by Wang and Chai (2009) [21], Zhang and Chai (2009) [27], and Zhou *et al.* (2014) [26]. They indicted that given the totally different historical development contributed by *Danwei*, recent large-scale urban expansion and free-market approach led to jobs-housing redistribution and resulting commuting distance is becoming longer and longer.

The British newspaper *The Daily Telegraph* published a list of world megacities on 25 January 2011 [28]. On the list were 25 megacities including Shanghai, each with a population of over 10 million. On 21 November 2014, the Chinese government issued the *Notice on Adjusting the Standards for Categorizing City Sizes*, adding the category of "megacities" [29]. According to the notice, the new standards, with permanent residents as the statistical caliber, categorize cities with a population of over 10 million as megacities. By the end of 2014, 6 cities had fallen into this category: Beijing, Shanghai, Tianjin, Chongqing, Guangzhou and Shenzhen. In particular, even the population in Shanghai's central districts had already topped 11 million with a density of 17,000/km^2. In downtown Shanghai (area within the Inner Ring), job densities of several areas where employment concentrates are more than 50,000/km^2 [30]. Shanghai has been pursuing polycentric urban spatial form, but the past decade saw a large-scale expansion of key development areas of Shanghai, a massive "suburbanization" drive that broke though the boundaries of central districts (the Outer Ring) and the commercialization of urban housing. Shanghai has made attempts to disperse the population in central districts and lower population density via policies such as "Double Increase and Double Decrease" (to increase green and open spaces and to decrease building height and site density) so as to improve residential conditions. In the process, the spatial distribution of jobs and housing as well as corresponding commuting characteristics have undergone drastic changes.

The degree of intense and concentrated development of the region comprising Shanghai central districts and peripheral areas has overtaken that of some metropolises such as London, New York, Tokyo, *etc.*; and a complex jobs-housing relationship has already taken shape, giving rise to a more noticeable jobs-housing spatial mismatch. That being the case, on the basis of foregoing researches, the present paper will discuss, in part II, indicators of the influence of jobs-housing balance on the commuting traffic and review literature relevant to the purpose of this research; the next part will be presenting the research philosophy of this paper, explaining the rationale of taking the intensely and concentrated developing region comprising Shanghai central districts and peripheral areas as the research subject and source of data for mobile signaling and transport networks. This part will also discuss typical employment centers with distinct spatial heterogeneity, take the dominant motorized transport mode "rail transport" as the basis for the analysis of transport networks and explain the selection of corresponding commuting distances and accessibility indicators. Then statistics will be studied to show hidden laws and lead to in-depth discussion over possible trends and solutions, including the influence of improved function mix, transport facility supply, population dispersion, and housing policies on jobs-housing spatial distribution and how to make improvements.

2. The Framework of the Influence of Jobs-Housing Spatial Mismatch on Commuting

2.1. Excess Commuting

The concept of excess commuting for a given city or region was firstly introduced by Hamilton in 1982 [31], which is the difference between the theoretical minimum (T_{min}) and the observed commuting distance or time (T_{act}) with the hypothesis of the same preference for house choice. Horner (2002) [32] proposed new index termed commuting potential utilized that considered both the theoretical minimum (T_{min}) and maximum commute (T_{max}). Charron (2007) [33] suggested an alternative commuting upper bound, the random commute. Murphy and Killen (2011) [34] later expanded on the random commuting work to propose the commuting economy index and a revised measure of commuting potential utilized called normalized commuting economy. Murphy (2009) [35] analyzed data on Dublin, Ireland and found that excess commuting traffic was caused more by personal motor vehicles than by the public transport. Therefore, the situation could be greatly improved by further diversifying the land functions, improving the jobs-housing balance and densifying public transport routes and networks. These indices were developed mainly as descriptive tools to compare urban areas in terms of commuting efficiency (Frost *et al.* (1998) [36]; Horner (2002) [32]; Ma and Banister (2006) [37]), give evidence that how urban form and commuting behavior in a city are changing over time or where an urban area stands with respect to other cities.

However, in the Chinese context, few studies have analyzed commuting patterns within the context of the excess commuting framework. Liu *et al.* (2008) [22] examined excess commuting in Guangzhou for 2001 and 2005 and found that it had decreased from 58% to 44% by using a small sample of commuters (n = 1500) and a relatively large unit of analysis (zonal units with an average size of 12.5 square kilometers), with the influence of road network on commuting distance ignored. Their studies analyzed the roles played by socio-economic factors including gender, household registration area, income, *etc.* and by housing characteristics in excessive commuting. But a limitation of the research consists in the fact that it did not consider the influence of the geographic features and corresponding urban spatial patterns. Yang and Wang (2013) [38] calculated excess commuting for the city of Mianyang, China. They assumed that the number of workers/jobs in each TAZ could grow by up to 30%. The purpose here was to find the number of extra workers and jobs by TAZ where the resultant T_{min} is optimized. Using this model, they found that T_{min} tends to follow a "U" shape as the total number of workers/jobs increases. The best situation of jobs-housing balance can be obtained when 77,500 jobs, that is 14% of total jobs, are increased and assigned to different TAZ. The limitation is that the constraint conditions were too much simplified and the realistic preferences were ignored. Zhou *et al.* (2014) [23] investigated the traveling efficiency of commuters in Beijing, China by combined using of smartcard data and household travel survey data. They find that the theoretical minimum commute is considerably lower for bus users than for car users in Beijing which suggests that there is a greater inter-mixing of jobs-housing functions associated with users of that mode compared to the corresponding land-use arrangement for car users, who locate further from the central area (Tian'anmen) than bus users. Their findings are different with those by Murphy and Killen (2011), and Zhou *et al.* (2014) explained that this is due to the differences in the overall spatial organization of the city and mode of public transport. Although they visualized the actual and minimum commuting patterns, the indices of excess commuting is faint to evaluate the land-use performance for a certain scope with urban spatial arrangement of the city-region.

Indicators of excess commuting touched upon by the above research are more suitable for the measurement of a city or a specific macro area. Studies carried out by Zhou *et al.* (2014) [23], though mapped out and visualized the maximum and minimum commuting traffic of Beijing, still stayed at a macro level. According to basic features of urban spatial distribution, in large cities and megacities, although key construction lands usually cover a large area, employment almost only concentrates in limited areas or several geographical points. Such areas have distinctively higher job densities and the number of jobs is usually much higher above the average. Additionally, it is quite possible that these jobs have commonalities or distinguishable characteristics that belong to different job categories. However, this is not the case with areas that do not see concentration of jobs. If the residential location is taken as a perspective to analyze job accessibility, it is quite hard to touch upon all the possible features of different types of housing areas in different districts and therefore, hard to identify problems concerning the distribution of houses in the city. Different from previous studies, the present article will, from the perspective of employment concentration areas, make an analysis of the overall employment spatial distribution. Different types of employment centers will be identified through macro analysis and spatial cluster analysis. Moreover, the impact of the jobs-housing spatial mismatch in Shanghai on commuting will be found out according to indicators. Liu *et al.* (2009) [22] conducted researches into issues related to the commuting distance on small samples of several employment centers in Beijing. Compared with them, the present study has advantages in the following three aspects: first, the researcher utilized the big data on mobile signaling; the sample rate was much higher than the Person Trip Survey (normally 1% for big cities) and in the future, the data could be updated dynamically to enable a comparative study of researches on cities at different developing stages in corresponding periods; second, the mobile signaling data were distributed to TAZs (each covers an area of approximately from 0.5 to 1 km^2) in Shanghai; and analog calculation was employed to accurately present the actual commuting distance using the real-life road, rail, and transport network models; third, the researcher used the actual commuting distance T_{act} to reflect a city's spatial size and residents' scale of activities in a more objective manner; besides the average commuting distance, cumulative percentage of different commuting distances was used to better measure the degree of jobs-housing spatial match of various employment centers. Some researchers, however, such as Gordon *et al.* (1998) [39], DeRango (2001) [40] pointed out that commuting distance, time or characteristics could not serve as direct measures for jobs-housing spatial mismatch because the factor that people may choose to live far away from their jobs due to better housing conditions or simply out of personal preference could not be excluded, by Houston (2005) [41]. On such a basis, the present study also probed into the impacts made by jobs-housing balance or spatial mismatch on commuting features using the Cumulative-Opportunities-Accessibility-Tool and from the perspectives of the employment centers' natures, employment size, jobs density, and the jobs-housing spatial relations between it and its peripheral areas.

