Travel Behaviour and Society 19 (2020) 184–193

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Measuring spatial mismatch and job access inequity based on transit-based job accessibility for poor job seekers

Dong Liu[a], Mei-Po Kwan[b,c,d,*]

[a] Department of Geography and Geographic Information Science, University of Illinois at Urbana-Champaign, Room 1054 Natural History Building, 1301 W Green Street, Urbana, IL 61801, USA

[b] Department of Geography and Resource Management, The Chinese University of Hong Kong, Shatin, Hong Kong

[c] Institute of Space and Earth Information Science, The Chinese University of Hong Kong, Shatin, Hong Kong

[d] Department of Human Geography and Spatial Planning, Utrecht University, 3584 CB Utrecht, The Netherlands

ARTICLE INFO

Keywords:
Spatial mismatch
Poor job seekers
Transit fare
Job accessibility
Chicago

ABSTRACT

The few spatial mismatch studies that have examined spatial mismatch based on job accessibility consider travel time as the sole travel impedance. However, travel cost (e.g., fuel cost, parking fee and transit fare) is also an important factor in determining job accessibility especially for poor job seekers and needs to be integrated into job accessibility measure, because socially vulnerable people including poor job seekers could be disadvantaged by high travel cost (e.g., poor job seekers discouraged from using transit services for commuting due to high fare). By focusing on transit-based job accessibility, this study seeks to improve the assessment of spatial mismatch based on job accessibility by taking transit fare into account and determine the inequity in job accessibility for poor job seekers by conducting comparisons across areas and races. Based on a study of the Chicago Metropolitan Area, we first determine the demand for each census tract's jobs based on a gravity model that integrates both transit-based travel time and transit fare of poor job seekers from other census tracts. Then, we measure the job accessibility for each census tract based on a gravity model considering the attraction of low-pay jobs weighted by job demand and the friction of transit-based travel time and transit fare. Finally, we assess spatial mismatch by comparing the job accessibility of central city poor job seekers against their suburban counterparts and determine the job access inequity for poor job seekers by comparing the results before and after including transit fare across different areas and races. The results show that central city poor job seekers, either before or after including transit fare, do not suffer from spatial mismatch and tend to have higher job accessibility compared to their suburban counterparts. However, the results obtained from including transit fare are quite different from those that considered travel time only, especially with respect to the differences between poor job seekers of different races living in different areas. For policymakers to be fully informed about spatial mismatch, it is important to take both travel time and transit fare into account.

1. Introduction

The spatial mismatch hypothesis (SMH) was originally formulated based on the mismatch between the African American population concentrated in the central cities and available job opportunities dispersed in the suburban areas in U.S. cities. When the SMH was first proposed by Kain (1968), it was stated that many jobs were not available or accessible to central city African American residents partly due to the lack of transit service for them to access the employment opportunities in suburban areas, in addition to housing market discrimination that restricted their housing choice. Over the years, other than the African American population, the scope of the SMH has been broadened to include other socially vulnerable groups, such as low-income people, that tend to be transit-dependent (Garrett and Taylor, 1999; Giuliano, 2005). Nevertheless, the mere presence of a transit system does not guarantee access to jobs as high travel costs might discourage the full utilization of public transit for low-income people (Ihlanfeldt and Sjoquist, 1998). As a result, jobs reachable by public transit might not be economically accessible to low-income people when transit fares exceed their travel budget, leading to the dearth of economically transit-accessible jobs and the exacerbation of spatial mismatch for low-income transit-dependent workers. Therefore, for disadvantaged groups like low-income people, spatial mismatch can be better measured by the spatial imbalance between the locations of

* Corresponding author.
E-mail addresses: dongl2@illinois.edu (D. Liu), mpk654@gmail.com (M.-P. Kwan).

https://doi.org/10.1016/j.tbs.2020.01.005
Received 11 July 2019; Received in revised form 14 December 2019; Accepted 15 January 2020
Available online 30 January 2020

transit-accessible jobs and the residences of these people (Fan et al., 2014).

Based on this reason, this study measures spatial mismatch based on transit-based job accessibility for poor job seekers with a focus on low-pay jobs in the Chicago Metropolitan Area and compares the results before and after including transit fare. We first measure job accessibility based on the gravity model proposed by Shen (1998), which considers the attraction of low-pay jobs in a census tract weighted by job demand (i.e., the number of poor job seekers capable of reaching those jobs in that census tract) and the friction of travel impedance. We measure job accessibility considering only travel time as well as considering both travel time and transit fare. Then, we use the average job accessibility for all job seekers in the Chicago Metropolitan Area as the benchmark. If central city poor job seekers have lower job accessibility than the metropolitan area benchmark, then we consider that these poor job seekers suffer from spatial mismatch. Traditional spatial mismatch studies have mainly focused on the spatial mismatch of racial minorities. In this study, we measure spatial mismatch for poor job seekers of both the majority race (i.e., white) and minority race (i.e., black and Hispanic).

This paper is organized as follows. Section 2 reviews the relevant literature regarding the measurement of spatial mismatch. Section 3 describes the study area and data sources. Section 4 presents the methodologies and findings of the study. The final section includes the discussion and conclusions of the study.

2. Literature review

2.1. The development of spatial mismatch

The SMH was first proposed by Kain (1968) based on the analysis of the geographic mismatch between the concentrated central city residences of African Americans and the suburbanization of relevant job opportunities in U.S. cities. Residential segregation confined many African Americans to residences in the central city and created a surplus of African American workers in centralcity relative to the number of available employment opportunities. Ihlanfeldt and Sjoquist (1998) considered spatial mismatch as a phenomenon that there are fewer jobs per worker in the proximity of dominantly African American central city neighborhoods than white suburban neighborhoods.

