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Research Article

Decade-Long Changes in Disparity and Distribution of Transit Opportunity in Shenzhen China: A Transportation Equity Perspective

Qingfeng Zhou,[1] **Donghui Dai**,[1] **Yaowu Wang**,[1] **and Jianshuang Fan**[2]

[1] *Harbin Institute of Technology Shenzhen Graduate School, Shenzhen, Guangdong 518055, China*
[2] *Zhejiang University of Technology, Hangzhou, Zhejiang 310014, China*

Correspondence should be addressed to Donghui Dai; dai_donghui@hotmail.com

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Efficiency and equity have always been the two points of focus of transport projects. Compared with efficiency, equity is easily overlooked in the evaluation of transport projects. Many studies emphasize that defining and operationalizing costs and benefits and the distributive principle are critical parts in the assessment of transportation equity. However, the scope and time frame of the assessment target are also critical. In this paper, we took China's fastest urbanizing city, Shenzhen, as a case study to assess transport equity by comparing accessibility among groups. First, the public transport system was divided into bus and subway, and the residents were divided into two groups: urban village and nonurban village. Second, we adopted an enhanced potential opportunity model to measure residents' bus and subway accessibility and summarized them as transit opportunity. Third, we used the Dagum Gini coefficient decomposition and kernel density estimation method to explore the fair distribution of transit opportunity among groups and districts from 2011 to 2020. Decade-long changes in disparity and distribution of transit opportunity gave us a clear picture. On the one hand, the development of Shenzhen public transport system had a positive effect. All populations are benefiting, and their accessibility is increasing. On the other hand, it also had a negative effect to exacerbate inequality between populations. For the absolute value of the opportunity, Shenzhen's urban village populations do have fewer transportation opportunities than nonurban villages, and this gap between them will be wider more and more. The public transport system is more inclined to improve the population with high initial opportunity and make them higher. The results illustrated the importance of examining transportation equity over an extended period and could provide information on urban development strategies.

1. Introduction

Public transport is an effective way to solve the problem of traffic congestion and environmental pollution in high population density metropolitan. More importantly, it provides the necessary motorized transport to access jobs and social activity needed especially for low-income people without cars [1]. Many cities are aware of the importance of urban public transport and are planning to enhance public transport services, but the improvement of transit may not help low-income people. Decision-makers need to know the scope and scale of the benefit of people from the public transportation system to make more sensible investment decisions for an equitable transportation system. In recent years, the public is increasingly concerned about the impact of traffic policy and investment on equity.

Transport-related equity involves a wide range of topics and previous studies can be divided into four areas: (1) research on the consequences of transport inequity and people who are vulnerable to suffer transport inequity, exploring the relationship between transit supply and time-poverty, social exclusion, and well-being [2–5]; (2) study on the conceptual frameworks to integrate equity assessment in transport project appraisals, such as discussing cost-benefit analysis (CBA) and multicriteria analysis (MCA) which is more suitable for transport equity assessment [6–8]; (3) focus on the match between transit supply and transit demand based on spatial mismatch theory concerning access to different opportunities among socioeconomic population [9–11]; (4) research on equity aspects of distribution effects of public transport policies and infrastructure projects through accessibility [12–14], guiding assessing the distribution of benefits generated by transport investment projects for transport agencies. In this field many studies recognized that defining and operationalizing costs and benefits and the distributive principle are critical parts in the assessment of transport equity [15]. However, the scope and time frame of the assessment target are also critical. At present, the topic of incorporating equity consideration is involved very little in transport projects evaluation and decision-making in China. This paper focuses on the fourth area taking the China fastest urbanizing city, Shenzhen, as a case study. The purpose of this paper is to assess transport equity from changes of disparity and distribution of transit opportunity over the period from 2011 to 2020. Does the development of transit have a different impact on different group of people and to what extent? What is the trend of change in transit equity effect?

This paper is organized as follows: Section 2 presents a literature review including equity types, variables, and measures involved in transport equity analysis. Section 3 briefly describes the variables and measures used in this paper, an enhanced transit opportunity measure, the decomposition of the Gini coefficient, and the kernel density estimation method. Section 4 introduces the basic situation of public transportation in Shenzhen, the data used in the research, and the concept of "urban village" to classify people. In Section 5, we assess transport equity from changes of disparity and distribution of transit opportunity in Shenzhen. Finally, Section 6 summarizes the results of this study and provides direction for improving the equity of transit opportunity distribution in future studies.

2. Previous Work

2.1. Type of Transportation Equity. Conducting transport equity analysis first involves conceptual issues of equity. The definition of equity has extensive discussions in all fields from philosophy to economics. It differs in different historical periods and different perspectives of research. The definition of equity used in this study is "the distribution of benefits and costs over members of society" [16]. There are two major types of transport equity: horizontal equity and vertical equity [17]. Horizontal equity advocates that individuals or groups are considered with the same weight considered equal in ability and need; transport should provide service equally regardless of need or ability and avoid favoring specific individual or group over another. Vertical equity recognizes that the ability and needs of individuals or groups are not the same; transport should favor spatially, economically, and socially disadvantaged individual or groups to compensate for overall inequities. Vertical equity comprises three components: spatial, social, and economic. Spatial equity refers to providing the equitable transport services and improvements in transport infrastructure, especially in peripheral or rural areas. Economic equity is related to transport services designed for users with lower incomes or without transport affordability. Social equity is related to the availability of special transport services adapted for persons with mobility impairments. Vertical equity can be divided into equity of opportunity and equity of outcome from another dimension. Equity of opportunity means that disadvantaged people have adequate access to social activity opportunities. Equity of outcome means that society must ensure disadvantaged people succeed in social activities. Many works of literature agree that people should have equity of opportunity; scholars focus on equal opportunity rather than equitable outcome; this study also holds this view.

2.2. Analysis of Transportation Equity. Three issues need to be clear when conducting an equity assessment of transport policy or infrastructure projects [18]. Frist, it is about inequality of what variable. We need to define costs and benefits of transport system; second, it is about what unit of inequality measured. The definition of equity introduced before involves the categorizing people; we need to choose target population groups over which costs and benefits are distributed; third, it is about the distributive principle used to judge what distribution of costs and benefits is "morally proper" and "socially acceptable." The distribution principle is related to the type of equity and equity measures.

2.2.1. The Variable of Costs and Benefits in Transportation Equity. Many variables can be used to represent the costs and benefits in transportation equity, and the most often used are transport affordability, access to transport, and accessibility to opportunities. Transport affordability measures individuals or household's actual expenditure on public transport usually as the percent of household disposable income [19]. Public transport affordability equity addresses that a city should enable their poorest citizens to afford at least the motorized trip rates reached by average income stratum. Equity strongly relates to distribution effects, so the main limitation of affordability is that it does not reflect the distribution effect well. Access to transport is the ability of a person to reach transit facilities [20]. It measures transport service characteristics and physical proximity to transport service. Many papers use it to assess the equity of public transit service provision [21–23]. Its disadvantage is that it does not consider whether the transport system can provide the individual with the desired destination. Having transport services does not mean that the transport system can enable people to go to the destination where they want to go to. Accessibility is the ability and ease of achieving activities, opportunities, and goods which is frequently used to evaluate transit provision concerning equity [14, 24, 25]. It can reflect the distribution effect; Martens K. [19] claims that accessibility is the most appropriate measure of benefits from transportation plans and investments.

Accessibility to opportunities is related to cumulative-opportunity and potential/gravity measures which sum the number of destinations/jobs reachable within certain times by transport mode; substantial literature discusses measure [26]. This measure is particularly useful in describing how well transportation networks perform about the distribution of destinations and the needs for subgroups. Measure accessibility to opportunities usually requires an attractiveness indicator, a transport network, and an impedance function of travel cost. The attractiveness indicator is expressed regarding the number of jobs or variables that represents opportunity size. The transport network is used to obtain travel costs, and travel cost can be travel time, distance, fares, or a combination of the three [27, 28]. There are many ways to get travel costs, such as simulation of the transport network in traffic software, calculation from simplified transport network in Geographic Information System (GIS), or calculation from a realistic transport network information database. The impedance function is an inverse function which indicates the increase in travel costs will reduce the opportunities of attraction.

2.2.2. The Categorizing People in Transportation Equity. Equity analysis needs to define a unit that can be distinguished, and units usually are groups of people/households or regions. Many studies use demographic and geographic factors categorizing people to identify transport disadvantaged people in equity evaluation [17], and these factors include income, car ownership, age, gender, career, household composition, and location of residence. Most papers distinguish between high income and low income, as well as car owners and car-less individuals or households. Indeed, disadvantaged status is multidimensional; some studies combine these factors to determine whether a person or area is a transport disadvantaged.