2.2. Accessibility

Accessibility is a term used in many fields. Essentially, it refers to people's occupation of transport resources and utilization of space and interaction opportunities. It involves land utilization, transport system, time, and individual factors, *etc.* Currently the generally accepted definition is that accessibility refers to "the ease with which any land-use activity can be reached from a location using a particular transport system" by Geurs and Wee (2004) [42]. It can be divided, according to the type of research subjects, into individual accessibility and spatial (venue) accessibility.

From the analysis viewpoint of household, Immergluck (1998) [43] suggested that job accessibility be used to measure the match, in different geographic units of a city, between the potential employment population and potential job opportunities so as to reflect the spatial structure of the city. The higher the index is, the better the match is between the two, and vice versa. Job accessibility is not simply reflected by the ratio of the number of jobs to the employed population within a specific community, but should be defined considering the competition for jobs from residents of nearby communities and the possibility that some within the community in question might seek employment in other communities. The measurement of job accessibility mainly relies on summarized data. But if the sources of data vary much, extensive work is needed to organize them. However, such an index has its limits. The estimate of job accessibility within a community should be the weighted sum of the number of jobs in the area weighted by distance. It is hard to draw the distance decay parameter out of empirical statistics. Instead, it is just an estimate. Additionally, to reflect the dynamics of urban spatial restructuring, it is more appropriate that the spatial mismatch be reflected by the discrepancy between job vacancies and the unemployed population or by the spatial mismatch between the distribution of new jobs and centers of population growth. Moreover, research on job accessibility and its influence have a higher demand on data. Unsummarized micro data are needed, with individual employment and salary data as the dependent variables and individual attributes as the controlling variables. These variables can be used to categorize communities.

This research proceeds from the employment centers, gauging the jobs-housing spatial mismatch by actual commuting distances and accessibility indicators and evaluating the balance between the employment quality and housing quality. Taking into account variables such as geographical position, job market size, and intensity, *etc.*, the paper discusses the impact on the commuting traffic of employment centers exerted by the accessibility of public transport in cities where public transport dominates the ways people travel. The subject area of analysis is set within an area accessible by public transport. An accessibility model based on the cumulative opportunity is used to reflect the employed population covered by a certain job concentration area and the distribution of commuters in different time intervals and with such information, the research could identify jobs-housing spatial mismatch in this area and ways to make improvements. In so doing, not only the spatial distribution and commuting patterns would be adjusted from the perspective of public facilities distribution, but also, flaws of the transport system would be reflected. Specifically, the increase of the commuting distance may reflect the jobs-housing spatial mismatch at a macro level. But such an increase could also be the result of enhanced mobility and efficiency of the transport system. Then to see whether the commuting time increases along with the distance or to measure to what extent the commuting distance influences the commuting time, analysis needs to be made on the cumulative ration of the former to the latter.

It is also worth mentioning that on the basis of the conclusion of previous research—better mix of land functions and improved jobs-housing balance have a greater impact on the choice of where to live made by public transport users and may lower their stress inflicted by excess commuting—the present study selected the backbone of the public transport system of Shanghai's central districts—the rail network as the foundation for the accessibility analysis.

2.3. Analysis of Shanghai's Jobs-Housing Spatial Mismatch

According to Figure 1 and Table 1, Shanghai has been on a path of rapid development in the past decade with distinct features of urban spatial restructuring. For one thing, housing lands and residents increased by large margins along the original boundaries of the city; for another, areas with high employment densities were mostly located within the construction land designated in 1997. In other words, employment still largely concentrated in central districts and took on a general trend of "indiscriminate expansion", stretching northward and southward along the Huangpu River. Comparison between the construction land in 1997 and 2011 and changes of permanent urban residents between the fifth (2000) and sixth national census (2010) show that although the construction land in central Shanghai hardly changed, the population density dropped steeply. Specifically, lands for traditional Li-Long residences in central districts evolved into commercial lands as the city developed. Namely, central Shanghai saw a decrease of housing lands and an increase of lands for infrastructure, while its peripheral areas and suburbs witnessed a considerable rise of housing lands and density of permanent residents.

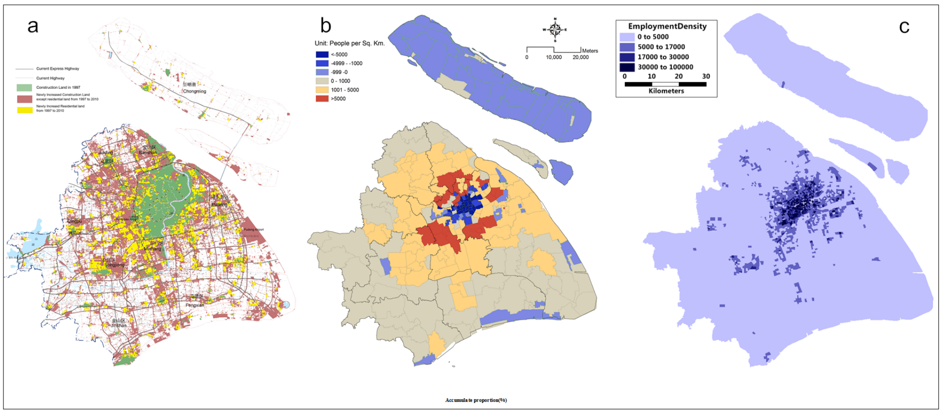

Figure 1. (**a**) growth of construction land between 1997 and 2010; (**b**) density of permanent residents between the fifth and sixth census; (**c**) employment density distribution in the second economic census.

Table 1. Construction lands in 1997 and 2010.

Category	1997 (km^2)	2010 (km^2)
Housing land	250.6	465.6
Land for public facilities	98.5	200.3
Land for industrial warehouse	398.0	699.1
Land for infrastructure	192.9	662.1
Green space	18.1	152.9
Others	114.9	246.3
Total	1073.0	2426.3

Under such circumstances, the urban spatial restructuring in Shanghai leads to the fact that a great number of residents living outside the central districts have to make long-distance commutes to work. Growing commuting distance gave rise to greater jobs-housing spatial mismatch. Statistics show that in 2014, the average daily travelling distance in Shanghai was 6.9 km, while the actual average commuting distance registered 8.2 km, and the figure for downtown Shanghai (area within the Inner Ring) hit 8.6 km. Another fact resulted from the urban spatial restructuring in Shanghai is that the urban public transport system, on which commuters largely rely, develops in a seriously uneven manner, causing traffic congestion on parts of the road network and especially on the metro system which has become the most important mode for commuters in central districts. Zhou and Chen (2015) [44] found that with the outward spread of the population of central Shanghai and the huge inflow of permanent migrants into its peripheral areas, morning peak hour congestion is seen in both the metro network and transport artery roads and has crept outwards, at some point even to the Middle Ring. Zhang (2015) [45] combining the matrices of commuting between home and workplace deduced from mobile signaling data, illustrated the demand for transport capacity through a spider diagram and defined the ratio of the large traffic cross section value to the small traffic cross section value as the commuting transport capacity imbalance coefficient, see Figure 2. The study showed that the demand for commuting transport capacity was highly concentrated in central districts and the highest imbalance coefficient was found between the transport capacities of central districts and of the area to the north of it. The coefficient for the area to the northwest of central districts was 4.0 and to the northeast, 2.2.

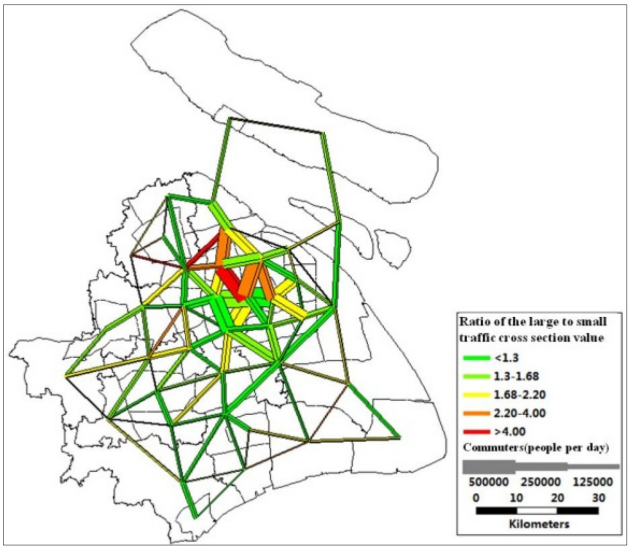

Figure 2. Commuting demand & imbalance coefficient distribution.