After years of development, the scope of the SMH has expanded in two aspects. First, a variety of socially vulnerable groups other than African Americans were studied, such a Asians and Latinos (e.g., McLafferty and Preston, 1992; Stoll and Covington, 2012; Taylor and Ong, 1995), low-income people (Blumenberg, 2004; Zhou et al., 2013), welfare recipients (Blumenberg and Manville, 2004; Blumenberg and Shiki, 2004), central city minority youths (Ellwood, 1986; Ihlanfeldt and Sjoquist, 1990) and immigrants (Hellerstein et al., 2009; Liu and Painter, 2012; Painter et al., 2007). However, spatial mismatch for disadvantaged groups (e.g., poor job seekers) of the majority race (e.g., white) has rarely been compared to that of the minority race (e.g., black and Hispanic). Second, traditional spatial mismatch measures were extended from job counts to job accessibility when quantifying spatial mismatch in recent studies. From early on, Ellwood (1986) examined spatial mismatch for black youths in the central city of Chicago through assessing job accessibility based on census tract-level data and the socioeconomic characteristics of central city black youths. Ihlanfeldt and Sjoquist (1990) investigated spatial mismatch for central city youths in Philadelphia, Chicago and Los Angeles by measuring job accessibility that considered only census tract-level automobile-based travel time as the travel impedance. Raphael (1998) uncovered spatial mismatch for black youths in the San Francisco Bay Area through job accessibility measured based on a gravity model that integrates travel time between residences and workplaces. Parks (2004) also measured job accessibility based on a gravity model to evaluate spatial mismatch for native-born black and immigrant women in Los Angeles. Among more recent studies, Fan et al. (2014) adopted a cumulative-opportunity approach to calculate the number of transit-accessible jobs based on a pre-determined transit travel time threshold and incorporated the transit-accessible jobs into a dissimilarity index to measure the magnitude of spatial mismatch for low-income workers in Beijing. Zhou et al. (2016) also used a cumulative-opportunity model to calculate the number of employees that could reach an employment center based on a pre-determined transit-based travel time threshold and gauged the impact of spatial mismatch on commuting behaviors. In comparison, Hu (2015) adopted a gravity approach to measure job accessibility for poor job seekers based on census tract-level automobile-based travel time and compared the job accessibility of central city poor job seekers against their suburban counterparts to assess spatial mismatch. Haddad and Barufi (2017) also used a gravity approach to measure job accessibility based on both automobile- and transit-based travel time to compare the spatial mismatch under these two different transportation modes. While cumulative-opportunity measures consider all job opportunities as equally desirable for job seekers, gravity measures discount the desirability of job opportunities by incorporating the distance decay function (i.e., more weight for jobs closer to the residential census tracts and less weight for jobs located further from the residential census tracts), which is closer to people's perception (Geurs and Van Wee, 2004). However, the above-mentioned studies considered only travel time, and none of them considered the role of transit cost in influencing job accessibility, which may adversely affect the accuracy of spatial mismatch evaluation.

2.2. Transit fare and spatial mismatch

Public transit is an important travel mode for commuting for many workers in major metropolitan areas, especially low-income workers who are less likely to own automobiles (Bureau and Glachant, 2011). Based on 2009 National Household Travel Survey, Blumenberg and Pierce (2012) found that low-income households are less likely to own automobiles and nearly 20% of low-income households (around 8 million households) in the United States travel without an automobile. Moreover, the percentage of workers who commute by public transit had been on a largely increasing trend between 2000 and 2010 (Dickens and Neff, 2011), indicating the increasing importance of public transit for job access, which many previous studies have examined. For instance, Sanchez (1999) used two-stage least squares regression to estimate the relationship between transit access and labor participation and found that transit access has a significant impact on labor participation. Yi (2006) conducted a disaggregate analysis in Houston, Texas to explain individual employment as a function of public transit access and found that public transit access has a significant impact on employment levels. More recently, Tyndall (2017) observed a significant causal relationship between public transit and unemployment status, especially for transit-dependent minorities. Johnson et al. (2017) used regression analysis to explain employment levels as a function of transit-based accessibility and also found a significant relationship between shorter transit-based travel time and higher employment levels.

Many people with entry-level low-pay jobs do not have any transport means other than public transit (Johnson et al., 2017). Given the importance of transit for accessing entry-level low-pay jobs as well as the significance of public transit for improving employment levels, transit fare has been increasingly employed to explore social inequity in the literature. Generally, low-income people tend to be more transit-dependent and their use of public transit is susceptible to transit fare structure change (Bocarejo and Oviedo, 2012; Brown, 2018; Farber et al., 2014). For instance, Cervero (1990) found that low-income transit commuters are less likely to change their travel behavior in the face of transit fare increase when compared to their higher-income counterparts as low-income transit commuters have very limited alternative travel modes for their commute trips. Nevertheless, reduced transit fare is more effective in improving transit equity for low-income transit riders than for their higher-income counterparts (Bureau and Glachant, 2011).

As another important measure for social inequity, spatial mismatch is essentially about the geographic separation between residences and workplaces. Travel time was usually used directly to examine spatial mismatch in earlier studies (Gabriel and Rosenthal, 1996; Holloway, 1996; Holzer et al., 1994; Johnston-Anumonwo, 1997; McLafferty and Preston, 1992). Recent studies, however, integrated travel time into job accessibility measure, i.e., the locations of job opportunities relative to the locations of workers, to examine spatial mismatch (Fan et al., 2014; Hu, 2015; Qi et al., 2018; Zhou et al., 2016). Spatial mismatch studies using job accessibility substantially improved spatial mismatch measurement because they could capture fine-grained patterns of job opportunities and available workers (Preston and McLafferty, 1999). However, those spatial mismatch studies have only integrated travel time into job accessibility measures (Fan et al., 2014; Hu, 2015) even when transit fare also affects job accessibility (El-Geneidy et al., 2016). Studies using travel time to examine spatial mismatch include both automobile-based (Hu, 2015; Ihlanfeldt and Sjoquist, 1990; Taylor and Ong, 1995) and transit-based (Ellwood, 1986; Fan et al., 2014; Qi et al., 2018) studies. Nevertheless, public transit is an especially critical means of commute in major metropolitan areas in the United States as on average 7% of all workers in the 100 largest metropolitan areas of the nation were transit-dependent commuters and the figure jumped to 11% for low-income people (Tomer et al., 2011). Ihlanfeldt and Sjoquist (1998) suggested that inadequate transit service between central city neighborhoods and suburban neighborhoods with job opportunities is one of the important contributing factors of spatial mismatch. Therefore, transit plays an important role in affecting work-residence balance and thus spatial mismatch.