2.2.3. The Equity Measures in Transportation Equity. Well-known horizontal equity measures are the Gini coefficient, Theil index, and coefficient of variation; they are expressed as ratios which are compared among groups to measure equity performance. Gini coefficient initially indicates level of equality of income distributions in economic studies; it ranges from 0 to 1; 0 means absolute equality, and 1 indicates absolute inequality; in transportation equity it is used to evaluate the degree of accessibility concentration level of different regions or groups of people and compare the level of equity before and after implementing a policy or transport infrastructure. Some argue that the Gini coefficient fails to indicate the structure of inequality; the same Gini coefficients can have different income distributions by the group. Theil index is using the information entropy concept to measure individual or interregional income inequality named. The Theil index has good decomposability as a measure of inequality when the sample is divided into multiple groups. The Theil index can measure the contribution of the intragroup gap and the intergroup gap to the total gap, so it provides more interpretation of the inequality among different groups. The primary approach of vertical equity is to evaluate transport policy or infrastructure projects according to how they affect accessibility between disadvantaged people/households or regions. It is fairer if transportation disadvantaged group benefits, like transport service improvements, favor lower-income areas, and groups, or transportation services provide more access to job opportunities and other "basic" activities.

The keys to equity analysis of public transportation are the measure of accessibility and the equity measure of distribution. Our work complements previous research from four aspects. First, when evaluating the equity impact of public transport, only one mode of public transport is concerned in previous studies, so the result of equity evaluation could be bias. We combined subways and buses to consider equity issues in this paper and proposed an enhanced potential opportunity model to measure residents' bus and subway accessibility considering public service reliability, attractiveness, and frequency. Second, due to the limitations of data acquisition, scholars discuss the impact on equity of transport policy or infrastructure projects during a relatively short period (before and after the implementation of the target). Our research used a long-term data to examine equity situation dynamic change, and it was helpful to capture the trends of equity influence on different groups in the development of public transport. Third, indicators of transport distribution effects were further explored and applied. We used the Dagum Gini coefficient decomposition which is more convenient than Theil measure and kernel density estimation method to investigate the fair distribution of potential opportunities. At last, existing research focused on Europe and the United States, and we took the China fastest urbanizing city, Shenzhen, as a case study to assess transport equity by comparing accessibility among social groups. The results can provide a reference for the study of the impact of transportation equity in the world.

3. Methodology

In this study, the public transport system was including bus and subway, and we divided the residents into two groups: urban village population and nonurban village population which will be explained in Section 4. We used an enhanced potential opportunity model to measure residents' bus and subway accessibility and summarized them as transit opportunity. Then, we used the Dagum Gini coefficient decomposition and kernel density estimation method to explore the fair distribution of transit opportunity among groups and districts from 2011 to 2020.

3.1. Measure of Accessibility. This research adopted cumulative-opportunity and potential/gravity measures models to measure transit-based job accessibility and made some enhancements. Given that accessibility measurement is especially important for the analysis of traffic equity, this section will detail how this research calculates accessibility.

Step 1. Calculate the service range of each transit stop. The service radius of the bus stop is 500 meters, and the service radius of the metro station is 700 meters.

Step 2. Calculate the population in each transit stop service area and calculate the job opportunity in each transit stop service area. In our study, job opportunity is represented by the floor area of factory, company, and government office.

Step 3. For transit line l, consider both i and j are transit stops of line l and calculate A_{ijl}; the job opportunity of i can be assessed at j as follows.

Calculate per capita service frequency:

$$S_{ijl} = \frac{V_{ijl}U}{P_i} \tag{1}$$

V_{ijl} is average of vehicles (one day or a week) of transit line l from i to j, U is transit vehicle capacity, and P_i is the population of transit stop i. S_{ijl} reflects different transit service capabilities of bus and subway.

Calculate T_{ijl}, travel time from i to j.

$$T_{ijl} = T_{access} + T_{wait} + T_{in-vehicle} + T_{egress} \tag{2}$$

The access and egress times are assumed to be 5 min of walking time, which transit users are generally willing to undertake, waiting time at transit stops is assumed to be one-half of the scheduled headway when the average headway of transit service is around 10 min, and the in-vehicle travel time is calculated using the scheduled arrival and departure time that is obtained from transit service schedules.

Calculate the distance decay factor:

$$f_{ijl} = \frac{1}{1 + \alpha e^{-\beta T_{ijl}}} \tag{3}$$

α and β are two coefficients which need to be calibrated, and we used an average travel time survey. The survey data show that, in Shenzhen, 96.3% of the people make their work trips in less than 60 min. Therefore, we assumed that the connectivity from an origin to a destination that takes 60 min travel time would be 0.037. The estimates of the parameters are α = 0.0024321 and β = -0.143161.

Calculate the job opportunity of i which can be assessed at j:

$$A_{ijl} = S_{ijl} O_j f_{ijl} \tag{4}$$

where O_j is the opportunity at j.

Step 4. Consider the job opportunity of i can be assessed at e that requires a transfer between transit lines l and m:

$$A_{ie}^{k} = \frac{1}{2}\left(\frac{A_{ikl}}{f_{ikl}} + \frac{A_{kem}}{f_{kem}}\right) f_{ie}^{k} \tag{5}$$

$$f_{ie}^{k} = \frac{1}{1 + \alpha e^{-\beta (T_{ikl} + 20 + T_{kem})}} \tag{6}$$

where i is the transit stop of line l, e is the transit stop of line m, and k is the transfer center between l and m.

Step 5. Calculate the cumulative opportunities of i:

$$A_i = \sum_j A_{ijl} + \sum_k \sum_e A_{ie}^{k} \tag{7}$$

Step 6. Convert residential area to the centroid and calculate the sum of job opportunities of bus stops in the 500-meter buffer of residential centroid and the number of metro job opportunities of metro stations in the 700-meter buffer of residential centroid (if there are more than 1 transit stops belonging to the same line in the buffer, they will be averaged as 1 transit stop). The sum of bus and metro opportunities is the transit opportunity for residential areas.

3.2. Decomposition of the Gini Coefficient. The method of decomposition of the Gini coefficient in a discrete space is proposed by Dagum [29]. The Dagum Gini coefficient is calculated using the following.

$$G = \frac{\sum_{j=1}^{k} \sum_{h=2}^{k} \sum_{i=1}^{nj} \sum_{r=1}^{nh} \left| y_{ji} - y_{hr} \right|}{2n^2 \overline{y}} \tag{8}$$

G is the Gini coefficient, $y_{ji}(y_{hr})$ is individual income of $i(r)$ belong to subgroup $j(h)$, $\overline{y}$ is the average income of all population, n is the number of all population, k is the number of subgroups, and $nj(\ nh)$ is the number of people in the j(h) subgroup. Dagum decomposes the Gini coefficient into three components [26]: (1) G_w, contribution of within groups income inequalities to G; (2) G_b, the net contribution of the between-group inequalities to G measured on all population; (3) G_t, the contribution of the transvariation between the subpopulations to G. Detailed derivation and calculation process for each component are listed in [29]; the equation of Gini coefficient decomposition in three components is shown as follows:

$$G = G_w + G_b + G_t \tag{9}$$

Decomposition of the Gini coefficient not only effectively solves the source of group disparities but also describes the distribution of subgroups and solves the problem of overlap between groups (shows the structure of inequality). In this paper, the Gini coefficient of transit opportunity is calculated and decomposed; the population in Shenzhen is divided into different groups; it helps us to know if the transit opportunity gaps within groups generate the inequalities or if the transit opportunity gaps between groups engender the inequalities.

3.3. Kernel Density Estimation. Kernel density estimation (KDE) is a nonparametric way to estimate the probability density function of a random variable in statistics [30]. Let $(x_1, x_2, \ldots, x_n)$ be a univariate independent and identically distributed sample drawn from some distribution with an unknown density f. Its kernel density estimator is shown as follows:

$$\widehat{f_h}(x) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \tag{10}$$

where K is the kernel, a nonnegative function that integrates to one; the normal kernel is often used. $h > 0$ is a smoothing parameter called the bandwidth.

As mentioned in Section 2.2, Gini coefficient or Theil measure are ratios which are compared among groups to measure equity. KDE enables us to shape the distribution of a variable and analyze differences from the perspective of visual graphics comparison. So, we use KDE as a complementary way to draw probability distribution curves of transit opportunity of different population groups and grasp disparity and distribution of transit opportunity changes in decade-long urban developments in Shenzhen.

4. Study Area

4.1. The Social Group. Shenzhen is located in the Pearl River Delta region with a land area of 1996.8 km^2 and an urban population of over 14 million in 2016. It is the first Special Economic Zone (SEZ) city after the institution of reform and the Open-Door Policy in China in 1979. In the past 30 years, the operation of a market economy has made Shenzhen's economy develop rapidly, bringing with it a dramatic population increase and spatial expansion. In the study of transport equity, an important part is to group residents according to their socioeconomic level. In Shenzhen, detailed data on residents' occupations and income is not easily accessible, so we use three characteristics of a resident's residence to reflect his/her socioeconomic status. These three characteristics are average house price of residence, the average rental price of residence, and whether the residence is in the urban village; the third feature especially is an essential basis for judging a resident as disadvantaged people.