3. Analytical Methods

3.1. Source of Data

The study used mobile signaling data, instead of data from traditional studies on residents' travelling or area-specific surveys, to conduct analysis on commuting transport and related jobs-housing spatial distribution. The data, collected from a mobile telecommunication service provider, include the mobile signaling data of 18.6 million users between January and June, 2013, 1.5 billion items per day on average [18]. Mobile signaling provides uninterrupted service to cell phone users according to the type of mobile communication network. Users' mobile terminals would contact the network on a regular or irregular basis, either passively or actively, and the network will recognize such contacts as control instructions. Mobile signaling mainly includes anonymous user ID, time, base station cell identification number, and type of event (e.g., active scanning, incoming/outgoing calls, internet browsing, text messaging, *etc.*) Activities of individual mobile phones were identified through activity analysis model and mode identification methods according to the geographic and spatial information of the city in specific time sequences. Additionally, permanent and mobile population, along with their places of residence and work, were pinned down in accordance with activity patterns. As a result, 12.7 million permanent residents and 6.32 million jobs were identified out of a permanent population of 24.15 million in 2013, indicating a sampling rate of approximately 53%. Mobile phone users' places of residence and work were identified according to their spatial locations during the day and night as well as the active level of their mobile signaling. Specifically, within half a year, people who spent more than 60% of the total days in Shanghai were defined as permanent residents. Then mass mobile data between 20:00 and 08:00 the next day were used to spot areas where the mobile signaling appeared the most and stayed for over 60% of the time period. Such areas were defined as the users' places of residence. The permanent residents were thus calculated as 12.7 million (with the total permanent residents of Shanghai being 24.15 million, the sampling rate is approximately 53%). Similarly, mass mobile data between 09:00 and 18:00 each day were utilized and mobile users whose places of residence during day and night were less than 400 m (the minimum commuting distance designated by Person Trip Survey of Shanghai) apart were excluded, the rest of the users were approximated as the job sample. The number of jobs was thus calculated as around 6.32 million. The sample, after being expanded, was taken as the source of data for the analysis of jobs-housing spatial distribution and residents' commuting behaviors in Shanghai. Residents such as taxi drivers and deliverymen whose work does not involve a regular place, were excluded from the sample due to irregularities of their commuting behaviors. Although some residents may use dual-SIM phones or have more than one mobile phone, they generally do not affect the analysis, large in both scale and scope, of commuting behaviors.

The advantage of mobile signaling data lies in their high spatial analyzability. Specifically, the spatial locations are first pinned down against the base station zones and then allocated accordingly to TAZs. The provider of mobile signals involved in the present research has 42,000 base stations in Shanghai, far exceeding the total number of TAZs (4518). Central districts have 20,000 base stations and 1569 TAZs. Admittedly, the design has limitations. Means of transport cannot be differentiated and currently, it is only possible to roughly present the subway transport data according to data from the base stations in the metro system. Although this study focuses on the rail network, the commuters are not limited to this specific way of transport.

3.2. Geographical Scope of the Study

There are two options to choose from as the geographic scope of the study. One is the entire city of Shanghai including all its administrative divisions which is approximately 6340 km^2; the other is the commuting area that consists of the central districts and their peripheral areas which is approximately 1250 km^2. The advantage of the former is that characteristics of employment centers in central districts and suburbs could be easily differentiated, while advantage of the latter is that the complexity of jobs-housing spatial distribution within the scope may facilitate a more profound analysis of a complex problem within a complex system. Meanwhile, initial data analysis report shows that more than 90% of jobs in central districts are taken by permanent residents in those districts or peripheral areas, see Figure 3. External commuters are distributed in a dispersive and corridor-shaped manner. That being the case, the latter was adopted by the present study.

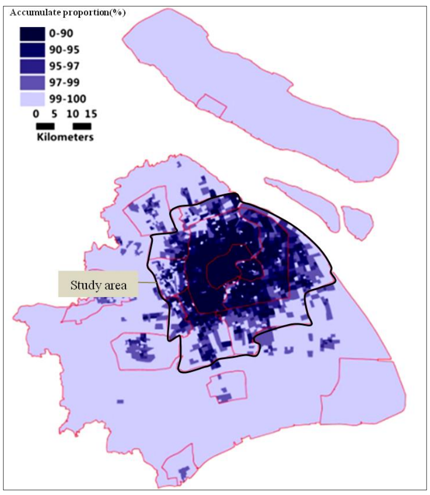

Figure 3. Cumulative jobs-housing distribution in central districts.

3.3. Identification and Selection of Employment Centers

The Hot Spot Analysis tool in ArcGIS was used to identify the employment centers in Shanghai's central districts. Local spatial cluster analysis was conducted on the job densities of different Traffic Analysis Zones (TAZs) to identify hotspot areas with high job densities. Moreover, the GiZScore value was applied to indicate the statistical significance of spatial autocorrelation. In the figure drawn according to the z values, positive values indicate high-high clustering while negative values, low-low clustering. According to the standard deviation of the standard normal distribution of Z values drawn out of the Hot Spot Analysis of 2543 TAZs (Figure 4b), areas with a Z value larger than 4.03 were categorized as significant hot spots, while with a Z value smaller than −1.28, significant cold spots. On the basis of the Hot Spot Analysis of current jobs and taking into account the distribution plan of municipal public centers (Figure 4a), researchers of the study selected Lujiazui (LJZ), People Square (RMGC), West Nanjing Road (NJXL), and Middle Huaihai Road (HHZL) as representatives of municipal centers; Xujiahui (XJH) and Wujiaochang (WJC) as representatives of municipal sub-centers; and Caohejing (CHJ) and Zhangjiang (ZJ) as representatives of hi-tech parks. In so doing, the scope within which the analysis of employment centers would be conducted was pinned down, see typical parameters in Table 2.

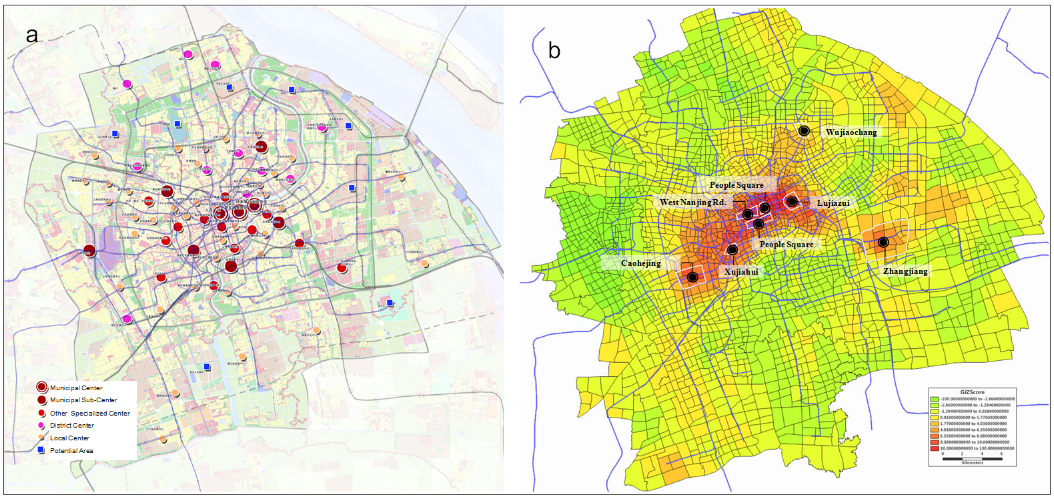

Figure 4. (**a**) distribution plan of public centers; (**b**) Z values of current job density hotspots.

Table 2. Typical parameters of employment centers.