This study thus focuses on the job accessibility of poor job seekers of both the majority race (i.e., white) and the minority race (i.e., black and Hispanic). It integrates transit fare into the measurement of spatial mismatch for central city poor job seekers. High fare as a percentage of income would discourage people, especially the low-income ones, from using transit and reduce available jobs for them (Carruthers et al., 2005). Reduced job accessibility would have a direct impact on spatial mismatch. Therefore, our study seeks to improve the assessment of spatial mismatch based on job accessibility by adding transit fare into consideration. Existing studies have mainly considered the influence of the spatial dimension of transit on spatial mismatch while neglecting the effects of the economic dimension (e.g., transit fare). In this study, we highlight the impact of the economic dimension on spatial mismatch and integrate transit fare into the examination of spatial mismatch.

3. Study area and data

3.1. Study area

The Chicago Metropolitan Area, the third-largest metropolitan area in the U.S., is our study area. It includes seven counties (Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will Counties) in northeastern Illinois. Cook County is the largest among the seven counties and includes the City of Chicago. We define the City of Chicago, the area delineated by the official administrative boundary of the city, as the central city and the study area outside the City of Chicago as the suburb. We further divide the suburb into the inner-ring suburb, which comprises areas within the official administrative boundary of Cook County but outside the official administrative boundary of the City of Chicago, and the outer-ring suburb, which comprises all the areas within the Chicago Metropolitan Area but outside the official administrative boundary of Cook County (Fig. 1).

The Chicago Metropolitan Area has the second-largest public transit system in the United States. In 2010, nearly half a million workers in the region used public transit for daily commute and around 35% of

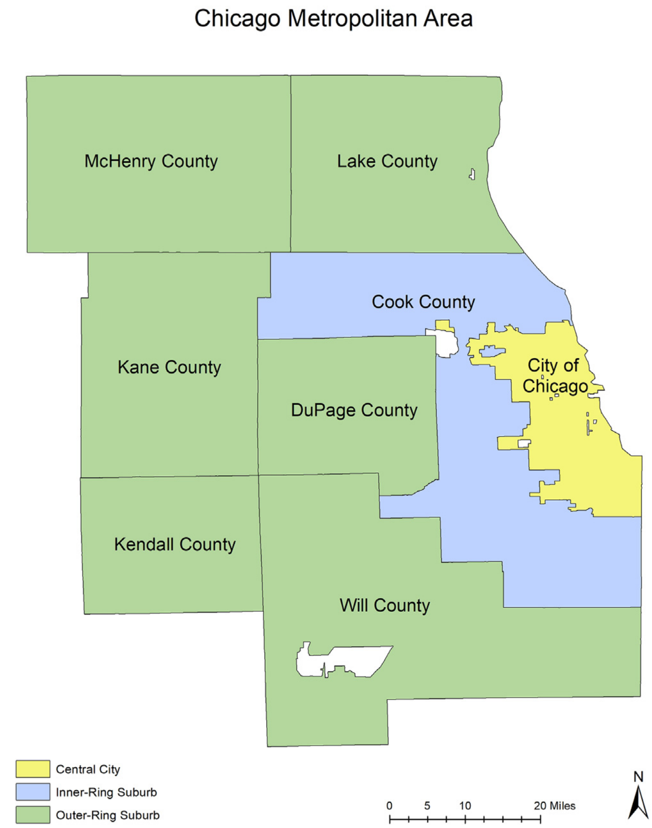


Fig. 1. The Chicago Metropolitan Area.

these transit-based commuters were low-income. Among the transit-dependent workers, nearly 70% resided in the central city, 16% resided in the inner-ring suburb and 14% resided in the outer-ring suburb.

Two census tract-level datasets of the 1,965 census tracts in the study area and two datasets that provide information about transit-based travel time and transit fare are used in this research. We choose census tract as the basic analytic unit in our study because it has been used in many traditional and recent studies on job accessibility (e.g., Blumenberg and Ong, 1998; Cervero et al., 1995; El-Geneidy et al., 2016; Ihlanfeldt and Sjoquist, 1990; Páez et al., 2013) and spatial mismatch (Cohn and Fossett, 1996; Ellwood, 1986; Hu, 2015; Ong and Miller, 2005). We decide to use census tract for our study based on the existing literature, and our result can be more meaningfully compared to the results of these studies that used the same spatial scale and analytic unit. The first dataset comes from the American Community Survey (U.S. Census Bureau, 2010). It includes the demographic data used for identifying the median income of each census tract, the percentage of the low-income population in each census tract as well as the number of unemployed people in each census tract. The second dataset is from Census Transportation Planning Products (CTPP) (2006 – 2010). It includes employment information (e.g., the total number of jobs and the number of jobs in specific industries) in each census tract in 2010, which is used to identify low-pay jobs. The third dataset includes transit-based travel time gathered through Google Maps Directions API. The fourth dataset includes transit fare in the study area and is gathered from the three transit operators in the Chicago Metropolitan Area, i.e., the Chicago Transit Authority (CTA), the Metra Commuter Rail (Metra) and the Pace Suburban Bus and Paratransit (Pace).

3.1.1. Transit fare rate and structure

Among the three transit operators in the study area, the CTA serves the transit need of the City of Chicago and its surrounding neighborhoods within Cook County. The Metra is a commuter rail that serves the

Table 1
Fare structure and rates of CTA, Pace and Metra in 2010 (in US $).