Urban village (Cheng Zhong Cun in Chinese), some scholars preferring the term "urbanized villages" or "villages in the city" to avoid the confusion with the Western planning concept "urban village", is an outcome of China's rapid urbanization and its associated rural-urban migration. When urban expansion encroaches into rural land; the city government needs to acquire land rights from the rural collective to convert the rural land into urban land. The city government only expropriates the farmland of the village to avoid the costly compensation to relocate villagers, and the housing land remains in the hands of the collective. Over time, the village settlement is surrounded by urban built-up area, creating the so-called urban village. **The bond between the urban village and the disadvantaged people is mainly caused by the residence registration (hukou) system and rural-urban migration tide in China**. The hukou system divides the population into the rural population and the urban population. Change from the rural to urban population needs to be approved by the authorities. Rural migrants can stay in large cities as temporary residents (do not have a local urban hukou), and they are excluded from the formal urban housing market. Commercial housing is generally expensive and thus not affordable to migrants who are employed in low-paid jobs. More affordable units provided by urban housing provision system generally require a local urban hukou and are thus not available to rural migrants. China's land policies have enabled the native farmers in the urban villages to construct inexpensive housing units and rent out these units to the rural migrants. In many cities, the urban village is a significant type of settlement for both local landless peasants and migrants, which are two groups with high urban poverty incidence.

The data supplied by the Shenzhen Urban Planning Bureau (SUPB) and the Urban Planning and Design Institute of Shenzhen (UPDIS) shows that there are 2,942 urban village residential lands and 4,683 nonurban village residential lands in Shenzhen 2009. The Municipal Building Survey 2009 provides information for all buildings in Shenzhen, including the urban villages. There are 615,702 buildings in 2009 and 333,576 (54%) in urban villages. Urban villages in Shenzhen, which are thought to accommodate approximately seven million, meet the basic needs of people, particularly poor and low-income residents [31, 32]. There are also some studies proving that immigrants in urban villages are vulnerable. Concerning economic sectors, the largest proportion of migrants is employed in retail, hotel, catering, and other services (50.8%). The second most common category is manufacturing (19.3%) and construction (9.2%). The proportion of people employed by highly paid public and finance sectors is tiny [32]. With the relatively poor employment profile, income among migrants is low in comparison with the city average. In 2004 the Municipal Government found that the average monthly income among migrants was only 1149 yuan, far below the average personal income in the city (2195 yuan) (Shenzhen Municipal Government Housing System Reform Office, 2004).

Our study first divided the population into two groups: residents living in urban villages called the urban village group (UVG) and residents not living in urban villages called the Not urban village group (NUV). The UVG is mainly composed of low-income migrants and contains some high-income local residents. A study shows that the ratio of local residents to migrants in the urban village is 1:88 [32]. Therefore, most of the residents in the urban village group are low-income people, and they are more dependent on transit to access jobs and social activity. The residents in NUV live in formal urban houses meaning that they have owned a house or can afford the higher rental price (the rent of a formal house is 2.5-5 times the rent in the urban village in Shenzhen), so they have higher disposable income than UVG. Second, according to housing prices and rents in different districts of Shenzhen, each group is further divided into subgroups. We collected more than 4,000 rental information and more than 3,000 residential house price information through the website (https://sz.fang.lianjia.com), which cover all areas in Shenzhen. Table 1 lists the detailed information; note that the price and rent in the table refer to the formal house, not the urban village. In each area, the rent price of the urban village is the lowest. Figure 1 is a map of Shenzhen and distributions of urban village lands and nonurban village lands in 2011.

Futian, Luohu, and Nanshan are the core areas of Shenzhen. Investments have been made in the service industry and high-technology companies in the three areas, so the

Table 1: Average house price and average rental price of ten districts in Shenzhen in 2017.

Spatial Location	District	Average house price in 2017 (yuan/m2)	Average rent in 2017 (yuan/m2)
Core area	Futian	52968	119.5
	Luohu	38143	94.7
	Nanshan	56597	121.7
Subcenter	Baoan	22580	76.9
	Longgang	27567	50.3
	Longhua	36432	61.2
	Yantian	33970	59.4
Suburb	Dapeng	13377	27.3
	Pingshan	12601	39.3
	Guangming	10278	24.6

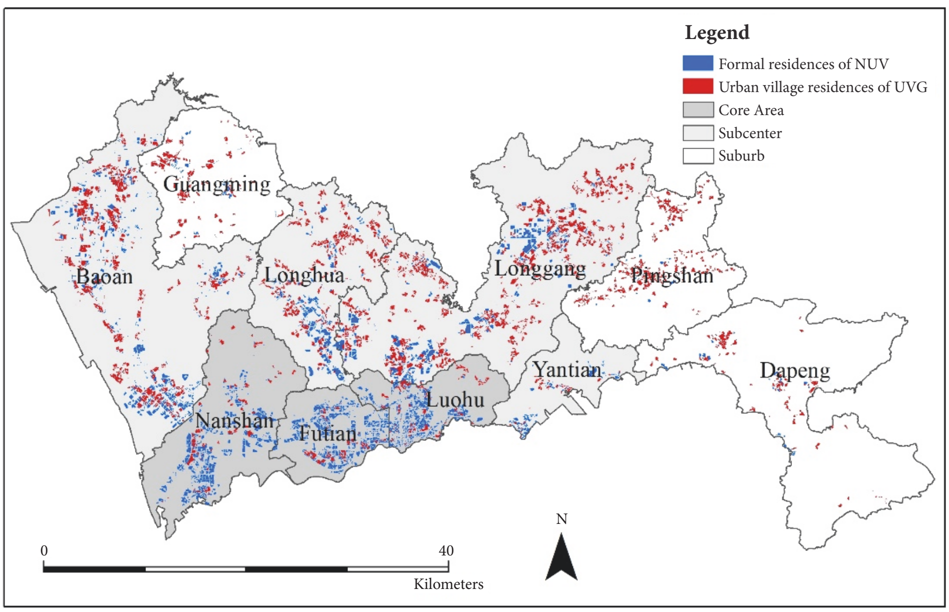

Figure 1: Distributions of urban village lands and nonurban village lands in 2011.

house price and rental price are the highest. Baoan, Longhua, Longgang, and Yantian are the subcenter of Shenzhen, and manufacturing industry provides many jobs in these three regions, so the house price and rental price are lower than in core areas. The remaining three regions are relatively far from the city center, and they have the lowest house price and rental price. For core areas, subcenters, and suburbs, there is a clear difference between house prices and rents, so NUV and UVG are each divided into three subgroups. The descriptions are shown in Table 2.

4.2. The Transit of Different Periods. This study mainly analyzes the changes in public transport opportunities in the three periods from 2011 to 2020. 2011 is a base scenario, and 2020 is analyzed as a planning scenario. Calculating transportation opportunity requires transportation network and active location information. Public transport data includes subway and bus network as shown in Figure 2. The data and operation information of subway in 2011 and 2016 come from the website (http://www.szmc.net) of Shenzhen Metro Group Co., Ltd., and the data and operation information of subway in 2020 is provided by SUPB. Due to the limitations of data acquisition, we use bus network and operation information of 2016 provided by Shenzhen Urban Transport Planning Center (SUTPC) in three measured years. We used the same level of bus service for the 10-year analysis period, and this operation would cause deviations in the calculation results of transit opportunities. This is one of the limitations of our study. The bus data contains 1,700 routes and more than 8,000 bus stops. Compared with the subway system, the changes in bus services are relatively small, and we assumed that using the same bus data had a smaller impact on the trends of the transit equity. As seen in Figure 2, subway lines are mainly concentrated in the core areas. The coverage of subway services in suburb areas will be improved

Table 2: Subgroups of NUV and UVG in Shenzhen.