Employment Center	Municipal Center				Municipal Sub-Center		Hi-Tech Park	
	LJZ	HHZL	NJXL	RMGC	WJC	XJH	CHJ	ZJ
Area (km^2)	1.7	2.3	1.9	1	1.8	1.3	5	15.6
Number of Jobs	157,033	117,707	148,122	70,452	47,813	82,488	150,374	218,955
Number of Internal Jobs	2048	5619	4617	1955	3724	2385	7846	34,168
Job Density (10,000/km^2)	9.2	5.1	7.8	7	2.7	6.3	3	1.4
Permanent Residents	15,173	59,926	46,503	27,621	43,999	31,819	53,312	122,729
Jobs-Housing Ratio	10.3	2.0	3.2	2.6	1.1	2.6	2.8	1.8

Among the four municipal centers, the job density and jobs-housing ratio (the ratio of the number of jobs to that of permanent residents) of LJZ were the highest, registering 92,000/km^2 and 10.3 respectively; while those of other municipal centers were similar. Among the municipal sub-centers, the job density and jobs-housing ratio of XJH were quite close to those of municipal centers; while WJC lagged behind by a large margin and demonstrated a mixed function due to the its relatively short history of development. CHJ and ZJ hi-tech parks, located outside central districts, had job densities significantly lower than those of other centers due to their large sizes.

4. Results and Analysis

4.1. Commuting Distance

Origin-Destination (OD) analysis was conducted on the spatial information of the user's place of residence and work yielded by mobile signaling data analysis to calculate the minimum length of path in a transport system, and this length was defined as the "commuting distance". One disadvantage of the mobile signaling data, compared with data from traditional studies on residents' travelling, is that only the data concerning users of the metro system could be identified, but not those of other means of transport. Suppose that Z is a collection of all the TAZs, then the average commuting distance for residents or jobs in area I, which includes several TAZs, could be calculated using the following formula:

$$D_w = \frac{\sum_{j \in I, j \in Z} c_{ij} d_{ij}}{\sum_{j \in I, j \in Z} c_{ij}} \tag{1}$$

where D_w represents the commuting distance (km), c_{ij} represents the number of people living in TAZ i but working in TAZ j, and d_{ij} represents the minimum length of path in the transport network linking TAZ i and j.

With this method, researchers drew the average commuting distance of each employment center and the cumulative statistics of jobs with different commuting distances, see Table 3, Figure 5.

Table 3. The average commuting distance of employment centers and cumulative percentage of commuters by public transport.

Commuting Distance (km)	Municipal Centers				Municipal Sub-Centers		Hi-Tech Parks	
	LJZ	HHZL	NJXL	RMGC	WJC	XJH	CHJ	ZJ
3	11%	28%	19%	17%	33%	20%	19%	16%
4	16%	32%	24%	22%	44%	25%	26%	22%
5	21%	36%	30%	28%	53%	30%	32%	30%
8	42%	54%	46%	44%	69%	45%	48%	47%
10	57%	65%	58%	56%	75%	56%	56%	56%
14	77%	82%	77%	78%	85%	75%	69%	70%
15	80%	86%	81%	82%	87%	78%	72%	72%
16	83%	88%	84%	85%	88%	81%	74%	74%
17	85%	90%	87%	87%	90%	83%	76%	76%
18	88%	92%	89%	89%	91%	85%	78%	77%
22	93%	96%	94%	94%	94%	92%	86%	84%
23	94%	96%	95%	95%	95%	93%	88%	85%
25	96%	97%	96%	97%	96%	95%	90%	89%
40	99%	100%	99%	99%	99%	100%	99%	99%
41	99%	100%	100%	99%	99%	100%	99%	99%
43	100%	100%	100%	100%	100%	100%	100%	99%
49	100%	100%	100%	100%	100%	100%	100%	100%
Average Commuting Dist. (km)	10.4	9.4	9.8	9.9	7.4	10.2	11.3	11.7

The average commuting distances for ZH and CHJ were the longest, registering 11.7 and 11.4 km respectively. However, WJC, which is also located in the peripheral area of central districts, had the shortest average commuting distance. Sub-center XJH was found to be similar with the four municipal centers in this regard, and RMGC, NJXL, and HHZL, as the very center of Shanghai with the best developed transport systems, had relatively short average commuting distances.

Higher cumulative percentage of short commuting distance (e.g., less than 3 km) indicates higher degree of jobs-housing spatial match between employment centers and peripheral areas. Among the eight employment centers, five were found to have 30% of their commuters living within a 5 km radius. They are NJXL, RMGC, XJH, CHJ, and ZJ. HHZL had 30% of its commuters living within a 3–4 km radius. WJC and LJZ saw a relatively different distribution of the cumulative percentage of commuters indicated by public transport. For the former, 30% of its commuters lived within a less-than-3 km radius; while for the latter, 6–7 km radius. Generally, the commuting distance of 85% of commuters increased by tiers. For the first tier which included HHZL, RMGC, and NJXL, the commuting distance was 15–16 km; for the second tier which included LJZ and XJH, 17–18 km; and for the third tier which included CHJ and ZJ, 22–23 km. The case with the sub-center WJC remained different. Although its location was similar to that of CHJ and ZJ, the average commuting distance for 85% of its commuters was only 14 km. This might be attributed to two reasons: one is that it had a relatively good jobs-housing spatial match within the accessibility of its public transport system. Namely, the types of job were consistent with the structure of the employable population. The other reason is that its commuting transport system was not developed enough to reach a big area.

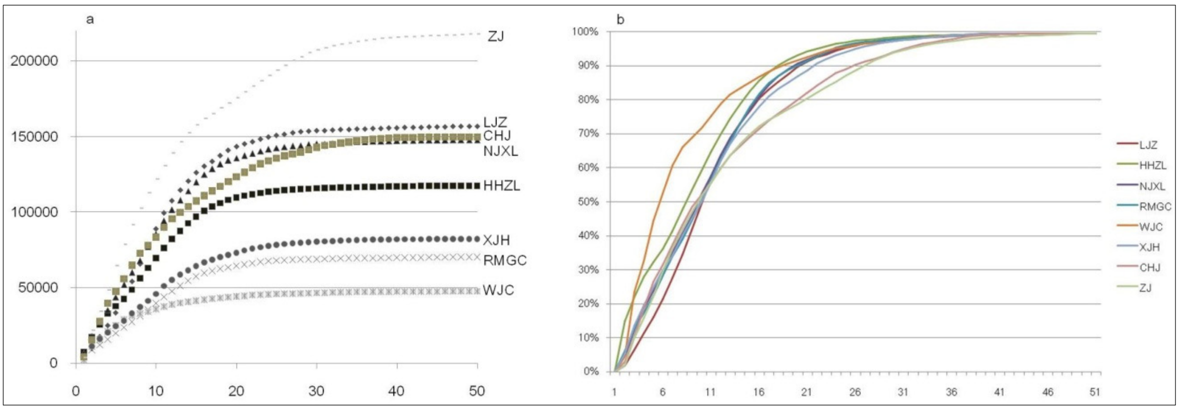

Figure 5. (**a**) distribution of cumulative commuters; (**b**) distribution of cumulative ratio of commuters for employment centers in accordance with commuting distances.

4.2. Accessibility

The present study used the cumulative opportunity model to calculate the number of employees that could reach an employment center in a specific time, and this number represented the accessibility of the center.

$$A_i = \sum_j O_{j\tau} \tag{2}$$

where t refers to the threshold time (min); $O_{j\tau}$ represents the opportunity of TAZ j. j refers to the TAZ with a commuting time to TAZ i that is less than t.

The threshold value t is normally determined in accordance with the size of the city or the experience value. The present study, taking into account the result of transport surveys, drew statistics of several time slots with a 15-min interval. Six time slots including minute 0–15, 15–30, 30–45, 45–60, 60–75, and 75–90 saw cumulative percentage of commuters of more than 95%. Another key parameter was people's travel time utilizing the public transport system. The data included both onboard and off-board time. The former was drawn out of a public transport passenger distribution model, including the pull-in time and running time of the vehicle. The speed of different metro and bus lines were set according to reality. The off-board time included the time for passengers to get on and off the vehicle and time they spent walking and waiting during transfers. The walking speed was set to be 4 km/h. Tables 4–11 shows particular indicators of employment center accessibility.