	One-Way Bus	One-Way Train	Transfer	Monthly Pass
CTA	2.00	2.25	0.25	86.00
Pace	1.75	N/A	0.25	86.00
Metra	N/A	Fare Zone Based	N/A	Fare Zone Based

transit need between the City of Chicago and the counties in the Chicago Metropolitan Area. The Pace serves all counties within the Chicago Metropolitan Area except Kendall (i.e., Cook, DuPage, Kane, Lake, McHenry, and Will Counties). We use the transit fare and employment data of 2010 to examine spatial mismatch based on transit-based job accessibility for poor job seekers; while travel time is calculated based on the current transit routes using Google Maps since the overall transit network did not change significantly since 2010. The fare structure of the CTA, Pace, and Metra in 2010 are shown in Tables 1 and 2.

The letter A-M in Table 2 represents the fare zone of the Metra. Terminals and stations in downtown Chicago are in Zone A and each outer zone generally represents an addition of 5 miles from the downtown terminals. Multiple stations of the same line could be located within the same fare zone. We consider two fare types for the study area in this research: one-way tickets and monthly passes.

We employ Google Maps Directions API to determine the travel routes and travel time between all 1965 census tracts in the study area using their centroids, considering all combinations of transit operators. Google Maps Directions API automatically takes transfer, frequency, and directness into consideration when calculating travel routes and travel time. Since Google Maps Directions API allows only a single time to be set as the departure time, we set the departure time within the morning rush hour period when many people commute and within which traffic condition does not fluctuate too much. The starting time is therefore set as 8:30 am on a weekday since 8:30 am is within the morning rush hour period. Based on the transit routes and fare structure of all three transit operators, we calculated the transit fare between the centroids of all 1965 census tracts based on one-way fare and monthly fare.

4. Analysis and findings

This study measures spatial mismatch by comparing the job accessibility of central city poor job seekers with the metropolitan area benchmark. We first measure transit-based job accessibility based on the gravity measure proposed by Shen (1998), which considers not only destination attraction (e.g., number of available job opportunities) and travel impedance (e.g., travel time and cost) but also the demand for the jobs in each census tract. Then, we use the average job accessibility score of the metropolitan area for poor job seekers as the benchmark and compare it with the job accessibility score of central city/inner-ring suburb/outer-ring suburb poor job seekers. If central city poor job seekers have lower job accessibility scores than the metropolitan area benchmark, then we consider the central city poor job seekers as suffering from spatial mismatch. Besides, we also compare the job accessibility of central city poor job seekers of different races against their respective counterparts living in the inner-ring and outer-ring suburbs in order to understand the inequity status of job accessibility across race in the study area. Although some poor job seekers living in one subregion (e.g., outer-ring suburb) might prefer to work in their residential subregion (i.e., outer-ring suburb), we do not limit their job search radius to their residential subregion in this study as we try to measure the potential transit-based accessibility to any jobs within the metropolitan area for all poor job seekers regardless of their personal preference.

4.1. Analysis of the geography of spatial mismatch

The spatial mismatch in this study specifically focuses on the mismatch between low-pay jobs and poor job seekers. We examine the mismatch by integrating both transit-based travel time cost and transit fare cost into a gravity model.

The number of low-pay jobs is determined by summing the number of jobs in four typical industries dominated by low-pay jobs (i.e., construction, manufacturing, wholesale and retail). The number of poor job seekers is estimated by multiplying the number of unemployed people, who are individuals looking for work during the last four weeks prior to the census and available to accept a job (U.S. Census Bureau, 2017), in each census tract by the percentage of low-income (i.e., lower than $21,660 according to 2010 Federal Poverty Guidelines) population in

Table 2
Fare zone and rates of Metra in 2010 (in US $).

Fare Zone	Fare Type	A	B	C	D	E	F	G	H	I	J	K	M
A	Monthly	58.05											
	One-Way	2.25											
B	Monthly	63.45	58.05										
	One-Way	2.50	2.25										
C	Monthly	90.45	63.45	58.05									
	One-Way	3.50	2.50	2.25									
D	Monthly	102.60	90.45	63.45	58.05								
	One-Way	4.00	3.50	2.50	2.25								
E	Monthly	116.10	102.60	90.45	63.45	58.05							
	One-Way	4.50	4.00	3.50	2.50	2.25							
F	Monthly	128.25	116.10	102.60	90.45	63.45	58.05						
	One-Way	5.00	4.50	4.00	3.50	2.50	2.25						
G	Monthly	139.05	128.25	116.10	102.60	90.45	63.45	58.05					
	One-Way	5.50	5.00	4.50	4.00	3.50	2.50	2.25					
H	Monthly	152.55	139.05	128.25	116.10	102.60	90.45	63.45	58.05				
	One-Way	6.00	5.50	5.00	4.50	4.00	3.50	2.50	2.25				
I	Monthly	164.70	152.55	139.05	128.25	116.10	102.60	90.45	63.45	58.05			
	One-Way	6.50	6.00	5.50	5.00	4.50	4.00	3.50	2.50	2.25			
J	Monthly	178.20	164.70	152.55	139.05	128.25	116.10	102.60	90.45	63.45	58.05		
	One-Way	7.00	6.50	6.00	5.50	5.00	4.50	4.00	3.50	2.50	2.25		
K	Monthly	190.35	178.20	164.70	152.55	139.05	128.25	116.10	102.60	90.45	63.45	58.05	
	One-Way	7.50	7.00	6.50	6.00	5.50	5.00	4.50	4.00	3.50	2.50	2.25	
M	Monthly	217.35	203.85	190.35	178.20	164.70	152.55	139.05	128.25	116.10	102.60	90.45	58.05
	One-Way	8.50	8.00	7.50	7.00	6.50	6.00	5.50	5.00	4.50	4.00	3.50	2.25