Group	Subgroup	Description	Population of 2011	Percent
NUV	1	Residents who live in formal urban housing at core area (Futian, Luohu, and Nanshan)	4007619	27.8%
	2	Residents who live in formal urban housing at subcenter (Longhua, Yantian, Longgang, and Baoan)	3505463	23.69%
	3	Residents who live in formal urban housing at suburb (Dapeng, Pingshan, and Guangming)	162948	0.37%
		Total	7676030	51.86%
UVG	4	Residents who live in the urban village at core area (Futian, Luohu, and Nanshan)	1402041	9.48%
	5	Residents who live in the urban village of subcenter (Longhua, Yantian, Longgang, and Baoan)	4724083	31.93%
	6	Residents who live in the urban village at suburb (Dapeng, Pingshan, and Guangming)	995467	6.73%
		Total	7121591	48.14%

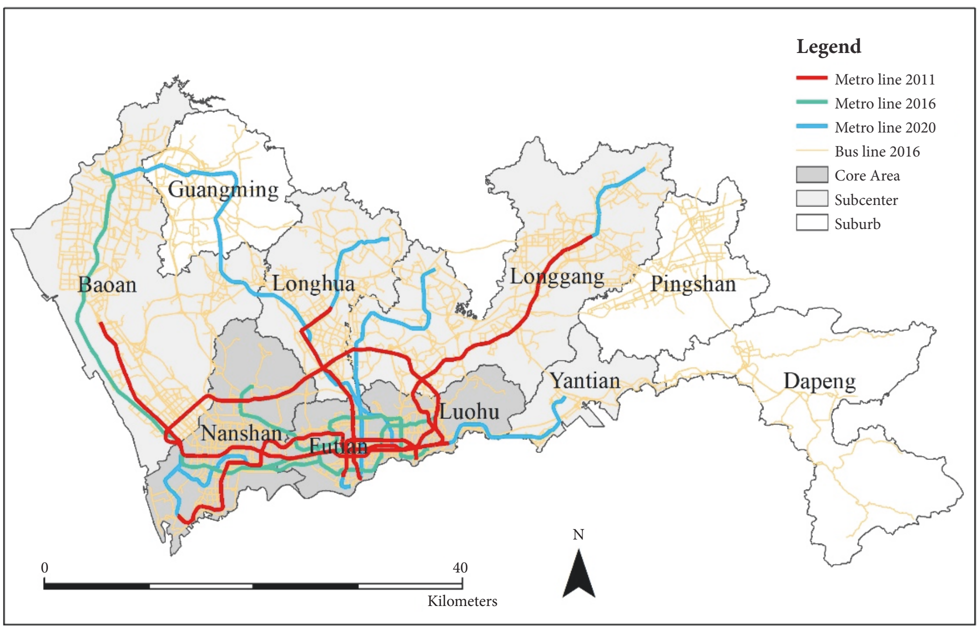

Figure 2: Maps of the transit network in three periods.

until 2020, so it is essential to analyze the impact of public transport networks on fairness. When calculating potential opportunity of residents, our definition of opportunity refers to jobs. UPDIS provides a detailed building data of Shenzhen, so the floor area of building in employment site is calculated to represent the opportunity.

5. Results and Discussions

5.1. The Average Transit Opportunity of Two Groups in Each District. The minimum unit for calculating transit opportunity is the residential land unit, and transit opportunity at the different aggregate levels are calculated by population weights. Figure 3 shows transit opportunity for the different years in Shenzhen at the community level. These maps illustrate how varied are the distributions of transit opportunity among the region by public bus and metro.

We examined the average transit opportunity of two groups in each district. Table 3 shows the average transit opportunity of two groups at the region level. Shenzhen's core area has the most significant opportunity. Futian which is the city center has the highest transit opportunities. Luohu is the former city center in the 1990s and has the second highest accessibility; Nanshan is the critical development area in the future with the third highest transit opportunities. These three regions are spatially adjacent and possess the most public transport resources which have many subway lines and bus routes. Baoan, Longhua, and Longgang are located outside the core area, which is the subcenter of Shenzhen. The transit opportunity in these areas is about one-third

Table 3: Transit opportunity of two groups in each region.

Year	2011		2016		2020	
	NUV	UVG	NUV	UVG	NUV	UVG
Futian	12381	13156	19592	21091	23095	23848
Luohu	12477	13041	16143	15106	18823	17035
Nanshan	5713	5886	8056	7372	10231	9035
Baoan	3367	2012	3821	2185	4197	2323
Longgang	4602	3337	4919	3543	6340	4820
Longhua	4499	2736	4805	2848	6170	4572
Yantian	1630	1285	2030	1411	4931	2858
Dapeng	274	373	431	420	431	420
Pingshan	1163	1107	1231	1134	1231	1134
Guangming	1862	909	1881	927	2835	1297

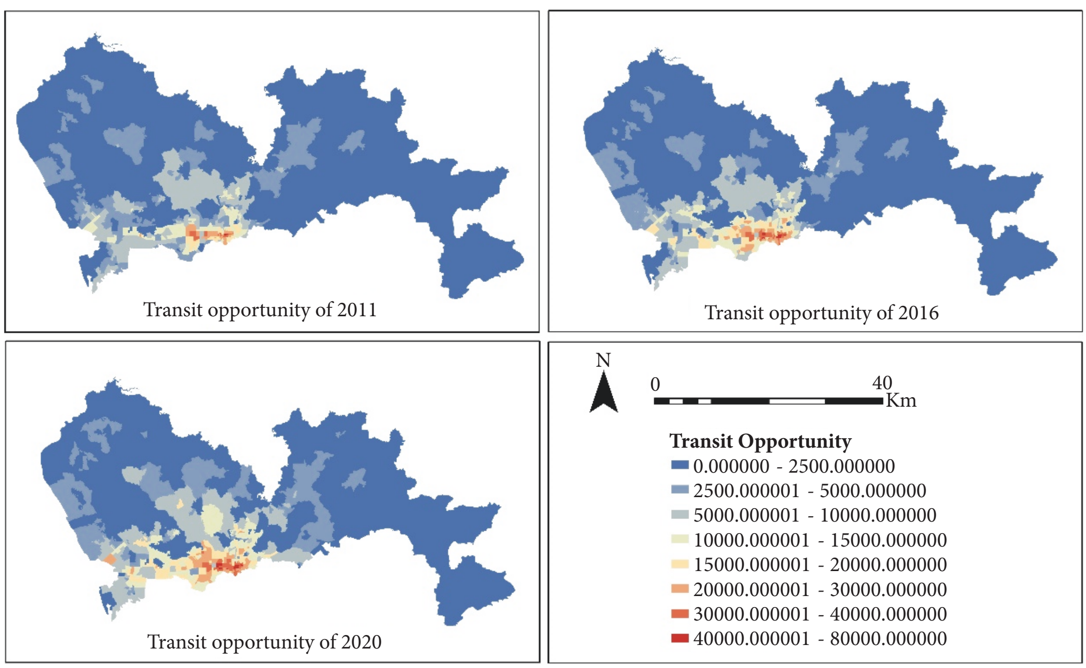

Figure 3: Maps of transit opportunity in three periods.

of the core area. Yantian District is a natural scenic tourist area and port area. Although it is located in the subcentral area, its public transportation system is not well-developed, so the transit opportunities are lower than other subcenters. The rest regions are in the outer suburbs of Shenzhen, which are far from the core area with a small population and minimal opportunity. The opportunity of all regions is growing over time for both groups. Transit opportunity of core area (especially in Futian) proliferated more than 25% from 2011 to 2016. Subcenters and suburbs had a smaller growth lower than 10%. Meanwhile, the differences in the absolute value of transit opportunity between the core area, subcenter area, and the suburbs were unusually large and will be more significant in 2020. It indicates that the residents in the city center have the most significant benefit from public transport system.

Table 4 shows the average transit opportunity in the whole city. In each measure year, transit opportunity of NUV is greater than UVG. The transit opportunity of UVG will increase 45% from 2011 to 2020 and NUV will increase 63% at the same time. The difference in growth rate is 22%. When comparing the absolute value of transit opportunity, the difference between the two groups has almost doubled from 2011 to 2020; in 2011 NUV's transit opportunity was 3279 more than UVG's, and the gap will be 6102 in 2020. From the perspective of the city, NUV has more public transport advantages than UVG. For subgroups, it is clear that the core area has the highest transit opportunities, whether it is UVG or NUV. Subgroup 4 (residents who live in the urban village at core area) even has higher opportunities than subgroup 2 (residents who live in formal urban housing at subcenter).

Table 4: The average transit opportunity of two groups in the whole city.

Year		2011	2016	2020
Group	**NUV**	7307	9959	11972
Subgroup	**1**	10597	15367	18249
	2	3819	4172	5255
	3	1457	1530	2090
Group	**UVG**	4028	4846	5870
Subgroup	**4**	10825	14397	16480
	5	2662	2835	3726
	6	943	987	1102

Table 5: Decomposition of the Gini coefficient between UVG and NUV.

Year		2011	2016	2020
Total Gini	$\mathbf{G}$	0.5725	0.5916	0.5736
Gini within	$\mathbf{G_{nuv}}$	0.5049	0.5160	0.4920
	$\mathbf{G_{uvg}}$	0.6267	0.6480	0.6385
Gini between	$\mathbf{G_{uvg}}$ VS $\mathbf{G_{nuv}}$	0.6026	0.6303	0.6140
Contribution	$\mathbf{G_w}$	48.14%	47.63%	47.38%
	$\mathbf{G_b}$	25.04%	28.84%	29.45%
	$\mathbf{G_t}$	26.81%	23.53%	23.17%

$\mathbf{G_w}$: contribution of the Gini inequality indexes within subpopulations to the total Gini ratio.
$\mathbf{G_b}$: contribution of the Gini inequality ratios between subpopulations to the total Gini ratio.
$\mathbf{G_t}$: contribution of the transit opportunity intensity of transvariation between subpopulations to the total Gini ratio.