Table 4. Indicators of LJZ employment center accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	6.8	75,336	11,085	12,032	8	16
30	50.7	778,113	15,362	29724	27	4
45	151.4	2,269,195	14,984	53,707	61	2
60	263.7	2,200,395	8343	34,672	83	2
75	346.7	1,839,197	5305	17,043	94	1
90	484.9	1,197,642	2470	5776	97	0
Total	1304.2	8,359,879	-	157,033	-	-

Table 5. Indicators of HHZL employment center accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	14.2	252,248	17,813	22,156	19	9
30	74.4	1,291,626	17,355	28,589	43	2
45	188.6	2,451,507	12,996	33,744	72	1
60	271.0	2,138,823	7893	20,957	90	1
75	401.8	1,407,286	3502	7234	96	1
90	621.7	1,296,975	2086	3077	98	0
Total	1571.8	8,838,464	-	117,707	-	-

Table 6. Indicators of NJXL employment center accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	14.0	244,471	17,492	24,040	16	10
30	76.0	1,405,245	18,487	38,865	42	3
45	177.0	2,070,720	11,696	36,963	67	2
60	272.4	223,2071	8193	29,372	87	1
75	397.6	1,550,188	3899	11,702	95	1
90	625.0	1,465,813	2345	4492	98	0
Total	1562.1	8,968,509	-	148,122	-	-

Table 7. Indicators of RMGC employment center accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	13.6	236,154	17,338	11,096	16	5
30	82.0	1,488,967	18,157	18,403	42	1
45	188.2	2,392,359	12,711	20,869	71	1
60	294.4	2,188,022	7432	12,991	90	1
75	412.6	1,436,236	3481	4260	96	0
90	731.3	1320,866	1806	1688	98	0
Total	1722.1	9,062,604	-	70,452	-	-

Table 8. Indicators of WJC employment sub-center accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	10.7	128,047	12,012	12,431	26	10
30	43.1	727,434	16,862	15,069	58	2
45	90.1	1,132,731	12,578	7749	74	1
60	162.5	1,983,802	12,205	5954	86	0
75	253.8	1,816,580	7158	3466	93	0
90	341.0	1,586,868	4654	1913	97	0
Total	901.2	7,375,462	-	47,813	-	-

Table 9. Indicators of XJH employment sub-center accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	11.7	198,455	16,986	13,414	16	7
30	66.2	1,062,090	16,047	18,298	38	2
45	180.1	2,172,768	12,061	23,483	67	1
60	268.8	2,337,475	8697	15,765	86	1
75	417.3	1,708,874	4095	7165	95	0
90	552.6	1,293,784	2341	2618	98	0
Total	1496.7	8,773,447	-	82,488	-	-

Table 10. Indicators of CHJ Hi-tech park accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	22.5	253,221	11,261	35,105	23	14
30	68.4	812,203	11,871	30,673	44	4
45	134.5	1,403,952	10,439	27,527	62	2
60	278.1	2,145,147	7713	24,869	79	1
75	379.9	2,211,002	5820	17,521	90	1
90	567.7	1,777,940	3132	9116	96	1
Total	1451.2	8,603,466	-	150,374	-	-

Table 11. Indicators of ZJ Hi-tech park accessibility calculated by public transport.

Time Interval (min)	Area (km^2)	Employment Population	Density of Employment Population (per km^2)	Commuting Population	Cumulative Percentage (%)	Percentage of Commuters in Employment Population (%)
15	35.5	173,716	4898	64,096	29	37
30	81.9	503,157	6143	45,998	50	9
45	158.3	1,403,160	8864	35,289	66	3
60	254.3	2,093,845	8233	28,927	80	1
75	360.3	1,942,320	5391	20,295	89	1
90	422.0	1,695,829	4019	14,485	95	1
Total	1312.2	7,812,025	-	218,955	-	-

According to the indicator of covered area (spatial area covered by public transport within a specific time period with the employment center as the starting point) in tables above, three municipal centers including HHZL, NJXL, and RMGC and the municipal sub-center of XJH were close to each other in terms of the level of accessibility; LJZ showed a lower accessibility indicated by the people who commute by public transport, especially within 30 min; CHJ and ZJ Hi-tech park were found to have slightly lower accessibility than most municipal centers; and the WJC sub-center had the lowest level of accessibility. This indicator illustrated the accessibility of the public transport system and the pedestrian network and their influence on surrounding areas.

According to the indicators of employment population and its density (which is dividing employment population by the covered area), a strong positive correlation was found between the employment population and the area, while the density of employment population decreased as the radius of the covered area increased. For most employment centers, the density of areas that required a commuting time of more than 45 min would drop to less than 10,000/km^2 area is consistent with the current spatial distribution features of Shanghai's permanent residents. ZJ hi-tech park, located in the peripheral area of the Pudong New District, showed a considerably lower employment population density in its non-central areas.

Combining the indicators of employed population and area covered and analyzing the data within 15 min, it would be possible to evaluate the development stage of areas where employment centers are located from the perspectives of low-carbon urban development and jobs-housing balance, thus identifying the degree of jobs-housing match. In another word, only under the conditions that there is a relatively good jobs-housing match between the employment center and its peripheral areas can the situation of excess commuting be improved and distribution features of the commuting traffic be adjusted by altering external circumstances.

According to the indicators of cumulative commuter percentage and the proportion of commuters in the employment population, higher cumulative percentage of short commuting time (gauged against the current average commuting time of Shanghai—42.7 min. e.g., less than 45 min) indicates a better self-adjusting ability of the employment center to achieve self-contained jobs-housing balance with nearby areas and a better quality of such a balance. Over 80% of commuters live in the area which required a 60-min travel time or less to the employment center (the percentage of CHJ was a slightly lower 79%), that percentage even reached 90% as for HHZL and RMGC. According to the indicators under the 15-min interval, the cumulative percentage and the percentage of commuters in the employment population of LJZ were both quite low, which corresponded to the feature of land use of LJZ and its peripheral areas: high overall development with a major focus on business use; HHZL, RMGC, NJZL, and XJH were similar to each other in this regard. They all showed a relatively low percentage of short-distance commuting with a cumulative percentage of 16%–19% and a percentage of commuters in the employment population of less than 10%. Besides, the cumulative percentages of these four centers under the 30-min interval were also close to each other; CHJ, WJC, and ZJ were found to have similar cumulative percentages, all over 20%. In particular, ZJ showed a cumulative percentage of nearly 30% and a percentage of commuters in the employment population of 37%. If the cumulative percentage is low, decisions need to be made as to whether to reorganize the residential land in the area accessible within a specific time period or to enhance the connection between the employment center and public transport in the residential communities. Further relating the cumulative percentage of commuters to the employed population covered and its density would facilitate the decision-making process.

5. Discussions

5.1. Overall Evaluation of Employment Centers

Based on the basic information and statistics of commuting distance and accessibilities of the eight employment centers and taking into account the initial analysis, the study evaluated the centers in different aspects including the development level, function mix, transport support, local environment, service capability, *etc*. Through horizontal comparison, the study categorized employment centers, identified their advantages and disadvantages and tried to figure out the possibilities for improvement. As for some cumulative parameters, 45 min was chosen as the time interval based on the fact that the average travel time of central districts was 42.7 min in 2014, see Table 12.

Table 12. Evaluation indicators for employment centers.

Evaluation Dimension	Indicator	Municipal Center				Municipal Sub-Center		Hi-Tech Park	
		LJZ	HHZL	NJXL	RMGC	WJC	XJH	CHJ	ZJ
Level of Development	Job Density (10,000/km^2)	9.2	5.1	7.8	7	2.7	6.3	3	1.4
Function Mix	Jobs-Housing Ratio	10.3	2.0	3.2	2.6	1.1	2.6	2.8	1.8
Transport Support	Area Reachable within 45 min (km^2)	208.9	277.2	267.0	283.8	143.9	258.0	225.4	275.7
	Cumulative Commuter Percentage within 45 min (%)	61	72	67	71	74	67	62	66
Local Environment	Employment Population Density in Area Reachable within 45 min (10,000/km^2)	1.5	1.4	1.4	1.5	1.4	1.3	1.1	0.8
Service Capability	Cumulative Number of Commuters within 45 min (10,000)	9.5	8.4	10.0	5.0	3.5	5.5	9.3	14.5
	Percentage of Cumulative Commuters within 45 min in Employment Population (%)	22	12	14	7	12	10	20	49

First, the evaluation criteria needed to be pinned down. For example, the more an area is developed, the higher the land use efficiency is; the closer the jobs-housing ratio is to 1, the greater the function mix is; the more the area reachable within 45 min and higher the cumulative percentage of commuters is, the better the transport support is; the higher the employment population density is in the peripheral areas, the better the environment is; the more the cumulative number of commuters is within a 45-min interval, the higher the percentage of commuters in the employment population and the greater the service capability toward specific areas in the city is. Then the highest or lowest value for each indicator was selected as the benchmark (5 points) to calculate the difference between the indicator value and corresponding benchmark. The final score of the indicator was then drawn according to the percentage that the difference value accounted for. Based on the results, a five-dimensional and seven-indicator radar diagram of each employment center was drawn, see Figure 6.