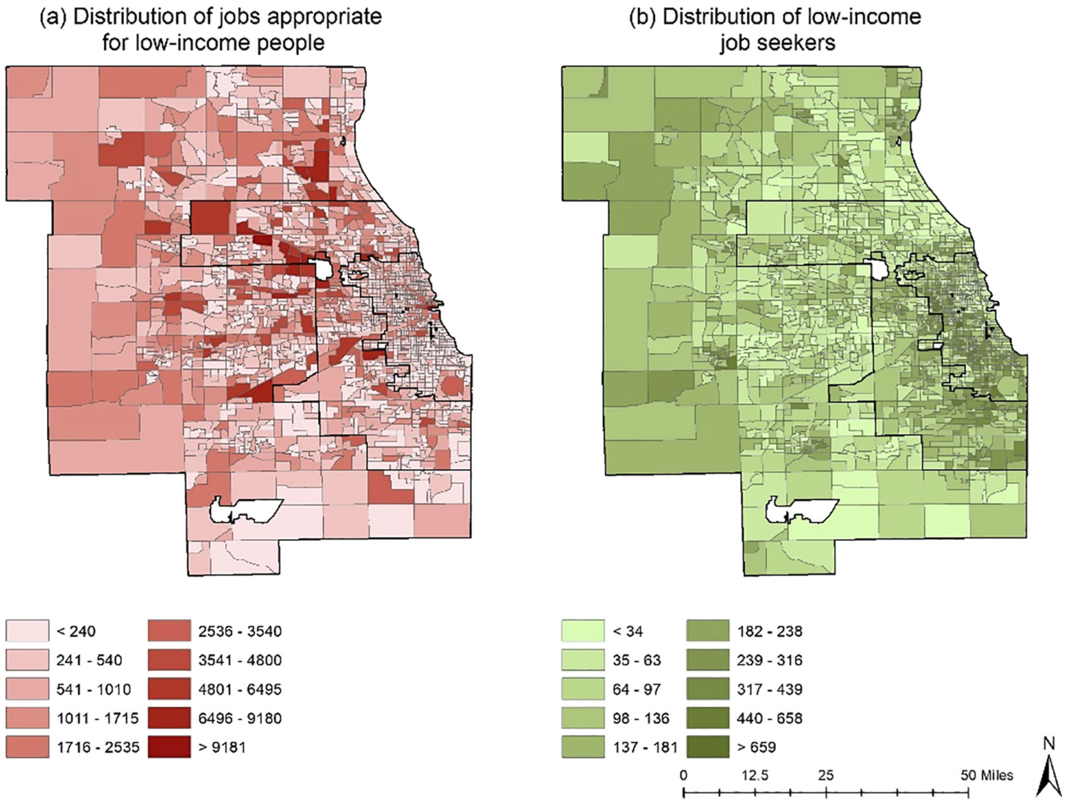


Fig. 2. Distribution of (a) low-pay jobs (b) low-income job seekers.

the same census tract. The distribution of low-pay jobs and poor job seekers can be seen in Fig. 2.

As shown in Fig. 2(a), census tracts with a high number of low-pay jobs are mostly concentrated near the boundary between the inner-ring suburb and outer-ring suburb while the central city has a higher concentration of poor job seekers but fewer low-pay jobs compared to the suburban areas, which potentially set the condition for spatial mismatch.

The transit-based travel time cost is calculated through multiplying the minimum hourly wage in the Chicago Metropolitan Area in 2010 ($8.25) by travel time while transit fare cost has been gathered as mentioned above. We then measure job accessibility based on a gravity model that considers the attraction of low-pay job opportunities weighted by the number of poor job seekers and the friction of total travel cost impedance (i.e., the sum of transit-based travel time cost and transit fare cost) and calculate the job accessibility score based on Eqs. (1), (2), (3) and (4).

$$A_i = \sum_{j=1}^{n} \frac{E_j f(O_{ij})}{S_j} \tag{1}$$

$$f(O_{ij}) = exp(-\beta(wT_{ij} + C_{ij})) \tag{2}$$

$$S_j = \sum_{k=1}^{n} P_k f(O_{kj}) \tag{3}$$

$$f(O_{kj}) = exp(-\beta(wT_{kj} + C_{kj})) \tag{4}$$

where A_i is the transit-based job accessibility for poor job seekers living in census tract i; E_j is the number of jobs in census tract j; S_j is the potential demand for jobs in census tract j; P_k is the number of poor job seekers in census tract k; $f(O_{ij})$ is the impedance function measuring the separation between census tract i and census tract j; w is the minimum hourly wage; T_{ij} is the transit-based travel time for a round trip from census tract i and census tract j; C_{ij} is the one-way fare/monthly fare cost for a round trip from census tract i to census tract j; β is the impedance function parameter; $f(O_{kj})$ is the impedance function measuring the separation between census tract k and census tract j; w is the minimum hourly wage; T_{kj} is the transit-based travel time from census tract k and census tract j; C_{kj} is the monthly transit fare cost for each one-way trip from census tract k to census tract j; β is the impedance function parameter.

We calculate the job accessibility scores under three different scenarios, i.e., 1) transit-based travel time only, 2) transit-based travel time and one-way transit fare, 3) transit-based travel time and monthly transit fare, and the results are shown in Fig. 3.

The differences in job accessibility between the results obtained with travel time only and the results obtained with both travel time and transit fare are shown in Fig. 4.

As shown in Fig. 4, after considering transit fare, job accessibility for central city poor job seekers decreases considerably while the job accessibility for most inner-ring and outer-ring suburban poor job seekers increases. The reason for having both increased and decreased job accessibility in different parts of the city is that although the increased travel impedance after integrating transit fare could decrease the access to jobs in one census tract, it may also lead to decreased job demand (i.e., number of job seekers that could reach those jobs) in this census tract at the same time. As low-pay jobs are concentrated in the suburban areas, increased travel impedance can discourage poor job seekers living in the central city from seeking low-pay jobs in the suburb and reduce the competition for suburban poor job seekers. While suburban poor job seekers also face increased travel impedance, however, due to their proximity to low-pay jobs located in the suburb, the job accessibility benefits brought by reduced competition from central city poor job seekers outweigh the job accessibility disadvantage brought by increased travel impedance.