5.2. Changes of Transit Opportunity Distribution

5.2.1. Decomposition of Transit Opportunity Gini Coefficient between NUV and UVG. To analyze the horizontal equity of public transport, we calculated and decomposed the Gini coefficient using the transit opportunity of 7625 residential units; the total populations of Shenzhen was divided into the following subgroups: UVG and NUV. Table 5 presents the decomposition of the Gini coefficients estimated for the two groups. The total Gini G reflects the equity situation of transit opportunity distribution in all populations of Shenzhen. From 2011 to 2020 its value changed from 0.5725 to 0.5736. Although the changes are not significant, we still can see the trends of transit opportunity equity. Compared with the public transport network in 2011, there were three new subway lines added to the public transport network in 2016 (in Figure 2, green lines). These lines are mainly located in the core area, and it caused an increase of inequity for all populations. In 2020, the subway network will expand from the core area to the subcenter area (in Figure 2, blue lines). The total Gini coefficient will be reduced; that is, the distribution of transit opportunity in 2020 will be more even than in 2016. For horizontal equity of the total population, the gap in transit opportunity between the overall population increases first and then decreases.

As for within group inequity, $\mathbf{G_{uvg}}$ is the equity index of transit opportunity distribution for UVG population and $\mathbf{G_{nuv}}$ is the equity index for NUV population. The result shows that in each measure year $\mathbf{G_{nuv}}$ is less than $\mathbf{G_{uvg}}$, so the transit opportunity distribution of NUV is more equitable than UVG, and the gap of Gini coefficients between UVG and NUV is significant from 0.1218 in 2011 to 0.1465 in 2020. The impact of changes in the public transport system on transportation equity is consistent for both NUV and UVG. In 2016 the Gini coefficient increased in both groups, and the Gini coefficient of both groups will decrease by 2020. However, in 2002 the NUV's distribution of opportunity is more equitable than the distribution in 2011, UVGs will not return to the level in 2011, which means that $\mathbf{G_{nvg}}$ (2020) > $\mathbf{G_{nvg}}$ (2011).

The between-group inequity ($\mathbf{G_{uvg}}$ **VS** $\mathbf{G_{nuv}}$) results show that the public transport network in 2016 resulted in the most considerable inequality between the two groups. With the expansion of the subway network from the core area to other areas in 2020, the inequality between the two groups will decrease. The analysis of inequality contribution shows that the within groups inequality ($\mathbf{G_w}$) has contributed the most to the total inequity in three periods. The contribution of inequality between groups ($\mathbf{G_b}$) is growing, so the development of public transport has led to growing inequality between the two groups.

5.2.2. Decomposition of Transit Opportunity Gini Coefficient between Subgroups. We know that within groups inequality has the most significant impact on overall inequality in Table 5, so we decomposed the Gini coefficient for each group and explored about the influence of spatial location of residence on equity. Table 6 presents the decomposition of transit opportunity Gini coefficient $\mathbf{G_{nuv}}$ between subgroups of NUV. G_i means the equity index of transit opportunity distribution of subgroup i. The result shows that most equitable

Table 6: Decomposition of the Gini coefficient of NUV between subgroups.

Year		2011	2016	2020
G_{nuv}		0.5049	0.5159	0.4920
Gini within NUV	G_1	0.4060	0.3685	0.3398
	G_2	0.5045	0.5192	0.5131
	G_3	0.5097	0.5101	0.5458
Contribution	$G_{w(nuv)}$	42.6%	38.75%	38.19%
	$G_{b(nuv)}$	47.32%	55.68%	56.36%
	$G_{t(nuv)}$	10.8%	5.57%	5.45%

Table 7: Decomposition of the Gini coefficient of UVG between subgroups.

Year		2011	2016	2020
G_{uvg}		0.6266	0.6480	0.6385
Gini within UVG	G_4	0.4333	0.3748	0.3567
	G_5	0.5441	0.5525	0.5760
	G_6	0.5424	0.5463	0.5572
Contribution	$G_{w(uvg)}$	32.76%	28.85%	31.53%
	$G_{b(uvg)}$	59.51%	65.66%	62.46&
	$G_{t(uvg)}$	7.73%	5.49%	6.01%

Table 8: The Gini coefficients and transit opportunities of all subgroups.

Year								
2011			2016			2020		
subgroup	G_i	ATO	subgroup	G_i	ATO	subgroup	G_i	ATO
1	0.406	10597	1	0.3685	15367	1	0.3398	18249
4	0.4333	10825	4	0.3748	14397	4	0.3567	16480
2	0.5045	3819	3	0.5101	1530	2	0.5131	5255
3	0.5097	1457	2	0.5192	4172	3	0.5458	2090
6	0.5424	943	6	0.5463	987	6	0.5572	1102
5	0.5441	2662	5	0.5525	2835	5	0.576	3726

G_i: transit opportunity Gini coefficient of subgroup i.
ATO: average transit opportunity.

distribution of transit opportunity in NUV is subgroup 1 in all three years. Compared with G_2 and G_3, G_1 is the smallest and is consistently decreasing in three periods, and its decrease is also the largest. G_2 and G_3 are almost equal in 2011 and 2016, but the value of G_3 will be larger in 2020. The analysis of inequality contribution of $\mathbf{G_{nuv}}$ shows that the between groups inequality ($\mathbf{G_{b(nuv)}}$) has contributed the most to the total inequity in three periods of NUV.

Table 7 presents the decomposition of transit opportunity Gini coefficient $\mathbf{G_{uvg}}$ between subgroups of UVG. For UVG, Table 7 shows that G_4 is significantly different from G_5 and G_6, and the most equitable distribution of transit opportunity is subgroup 4. From the changes in the Gini coefficient, the inequality of all UVG population has increased, and the opportunity distribution gap of UVG population in core area tends to be smaller. Subgroup 5 is the most unfair distribution of opportunities in UVG. G_6 is slightly smaller than G_5. The construction of subway infrastructure from 2011 to 2020 will have a negative impact on the distribution of transit opportunity in subcenters and suburbs. From the analysis of the contribution to overall inequality of UVG, the inequality among the groups $\mathbf{G_{b(uvg)}}$ contributes the most, accounting for about 60%. This shows that the unfairness between regions mainly causes the overall inequality of UVG.

Table 8 summarizes the Gini coefficients and transit opportunities of all subgroups. The order of the subgroups in the table is arranged according to the value of the Gini coefficient. For each region (core area, subcenters, and suburb), the Gini coefficient of NUV is always smaller than UVG in all three years, and transit opportunity of NUV is larger than of UVG. Residents of NUV in the core areas have the highest opportunities and the most equitable distribution. Residents of UVG in the core areas have the second highest opportunities and equitable distribution. For subcenters and suburbs, the opportunity gap between the two regions is significant, but the difference in equity distribution is not apparent. With the development of urban public transportation systems, the absolute value of residents' transit opportunities is improved, but it may lead to unfair

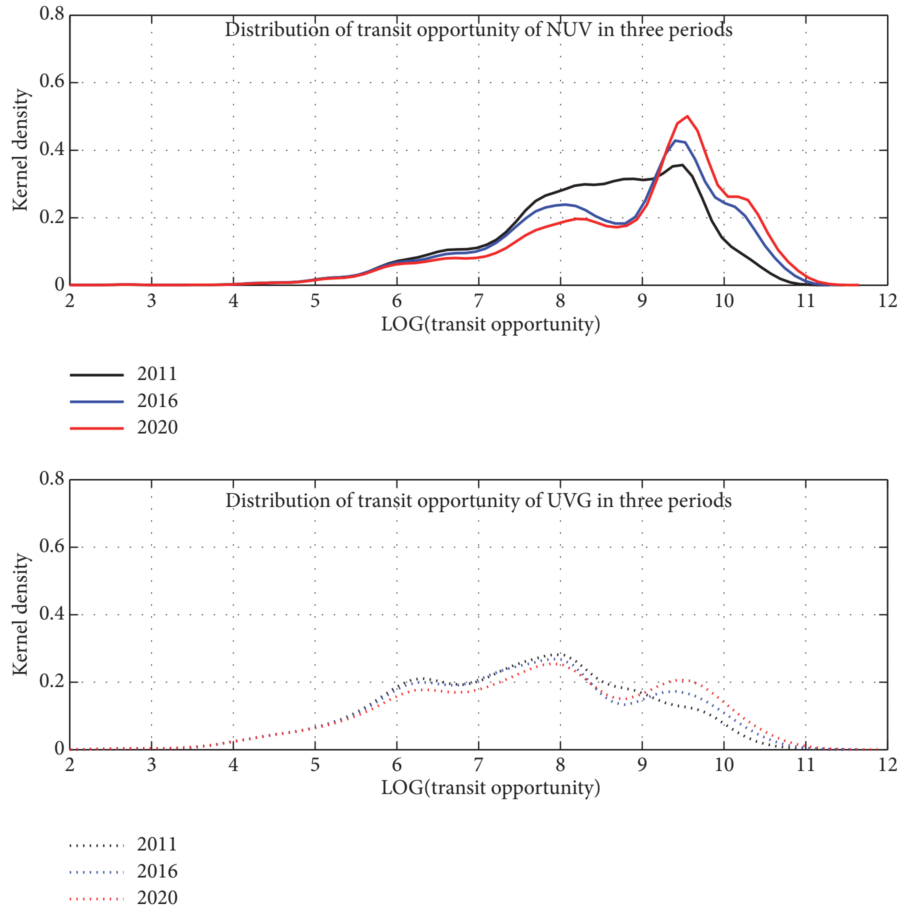

FIGURE 4: Distribution of transit opportunity probability of NUV and UVG population.