According to macro analysis and overall evaluation if the radar maps, the eight employment centers selected by the study could be divided into the following categories:

The first is the employment center with a gathering power, including three municipal centers—HHZL, NJXL, RMGC—and one sub-center, that is XJH. They were similar with regard to quite a few indicators, implying their superiority in terms of location, function, transport, *etc.* in the urban spatial structure. Meanwhile, they are the most traditional city centers of Shanghai. As regards the influence on peripheral areas, individual employment centers did not demonstrate a high indicator value concerning the employment population gathering effect. The main reason could be that the population of the inner city kept spreading outward and its function turned more into business. Under such circumstances, the inner city as a whole became an area of core functions with the greatest gathering power, but individually, indicators of them did not appear to be significant. Therefore, central districts, namely the inner city, need to disperse both the population and public service. Otherwise, the spatial mismatch of central districts of Shanghai would be intensified and it would be harder for peripheral areas to become influential employment centers.

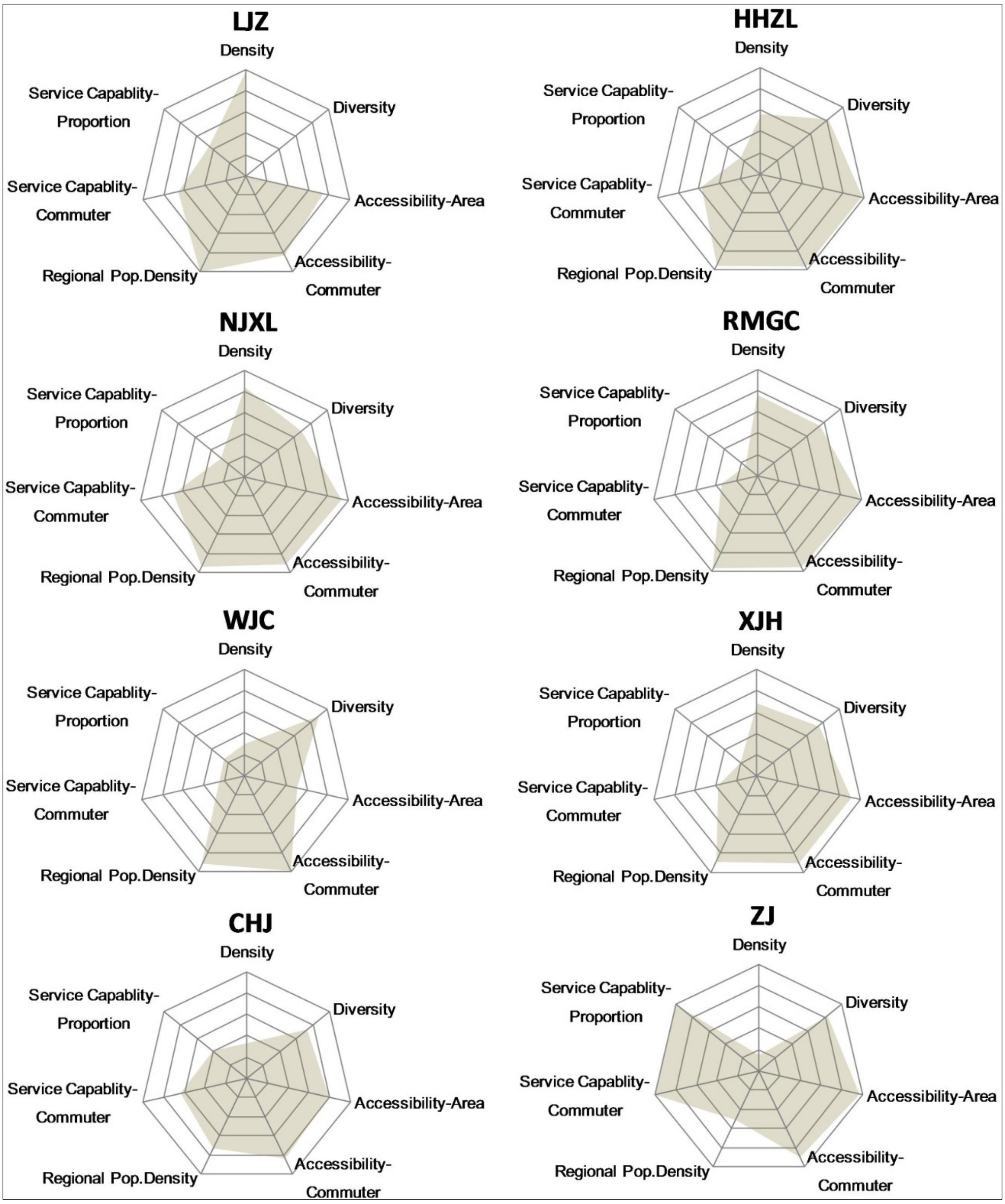

Figure 6. Multi-dimensional evaluation radar maps of employment centers.

The second is the employment center with improvable functions, including the CHJ hi-tech park and WJC sub-center. The former demonstrated quite balanced indicator values but would score a better development only after the improvement of functions and supporting facilities; while the latter showed distinct advantages and shortcomings which were somewhat related to temporal and spatial factors. For example, due to a relatively short development history, centers in this category lay focus mainly on a mix of functions which are not well developed and therefore have a limited service capability. Additionally, due to geographical disadvantages, their current supporting facilities such as the metro system are relatively weak. These centers, through improvement of functions, would make positive contributions to the jobs-housing spatial adjustment of their peripheral areas.

The third is the employment center with local adjustment potentials, including LJZ municipal center and the ZJ hi-tech park. As an area developed at a later stage of urban development of Shanghai, LJZ grows along with the Pudong district and now has the highest job density among central districts. Its function has been monotonous since the very beginning and that remains one of its limits though attention has been paid to the function mix. Meanwhile, since it is located in the coastal area, the transport facilities were relatively weak. To solve the problem, efforts need to be made to enhance the transport system, promote the development of mutually complementary functions within a certain accessibility scope (e.g., 30 min) and improve the local jobs-housing spatial match. ZJ has a distinctly positive impact on peripheral areas. However, it remains a relatively sparsely populated area with low development density. The increase of jobs and expansion of employment scope would inevitably lead to longer commuting distance and higher investment in transport resources.

5.2. Improvements in Favor of the Commuters

According to the distribution of commuters within the employment centers and its superposition with the public transport network isochronous data, commuters prefer a geographical proximity between their houses and workplaces (see Figure 7). Specifically, the indicators showed that with proper transport support, commonalities could be found among the cumulative percentages of commuters who travel short distance, for instance the above-mentioned finding that the percentage of commuters living with a 3–4 km radius accounted for about 30%. However for megacities, this is of low probability. Due to the high housing costs, most commuters have to buy houses in the peripheral areas of central districts or suburbs at the expense of short commuting time. This is proved by another finding mentioned earlier that 85% of the commuters lived within a 15 or 22 km radius and their average commuting time registered about 60 min.

Under such circumstances, for a large city or megacity, the most effective way is to improve the efficiency of its public transport system so as to support spatial activities of large scale and scope. Only in so doing could the commuters find suitable places of residence in a broader area. A prerequisite for the improvement of efficiency is the enhancement of the system capacity. Most importantly, a balance should be built between demand and supply. Major efforts include increasing the capacity and efficiency of the radiative public transport corridor and adding ring roads or tangent roads, connecting employment centers in the peripheral areas to the transport hubs. In this way, the scale effect of the population-gathering transport hubs could be fully utilized to improve the transport accessibility and attractiveness of those employment centers and balance the passenger flows of the radiative corridors. This is a discussion over the impact of the improvement of jobs-housing spatial mismatch on residents' commuting behaviors from the perspective of an improved transport system.