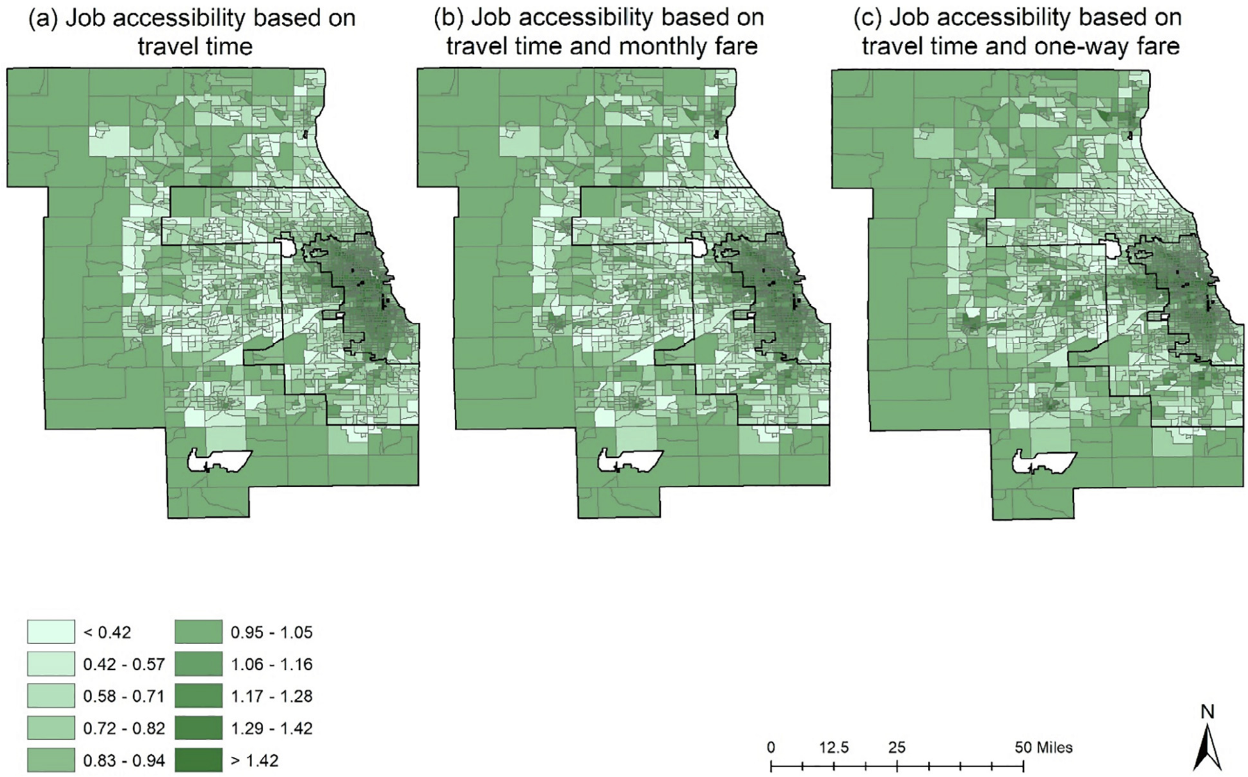


Fig. 3. Job accessibility based on (a) travel time (b) travel time and monthly fare (c) travel time and one-way fare.

4.2. Analysis and comparison of spatial mismatch

This section analyzes spatial mismatch by comparing the job accessibility of poor job seekers and that of the metropolitan area benchmark. It also examines job access inequity spatially and racially by comparing job accessibility scores across different areas (i.e., central city, inner-ring suburb and outer-ring suburb) and race (i.e., white, black and Hispanic). As the study area has a high degree of residential and economic segregation (Florida and Mellander, 2015), people living in the same census tracts tend to be racially and economically homogeneous. We first classify all census tracts based on the majority (over 50%) race into three racial categories (i.e., dominantly white, black and