distribution. From 2011 to 2020, transit opportunities of subgroup 5 and subgroup 6 will rise, but equity performance will fall. Spatial location and low-income both have impact on equity, but spatial location plays a significant role in the difference and opportunities distributions between groups especially for the UVG.

5.3. Changes of Transit Opportunity Probability Distribution. Based on the transit opportunity of 7825 settlements, we used kernel density estimation to get the probability of transit opportunity and plotted the probability density distribution map.

5.3.1. The Comparisons of Probability Density Maps between UVG and NUV. Figure 4 shows the distribution of transit opportunity probability of NUV and UVG. The horizontal axis is the value of transit opportunity. Since the range of opportunity in different residential areas is too large, a LOG conversion is performed. The vertical axis is the probability of transit opportunity.

The top of Figure 4 is transit opportunity probability of NUV. From 2011 to 2020, there is a slight right movement of the curve which means the value of the opportunity will increase. The density curve in 2016 is quite different from in 2011, and it shows that the subway line in 2016 has a significant influence on the opportunity distribution of NUV population. In 2011, the probability of opportunity value “8” and opportunity value “9” was not much different. Considering vertical equity, an ideal situation is that the public transport system prioritizes raising the odds of lower opportunity population and reduces the probability of lower opportunity. The person with the opportunity “8” should obtain the priority of improvement. In fact, the probability of “9” was reduced more than the probability of “8” in 2016 which means that the public transport system is more inclined to improve the population with high initial opportunity and make them higher. Therefore, the distribution of unfairness increased. The probability density curve shape in 2016 is very similar to that in 2020, and it indicates that the subway line in 2020 will have a little influence on the opportunity distribution of NUV population. The tendency of concentration will be more obvious and further reduce the probability of around “8” in 2020, and distribution of unfairness will decrease. The bottom of Figure 4 shows the distribution of transit opportunity of UVG population. There is no significant change in the density curve shape compared with NUV, and it means that from 2011 to 2020 the improvement of the public transportation system has a smaller impact than NUV. It has the same phenomenon with

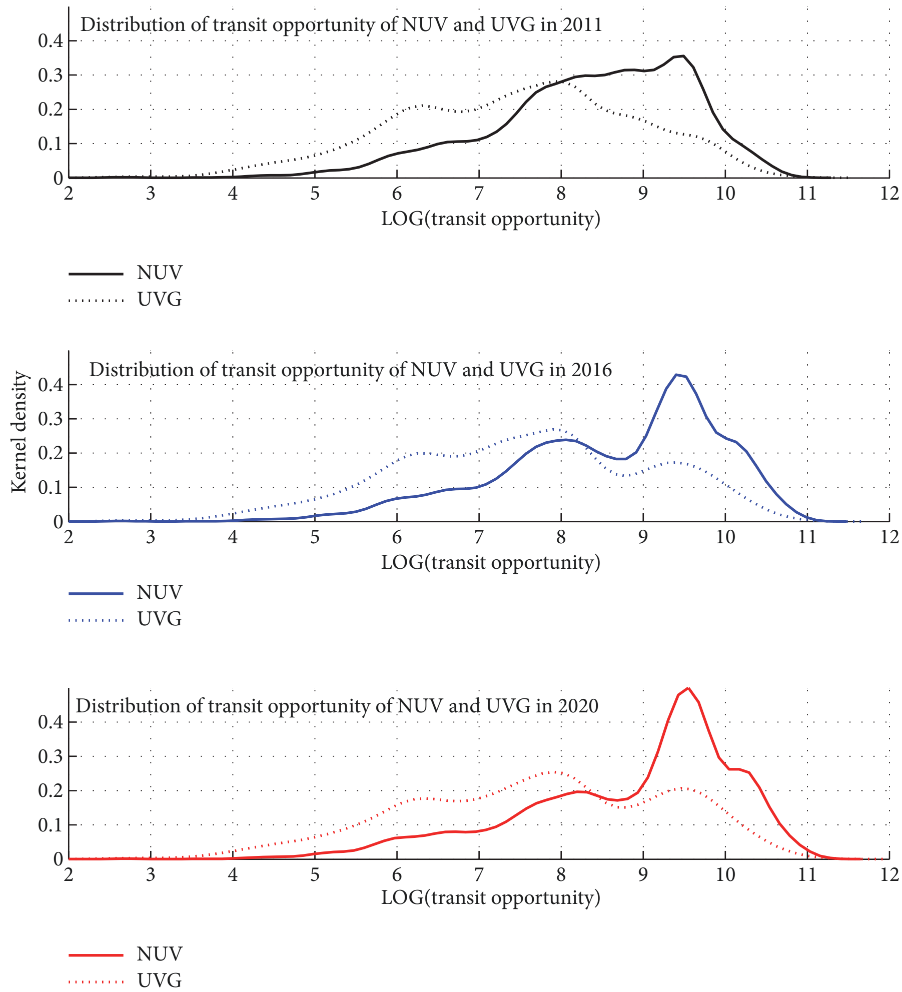

FIGURE 5: Comparisons of the probability distribution of the two groups in the whole city.

NUV which has a priority to improve the high opportunity population. Besides, the curves have three peaks in 2016 and in 2020, which shows that multipolarity is more severe and noticeable.

Figure 5 shows the comparisons of the probability distribution of the two groups at the whole city level. We can observe that the opportunity value "8" is a dividing point in 2011 and 2016. For transit opportunity which value is less than 8, the probability of UVG is higher than NUV. This means that the UVG population is more likely to have low public transport opportunities. For transit opportunity which value is larger than 8, the probability of UVG is less than NUV, so the NUV population is more likely to have high public transport opportunities. In 2020, the dividing point of the two group is 8.5, and this means that the opportunities of both groups will be improved. The comparison of the two groups in the three periods illustrates Shenzhen public transportation system is very favorable to NUV in all three periods. The probability gap of high transit opportunity between the two groups is increasing in different periods; this also shows that NUV benefits more than UVG from the improvement of the urban transport system.

5.3.2. The Comparisons of Probability Density Maps between Subgroups. Figure 6 is the comparisons of the probability distribution of the two groups in core areas. The distributions of the two groups are very similar. The width of the wave in the distribution curve of the two groups becomes narrower over time indicating that the difference of transit opportunity between population is smaller. Figure 7 is comparisons of the probability distribution of the two groups in subcenter. Compared with Figure 6, the difference in probability distribution curves between the two groups is noticeable, and the width of the wave in the distribution curve is wider than the core areas. From 2011 to 2020, the probability gap of high transit opportunity between UVG and NUV is getting larger. The distributions of transit opportunities between the two groups of suburbs have the same characteristics as that of the subcenter in Figure 8, including broader wave and significant distribution differences between UVG and NUV. The three figures show that there is a difference in the distribution of opportunities between different regions, and there are also differences between the two groups in the same region. Spatial location and type of group have an impact on access to transit opportunities.