On the basis of an improved public transport network, attempts need to be made to carry out further jobs-housing spatial adjustments and achieve a jobs-housing match within a reasonable scope. This is to ensure that public resources of all sorts could be utilized to the fullest at the lowest cost. On the condition that the development of central districts has already broken the boundaries of the Outer Ring, expanding from a spatial scope of around 600 km^2 to 1000 km^2, the radius extended from 10 km to 15–20 km with part of the roads and corridors seeing their spatial activity scopes almost doubled. Therefore, it is necessary to establish more employment centers in the peripheral areas of the central districts. The accessibility analysis made by the study is also applicable to the new employment centers. It is feasible to connect them to the transport hubs around the Middle Ring or outside the Outer Ring so as to reinforce their role as employment centers and their public service function. By combining them with the current transport corridors, their influence on surrounding areas would be enhanced, eventually leading to a decrease of the commuting time and improvement of residents' life.

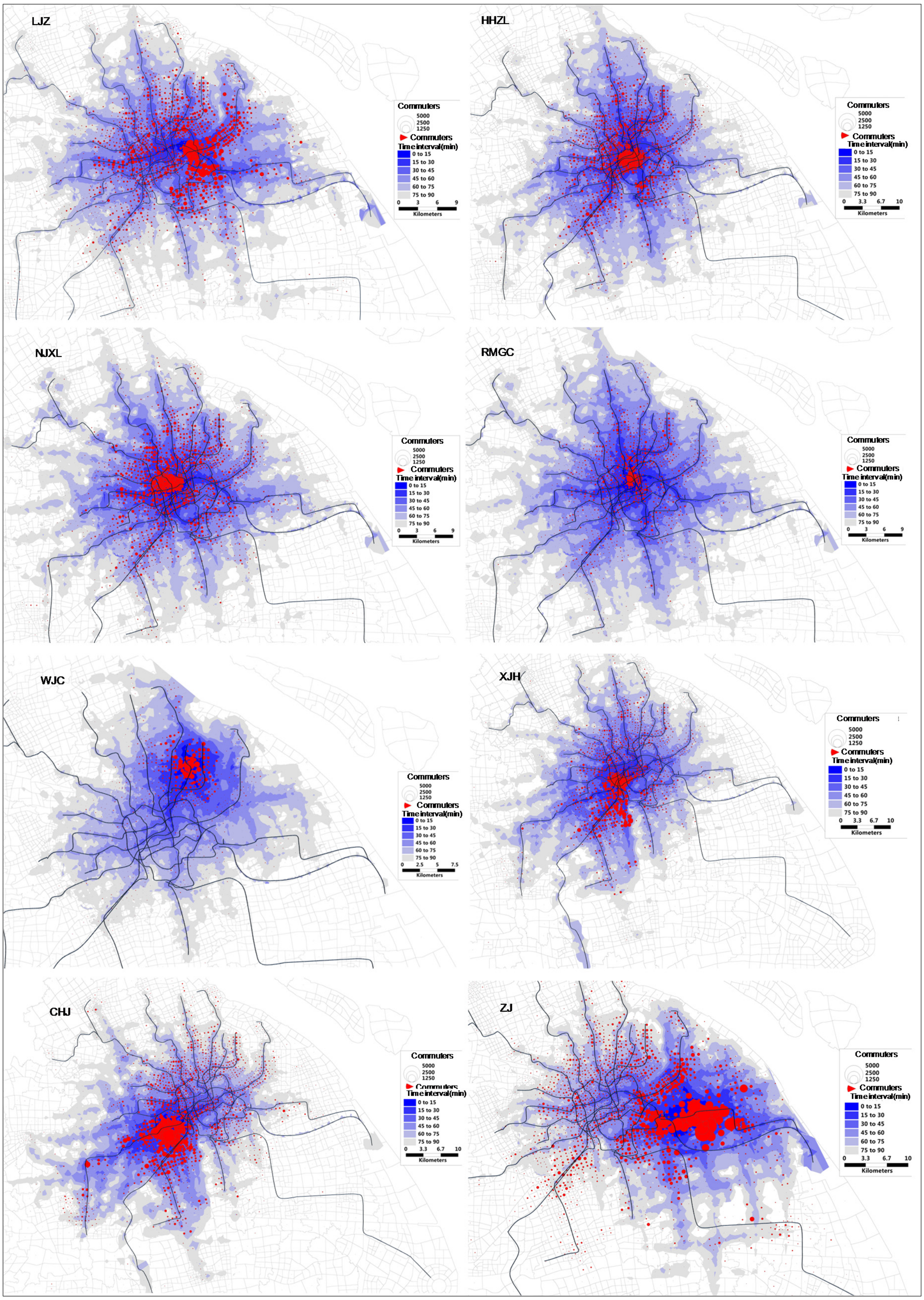

Figure 7. Distribution of commuters in employment centers and its superposition with the public transport network isochronous data.

6. Conclusions

The study analyzed the jobs-housing spatial relations of Shanghai's central districts from the perspective of the commuting transport, illustrating, at a macro level, the issue of jobs-housing spatial mismatch on the basis of the commuting distance data and presenting the reality of jobs-housing spatial mismatch via the superposition of commuter distribution and accessibility indicators calculated by the cumulative opportunity model. The author found that, according to the analysis of typical employment centers, jobs-housing spatial mismatch was inevitable under some conditions. It took shape during the formation of the urban spatial structure and was resulted from the lag of policies. The mismatch itself is hypothetical and therefore needs to be proved by the change of commuting distances, employment center accessibility, and commuter distribution. In the meantime, it is more relevant to discussion how to address the mismatch of the slow variable of spatial structure through the adjustment of fast variables.

Therefore, the study is not of the purpose of proving that jobs-housing mismatch exists in Shanghai, nor does it aim at identifying indicators that could be used to prove the mismatch. Instead, it analyzed the impact of a hypothetical jobs-housing mismatch on the commuting characteristics and behaviors so as to prove the existence of it and more importantly, identify possible ways to improve jobs-housing spatial distribution and the commuting transport system. One strategy is to improve the accessibility or functions of the employment centers, namely, to adjust the transport system or enhance its functions; another is to increase residences in areas with good accessibility to employment centers; a third is to establish more employment centers in areas with good overall accessibilities such as the passenger flow breaking points on public transport corridors.

The study attempts to establish a planning and analyzing method which can be used to identify, in the spatial systems of megacities, the problems of jobs-housing imbalance and spatial mismatch, as well as defects in the transport network. Such a method can hopefully be used to optimize the utilization of land and spatial layout of city functions, improve the public transport system, relieve the excessive commuting traffic load and meet the goal of low carbon and energy-saving transport. Such a planning issue is commonly faced by megacities in China and the world as a whole as they develop rapidly. Findings of the study can be drawn upon by other megacities and fast developing big cities.

At present, theoretical and empirical studies on the relationship between jobs-housing balance and the commuting traffic mainly focus on excess commuting and transport accessibility. While studies on the former discuss the overall efficiency of a city or a specific macro area and are used to evaluate the development of personal motor vehicles and public transport networks in the city; studies on the latter attach emphasis on a local area or a group and are more used to analyze and address specific problems. First, on the basis of the present study and following the methodology of research on excess commuting, we analyzed the overall development situations of Shanghai central districts, discussed the service quality of personal motor vehicles and the public transport network and compared the findings with situation in Beijing. Second, commuters of an employment center who use their personal vehicles were separated from those relying on the public transport. Competent authorities of Shanghai lately released part of the public transport IC card record, which could be utilized together with the mobile signaling data to reinforce the accuracy of accessibility analysis based on the road networks for motor vehicles. Third, the accessibility analysis in the present research was developed upon the cumulative opportunities model and is fitter for case studies. We are currently improving the accessibility model so as to better assess the service efficacy or geographical locations of employment centers. In so doing, we could evaluate the results against the current concentrated employment size and thus expound on the degree of match between different transport networks and jobs-housing spatial development.

Acknowledgments: The authors would like to acknowledge Key Laboratory of Road and Traffic Engineering (Tongji University), Ministry of Education, P.R.C. and Shanghai Urban Planning & Design Research Institute for the daily administrative and financial support.