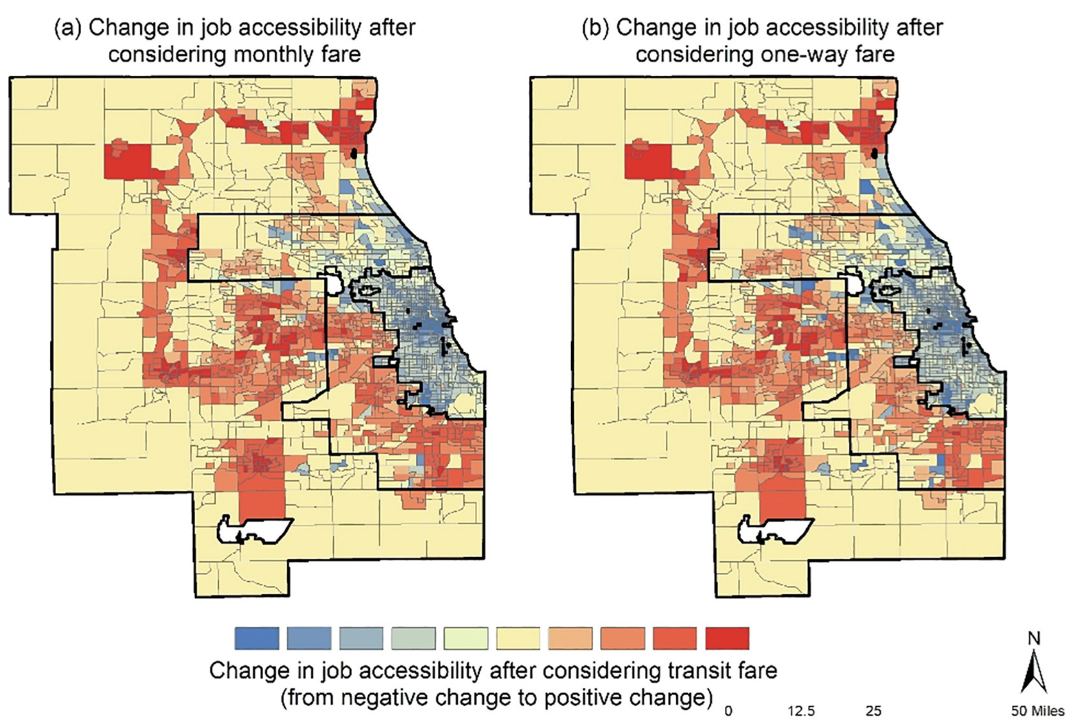
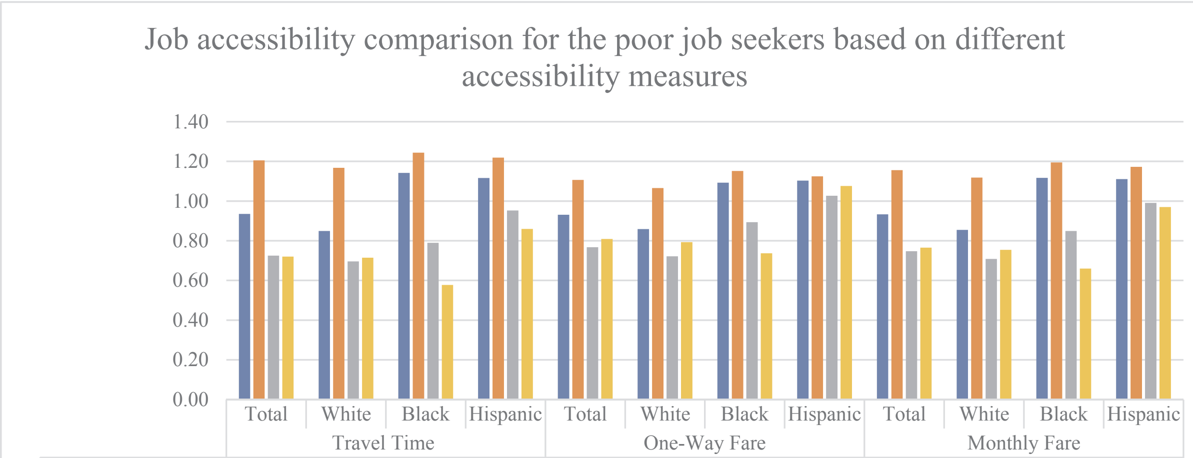


Fig. 4. Differences in job accessibility before and after considering transit fare.



	Travel Time				One-Way Fare				Monthly Fare			
	Total	White	Black	Hispanic	Total	White	Black	Hispanic	Total	White	Black	Hispanic
Metropolitan Area	0.94	0.85	1.14	1.12	0.93	0.86	1.09	1.10	0.93	0.85	1.12	1.11
Central City	1.21	1.17	1.24	1.22	1.11	1.07	1.15	1.12	1.16	1.12	1.19	1.17
Inner-Ring Suburb	0.73	0.70	0.79	0.95	0.77	0.72	0.89	1.03	0.75	0.71	0.85	0.99
Outer-Ring Suburb	0.72	0.71	0.58	0.86	0.81	0.79	0.74	1.08	0.77	0.75	0.66	0.97

Fig. 5. Job accessibility comparison for poor job seekers based on different accessibility measures.

Hispanic) and call the poor job seekers living in census tracts that have 50% or more people who are white/black/Hispanic as white/black/Hispanic poor job seekers in the following for the sake of simplicity. We then select the low-income census tracts from all census tracts and then classify them based on the majority (over 50%) race into the same three racial categories. By using the average job accessibility score of all census tracts in the Chicago Metropolitan Area under three different scenarios (i.e., travel time only, travel time and one-way fare, travel time and monthly fare) as the benchmark score, we compare the central city job accessibility score of different race with the benchmark score. If the job accessibility score of the central city is lower than that of the benchmark score, then we regard the central city as suffering from spatial mismatch.

The numbers within Fig. 5 represent job accessibility score with higher score indicating higher job accessibility and lower score indicating lower job accessibility

As shown in Fig. 5, when considering travel time only, the job accessibility score for central city poor job seekers of all races (1.21) is higher than that of the metropolitan benchmark score (0.94), while the job accessibility scores for poor job seekers of all races from both the inner-ring suburb (0.73) and outer-ring suburb (0.73) are lower than the benchmark score, which means that poor job seekers living in the central city do not suffer from spatial mismatch and actually have much better job accessibility than their suburb counterparts. When including travel time and one-way fare into the measure, the job accessibility score for central city poor job seekers of all races (1.11) is higher than that of the metropolitan benchmark score (0.93), while the job accessibility scores of both the inner-ring suburb (0.77) and the outer-ring suburb (0.81) are lower than the benchmark score, which means that poor job seekers living in the central city do not suffer from spatial mismatch and still maintain much better job accessibility than their suburb counterparts. When including travel time and monthly fare into the measure, the job accessibility score for central city poor job seekers of all races (1.16) is higher than that of the metropolitan benchmark score (0.93) while the job accessibility scores of both inner-ring suburb (0.75) and outer-ring suburb (0.77) are lower than the benchmark score, which means that poor job seekers living in the central city do not suffer from spatial mismatch and still maintain much better job accessibility than their suburb counterparts.