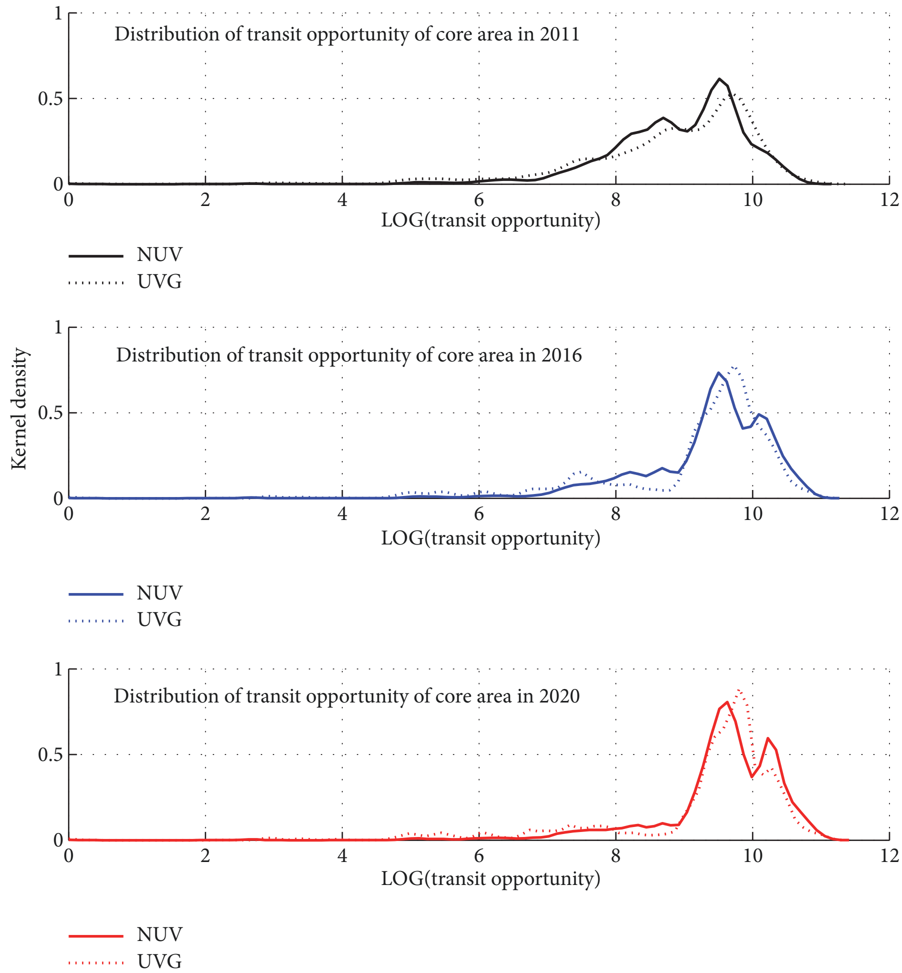

Figure 6: Comparisons of the probability distribution of the two groups in core areas.

6. Conclusions

Decade-long changes in disparity and distribution of transit opportunity gave us a clear picture, and the results illustrated the importance of examining transportation equity over a long period. (1) For the absolute value of the opportunity, Shenzhen's core area has the most significant opportunity, and urban village populations do have fewer transportation opportunities than nonurban villages. People in the different regions and groups inevitably do not have equal transit opportunity, and this is not necessarily problematic. Transport policy is fair if it distributes transport investments and services in ways that reduce inequality of opportunity. With the development of Shenzhen public transport infrastructures, although all populations are benefiting from increasing transit opportunity, transit opportunity of NUV is greater than UVG. Their gap is widening in each measure year, and it is necessary to limit the highest levels of accessibility of social groups when a marginal improvement of accessibility at the upper levels would harm those groups at the bottom. (2) For the vertical equity, the public transport system is more inclined to improve the population with high initial opportunity and make them higher. The improvement of the public transportation system has a smaller impact than NUV in all three periods, and policies should prioritize disadvantaged groups. (3) From the horizontal equity of transit opportunity distribution, for all population, the development of public transport in different periods in Shenzhen first exacerbated unfair distribution of transit opportunity and then increased fairness. The development of transit also has a different impact on the different group of people. In each measure year, the distribution of NUV is more equitable than UVG, and the gap of Gini coefficient between the two groups is significant and is widening. (4) People's social status and spatial location are both factors that contribute to the total inequity. The spatial location has more impact on equity, and low-income people do not necessarily have traffic disadvantages. Low-income people living in the core area of Shenzhen such as Futian and Luohu have high transit opportunity and a more equitable distribution.

Our research is beneficial for providing information to adjust the planning of future Metro routes and urban development strategies in Shenzhen. Since social status and spatial location are factors of impact equity, Shenzhen should

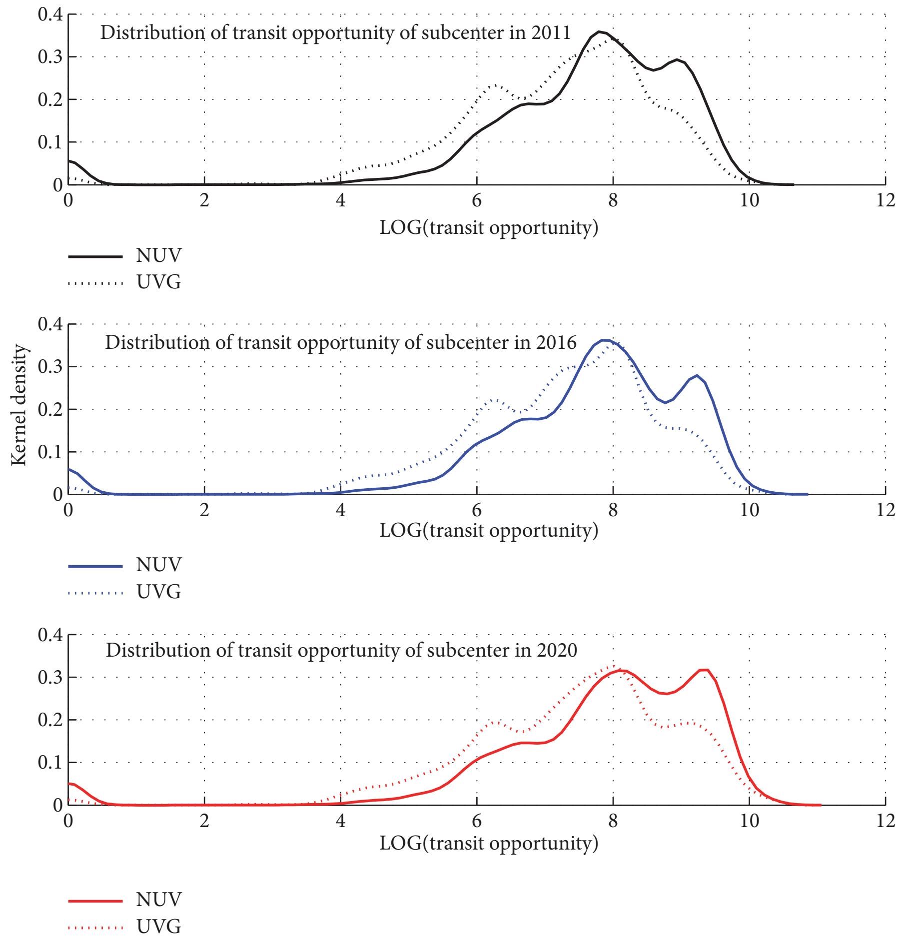

Figure 7: Comparisons of the probability distribution of the two groups in subcenter.

strengthen public transport services in subcentral areas, especially Baoan and Longgang. The two regions have a large population for both NUV and UVG, and improvement of public transport in these areas will be the most effective way for improving public transport accessibility and fair distribution. Our study also has some limitations. First, we used the same bus network for the 10-year analysis period, and this operation would cause deviations in the calculation results of transit opportunities. So, the analysis of equity ignored the changes in fairness brought about by the improvement of bus service level. Second, transportation equity not only is an infrastructure issue but also involves land use planning as well. The transit opportunity of a resident is related to the public transport system and to the distribution and size of the opportunities. The distribution of opportunities is related to urban planning, especially land use. This study does not explore the impact of land use on transportation equity. Third, it is not only the distribution of access to destinations that matter, but also in some cases the absolute level of access for those who are worse. We only discussed the changes of the residents' opportunities and the changes of disparity and distribution of transit opportunity, and we do not discuss whether transit opportunities meet the needs of different groups of people and their satisfaction of transportation opportunities. In the future research, those are our next research direction.

Data Availability

The population distribution data, employment distribution data, and transit data of Shenzhen used to support the findings of this study were supplied by Shenzhen Urban Planning Bureau (SUPB) and the Urban Planning and Design Institute of Shenzhen (UPDIS) under license and so cannot be made freely available. Requests for access to these data should be made to Qingfeng ZHOU, zhouqingfeng@hit.edu.cn.

Conflicts of Interest

The authors declarethat they have no conflicts of interest.