Author Contributions: Xiang Zhou: Wrote the main part of this manuscript; collected part of the statistical and spatial data; established the methods and analyzed the data; Xiaohong Chen: Proposed the research direction of this manuscript; Tianran Zhang: Collected and conducted the preliminary analysis of the statistical and spatial data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kain, J. Housing segregation, Negro unemployment and metropolitan segregation. *Q. J. Econ.* **1968**, *82*, 175–197. [CrossRef]
2. Mooney, J. Housing segregation, Negro employment, and metropolitan decentralization: An alternative perspective. *Q. J. Econ.* **1969**, *83*, 299–311. [CrossRef]
3. Wilson, J. *The Truly Disadvantaged: The Inner City, the Underclass, and Public Policy*; University of Chicago Press: Chicago, IL, USA, 1987; pp. 3–10.
4. Taylor, B.D.; Ong, P.M. Spatial mismatch or automobile mismatch: An examination of race, residence and commuting in US metropolitan areas. *Urban Stud.* **1995**, *32*, 1453–1473. [CrossRef]
5. Holzer, H.J.; Ihlanfeldt, K.R.; Sjoquist, D.L. Work, search, and travel among white and black youth. *J. Urban Econ.* **1994**, *35*, 320–345. [CrossRef]
6. Thompson, M.A. The impact of spatial mismatch on female labor force participation. *Econ. Dev. Q.* **1997**, *11*, 138–145. [CrossRef]
7. Cervero, R. Jobs-Housing Balance as Public Policy. *Urban Land* **1991**, *10*, 4–10.
8. Cervero, R. Jobs-housing Balance and Regional Mobility. *J. Am. Plan. Assoc.* **1989**, *55*, 136–150. [CrossRef]
9. Cervero, R. Jobs-Housing Balance Revisited. *J. Am. Plan. Assoc.* **1996**, *62*, 492–511. [CrossRef]
10. Bento, A.M. *The Impact of Urban Spatial Structure on Travel Demand in the United States*; World Bank: Washington, DC, USA, 2002.
11. Ewing, R.; Pendall, R.; Chen, D. *Measuring Sprawl and Its Impact*; Smart Growth American: Washington, DC, USA, 2002.
12. Levingston, B.L. *Using Jobs/Housing Balance Indicators for Air Pollution Control*; Institute of Transportation Studies, University of California: Berkeley, CA, USA, 1989.
13. Deakin, E. *Land Use and Transportation Planning in Response to Congestion Problems: A Review and Critique*; Transportation Research Record; Transportation Research Board: Washington, DC, USA, 1989; pp. 77–86.
14. Peng, Z.R. The Jobs-Housing Balance and Urban Commuting. *Urban Stud.* **1997**, *34*, 1215–1235. [CrossRef]
15. Nowlan, D.M.; Stewart, G. Downtown Population Growth and Commuting Trips: Recent Experience in Toronto. *J. Am. Plan. Assoc.* **1991**, *57*, 165–182. [CrossRef]
16. Ewing, R. Before We Write Off Jobs-Housing Balance. In *Best Development Practices: Doing the Right Thing and Making Money at the Same Time*; American Planning Association: Chicago, IL, USA, 1995.
17. Weitz, J.; Schindler, T. *Are Oregon's Communities Balanced?*; Portland State University: Portland, OR, USA, 1997.
18. Lobyaem, S. The Effectiveness of Jobs-housing Balance as a Strategy for Reducing Traffic Congestion: A Study of Metropolitan Bangkok. Ph.D. Thesis, Texas A & M University, College Station, TX, USA, 2006.
19. Loo, B.P.Y.; Chow, A.S.Y. Jobs-housing Balance in an Era of Population Decentralization: An Analytical Framework and a Case Study. *J. Transp. Geogr.* **2011**, *19*, 552–562. [CrossRef]
20. Li, Q.; Li, X.L. Characteristics of commuting travel of residents in suburban communities in Beijing. *Urban Probl.* **2007**, *7*, 55–59. (In Chinese)
21. Wang, D.; Chai, Y.W. The job-housing relationship and commuting in Beijing, China: The legacy of *Danwei*. *J. Transp. Geogr.* **2009**, *17*, 30–38. [CrossRef]
22. Liu, Z.L.; Zhang, Y.; Chai, Y.W. Home-work separation in the context of institutional and spatial transformation in urban China: Evidence from Beijing household survey data. *Urban Stud.* **2009**, *16*, 123–130. (In Chinese)
23. Zhou, J.P.; Murphy, E.; Long, Y. Commuting efficiency in the Beijing metropolitan area: An exploration combining smartcard and travel survey data. *J. Transp. Geogr.* **2014**, *41*, 175–183. [CrossRef]
24. Zhou, S.L.; Yan, X.P. The impact of commuters' travel pattern on urban structure: A case study in some typical communities in Guangzhou. *Acta Geogr. Sin.* **2006**, *61*, 179–189. (In Chinese)

25. Sun, B.D.; Li, N.F.; Song, J.J.; Wu, X.S. A study on the impact of job-housing balance on commuting travels: An empirical test of a traditional idea in the field of urban planning. *Urban Plan. Forum* **2010**, *11*, 56–60. (In Chinese)
26. Zhou, J.P.; Zhang, C.; Chen, X.J.; Huang, W.; Yu, P. Has the legacy of Danwei persisted in transformations? the jobs-housing balance and commuting efficiency in Xi'an. *J. Transp. Geogr.* **2014**, *40*, 64–76.
27. Zhang, Y.; Chai, Y.W. Characteristics of commuting pattern in Beijing: Based on the comparison of different urban residential areas. *Geogr. Res.* **2009**, *15*, 1327–1340. (In Chinese)
28. The Daily Telegraph. China's Mega City: The World's Largest Cities. Available online: http://www.telegraph.co.uk/news/worldnews/asia/china/8278448/Chinas-mega-city-the-worlds-largest-cities.html (accessed on 18 October 2015).
29. The Chinese Government. Notice on Adjusting the Standards for Categorizing City Sizes. Available online: http://news.cntv.cn/2014/11/21/VIDE1416584519180399.shtml (accessed on 18 October 2015).
30. Shanghai Urban Planning & Design Research Institute. Evaluation of city size of Shanghai from 2001–2014. In *Shanghai City Planning and Land Resources Administration*; Shanghai Urban Planning & Design Research Institute: Shanghai, China, 2015.
31. Hamilton, B.W. Wasteful commuting. *J. Polit. Econ.* **1982**, *90*, 1035–1051. [CrossRef]
32. Horner, M.W. Extensions to the concept of excess commuting. *Environ. Plan.* **2002**, *34*, 543–566. [CrossRef]
33. Charron, M. From excess commuting to commuting possibilities: More extension to the concept of excess commuting. *Environ. Plan.* **2007**, *39*, 1238–1254. [CrossRef]
34. Murphy, E.; Killen, J.E. Commuting economy: An alternative approach for assess-ing regional commuting efficiency. *Urban Stud.* **2011**, *48*, 1255–1272. [CrossRef]
35. Murphy, E. Excess Commuting and modal choice. *Transp. Res. A* **2009**, *43*, 735–743. [CrossRef]
36. Frost, M.; Linneker, B.; Spence, N. Excess or wasteful commuting in a selection of British cities. *Transp. Res. A* **1998**, *32*, 529–538.
37. Ma, K.R.; Banister, D. Excess commuting: A critical review. *Transp. Rev.* **2006**, *26*, 749–767. [CrossRef]
38. Yang, C.; Wang, C. Excess commuting and jobs-housing balance model. *J. Tongji Univ. (Nat. Sci.)* **2013**, *41*, 1712–1716.
39. Gordon, P.; Kumar, A.; Richardson, H.W. The spatial mismatch hypothesis: Some new evidence. *Urban Stud.* **1998**, *26*, 315–326. [CrossRef]
40. DeRango, K. Can commutes be used to test the spatial mismatch hypothesis? *Urban Stud.* **2001**, *38*, 1521–1529. [CrossRef]
41. Houston, D.S. Methods to test the spatial mismatch hypothesis. *Econ. Geogr.* **2005**, *81*, 407–434. [CrossRef]
42. Geurs, K.T.; Van, W.B. Accessibility evaluation of land-use and transport strategies: Review and research directions. *J. Transp. Geogr.* **2004**, *12*, 127–140. [CrossRef]
43. Immergluck, D. Job proximity and the urban employment problem: Do suitable nearby jobs improve neighborhood employment rates? *Urban Stud.* **1998**, *35*, 7–23. [CrossRef]
44. Zhou, X.; Chen, X.H. Urban Congestion reduction: Promotion of polycentric spatial structure development from the viewpoint of Transport. *Shanghai Urban Plan. Rev.* **2015**, *2*, 49–55.
45. Zhang, T.R. Shanghai Job-housing spatial analysis based on cell phone big data. *Urban Transp. China* **2016**, in press.