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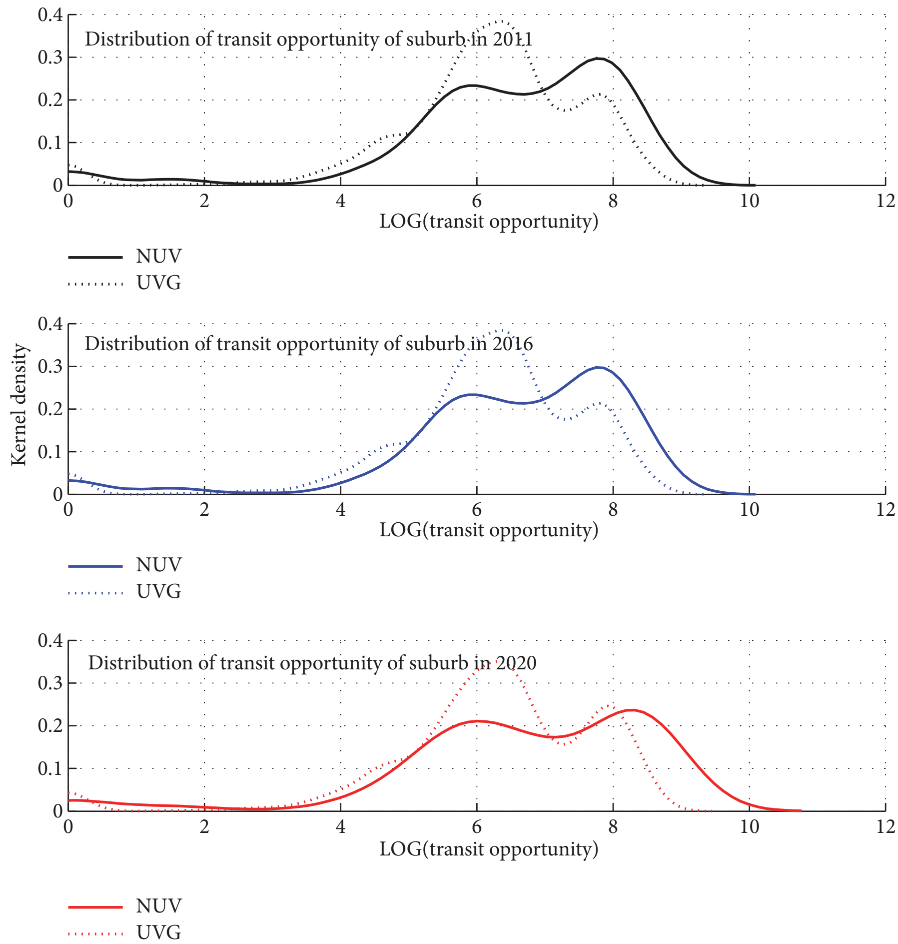

Figure 8: Comparisons of the probability distribution of the two groups in the suburb.

Center for Urban and regional Studies, University of North Carolina at Chapel Hill.

References

[1] J. Jain, T. Line, and G. Lyons, "A troublesome transport challenge? Working round the school run," *Journal of Transport Geography*, vol. 19, no. 6, pp. 1608–1615, 2011.

[2] G. Currie and A. Delbosc, "Modelling the social and psychological impacts of transport disadvantage," *Transportation*, vol. 37, no. 6, pp. 953–966, 2010.

[3] A. Lubin and D. Deka, "Role of public transportation as job access mode: lessons fromfbfbsurvey of people with disabilities in New Jersey," *Transportation Research Record*, vol. 2277, pp. 90–97, 2012.

[4] A. Matas, J.-L. Raymond, and J.-L. Roig, "Job accessibility and female employment probability: The cases of Barcelona and Madrid," *Urban Studies*, vol. 47, no. 4, pp. 769–787, 2010.

[5] À. Cebollada, "Mobility and labour market exclusion in the Barcelona Metropolitan Region," *Journal of Transport Geography*, vol. 17, no. 3, pp. 226–233, 2009.

[6] K. Martens, "Substance precedes methodology: On cost-benefit analysis and equity," *Transportation*, vol. 38, no. 6, pp. 959–974, 2011.

[7] K. Martens, A. Golub, and G. Robinson, "A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States," *Transportation Research Part A: Policy and Practice*, vol. 46, no. 4, pp. 684–695, 2012.

[8] N. Thomopoulos and S. Grant-Muller, "Incorporating equity as part of the wider impacts in transport infrastructure assessment: An application of the SUMINI approach," *Transportation*, vol. 40, no. 2, pp. 315–345, 2013.

[9] G. Currie, "Quantifying spatial gaps in public transport supply based on social needs," *Journal of Transport Geography*, vol. 18, no. 1, pp. 31–41, 2010.

[10] B. Epstein and M. Givoni, "Analyzing the gap between the QOS demanded by PT users and QOS supplied by service operators," *Transportation Research Part A: Policy and Practice*, vol. 94, pp. 622–637, 2016.

[11] C. Jaramillo, C. Lizárraga, and A. L. Grindlay, "Spatial disparity in transport social needs and public transport provision in Santiago de Cali (Colombia)," *Journal of Transport Geography*, vol. 24, pp. 340–357, 2012.

[12] E. M. Ferguson, J. Duthie, A. Unnikrishnan, and S. T. Waller, "Incorporating equity into the transit frequency-setting problem," *Transportation Research Part A: Policy and Practice*, vol. 46, no. 1, pp. 190–199, 2012.

[13] A. Monzón, E. Ortega, and E. López, "Efficiency and spatial equity impacts of high-speed rail extensions in urban areas," *Cities*, vol. 30, no. 1, pp. 18–30, 2013.

[14] J. P. Bocarejo S. and D. R. Oviedo H., "Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments," *Journal of Transport Geography*, vol. 24, pp. 142–154, 2012.

[15] B. van Wee and K. Geurs, "Discussing equity and social exclusion in accessibility evaluations," *European Journal of Transport and Infrastructure Research*, vol. 11, no. 4, pp. 350–367, 2011.

[16] D. Boucher and P. J. Kelly, *Social justice: from Hume to Walzer*, Psychology Press, 1998.

[17] T. Litman, "Evaluating transportation equity," *World Transport Policy & Practice*, vol. 8, no. 2, pp. 50–65, 2002.

[18] F. Di Ciommo and Y. Shiftan, "Transport equity analysis," *Transport Reviews*, vol. 37, no. 2, pp. 139–151, 2017.

[19] C. Falavigna and D. Hernandez, "Assessing inequalities on public transport affordability in two latin American cities: Montevideo (Uruguay) and Córdoba (Argentina)," *Transport Policy*, vol. 45, pp. 145–155, 2016.

[20] A. T. Murray, "Strategic analysis of public transport coverage," *Socio-Economic Planning Sciences*, vol. 35, no. 3, pp. 175–188, 2001.

[21] A. Delbosc and G. Currie, "Using Lorenz curves to assess public transport equity," *Journal of Transport Geography*, vol. 19, no. 6, pp. 1252–1259, 2011.

[22] K. Fransen, T. Neutens, S. Farber, P. De Maeyer, G. Deruyter, and F. Witlox, "Identifying public transport gaps using time-dependent accessibility levels," *Journal of Transport Geography*, vol. 48, pp. 176–187, 2015.

[23] T. Saghapour, S. Moridpour, and R. G. Thompson, "Public transport accessibility in metropolitan areas: A new approach incorporating population density," *Journal of Transport Geography*, vol. 54, pp. 273–285, 2016.

[24] E. C. Delmelle and I. Casas, "Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: The case of Cali, Colombia," *Transport Policy*, vol. 20, pp. 36–46, 2012.

[25] J. Grengs, "Nonwork Accessibility as a Social Equity Indicator," *International Journal of Sustainable Transportation*, vol. 9, no. 1, pp. 1–14, 2015.

[26] A. Páez, D. M. Scott, and C. Morency, "Measuring accessibility: Positive and normative implementations of various accessibility indicators," *Journal of Transport Geography*, vol. 25, pp. 141–153, 2012.

[27] A. El-Geneidy, D. Levinson, E. Diab, G. Boisjoly, D. Verbich, and C. Loong, "The cost of equity: Assessing transit accessibility and social disparity using total travel cost," *Transportation Research Part A: Policy and Practice*, vol. 91, pp. 302–316, 2016.

[28] M. Niehaus, P. Galilea, and R. Hurtubia, "Accessibility and equity: An approach for wider transport project assessment in Chile," *Research in Transportation Economics*, vol. 59, pp. 412–422, 2016.

[29] C. Dagum, "A new approach to the decomposition of the Gini income inequality ratio," in *Income Inequality, Poverty, and Economic Welfare*, pp. 47–63, Physica-Verlag HD, 1998.

[30] M. Rosenblatt, "Remarks on some nonparametric estimates of a density function," *Annals of Mathematical Statistics*, vol. 27, pp. 832–837, 1956.

[31] J. Zacharias and Y. Tang, "Restructuring and repositioning Shenzhen, China's new mega city," *Progress in Planning*, vol. 73, no. 4, pp. 209–249, 2010.

[32] Y. P. Wang, Y. Wang, and J. Wu, "Housing migrant workers in rapidly urbanizing regions: A study of the Chinese model in Shenzhen," *Housing Studies*, vol. 25, no. 1, pp. 83–100, 2010.