When different racial groups under each scenario are considered, poor job seekers of each of the three racial groups living in the central city do not suffer from spatial mismatch. Specifically, for white poor job seekers (i.e., poor job seekers living in census tracts that have 50% or more people who are white), 1) the job accessibility score of the central city (1.17) is higher than the metropolitan benchmark score (0.85), while the job accessibility scores of both the inner-ring suburb (0.70) and the outer-ring suburb (0.71) are lower than the benchmark score, which indicates white poor job seekers in the central city do not suffer from spatial mismatch when considering travel time only, and they have significantly higher job accessibility than their suburban counterparts; 2) the job accessibility score of the central city (1.07) is higher than the metropolitan benchmark score (0.86), while the job accessibility scores of both the inner-ring suburb (0.72) and the outer-ring suburb (0.79) are lower than the benchmark score, which indicates that white poor job seekers in the central city do not suffer from spatial mismatch when considering travel time and one-way fare and still maintain higher job accessibility than their suburban counterparts despite the smaller difference in central city and suburban job accessibility when compared to the travel time only scenario; 3) the job accessibility score of the central city (1.12) is higher than the metropolitan benchmark score (0.85), while the job accessibility scores of both the inner-ring suburb (0.71) and the outer-ring suburb (0.75) are lower than the benchmark score, which indicates that white poor job seekers in the central city do not suffer from spatial mismatch when considering travel time and monthly fare and maintain higher job accessibility than their suburban counterparts, while the central city-suburban job accessibility difference is similar to the travel time only scenario.

For black poor job seekers (i.e., poor job seekers living in census tracts that have 50% or more people who are black), 1) the job accessibility score of the central city (1.24) is higher than the metropolitan benchmark score (1.14), while the job accessibility scores of both the inner-ring suburb (0.79) and the outer-ring suburb (0.58) are lower than the benchmark score, which indicates that black poor job seekers in the central city do not suffer from spatial mismatch when considering travel time only and have significantly higher job accessibility than their suburban counterparts while the difference is much more prominent between the central city and the outer-ring suburb; 2) the job accessibility score of the central city (1.15) is higher than the metropolitan benchmark score (1.09) while the job accessibility scores of both the inner-ring suburb (0.89) and the outer-ring suburb (0.74) are lower than the benchmark score, which indicates that black poor job

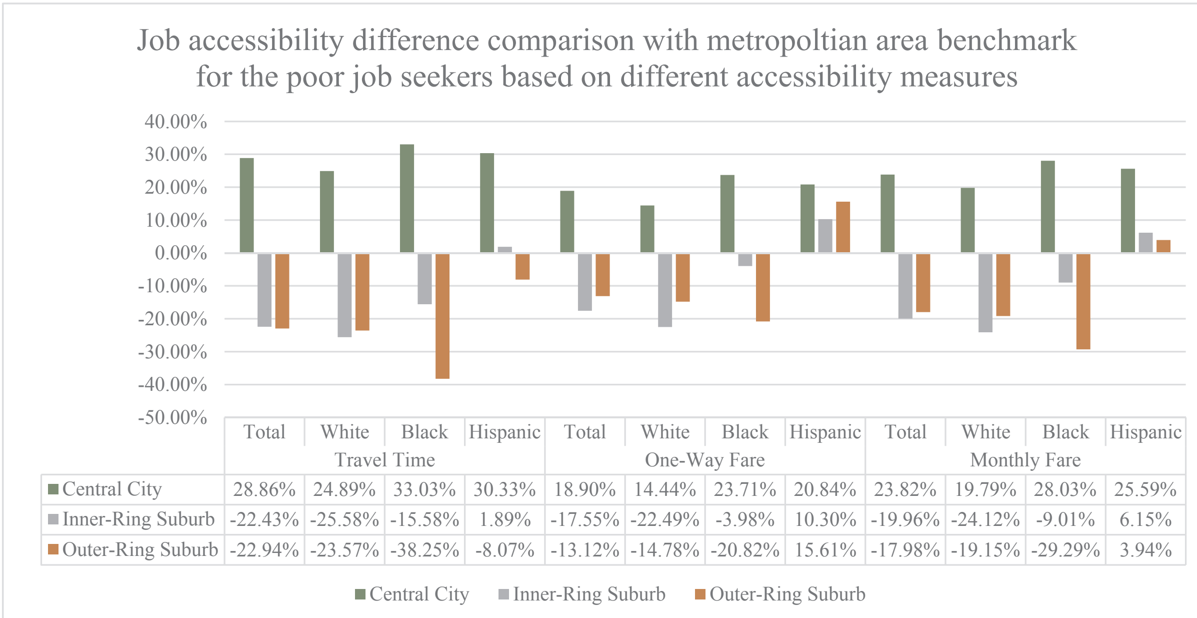


Fig. 6. Job accessibility difference comparison with metropolitan area benchmark for the poor job seekers based on different accessibility measures.

seekers in the central city do not suffer from spatial mismatch when considering travel time and one-way fare and maintain better job accessibility than their suburban counterparts while the central city-suburb difference in job accessibility narrows compared to the travel time only scenario; 3) the job accessibility score of the central city (1.19) is higher than the metropolitan benchmark score (1.12) while the job accessibility scores of both the inner-ring suburb (0.85) and the outer-ring suburb (0.66) are lower than the benchmark score, which indicates that black poor job seekers in the central city do not suffer from spatial mismatch when considering travel time and monthly fare and maintain better job accessibility than their suburban counterparts while the central city-suburb difference in job accessibility narrows compared to the travel time only scenario.

For Hispanic poor job seekers (i.e., poor job seekers living in census tracts that have 50% or more people who are Hispanic), 1) the job accessibility score of the central city (1.22) is higher than the metropolitan benchmark score (1.12), while the job accessibility scores of both the inner-ring suburb (0.95) and the outer-ring suburb (0.86) are lower than the benchmark score, which indicates that Hispanic poor job seekers in the central city do not suffer from spatial mismatch when considering travel time only and have better job accessibility than their suburban counterparts; 2) the job accessibility score of the central city (1.12) is higher than the metropolitan benchmark score (1.10) while the job accessibility scores of both the inner-ring suburb (1.03) and the outer-ring suburb (1.08) are lower than the benchmark score, which indicates that Hispanic poor job seekers in the central city do not suffer from spatial mismatch when considering travel time and one-way fare and maintain only slightly better job accessibility than their suburban counterparts while the central city-suburb difference in job accessibility almost disappears when compared to the travel time only scenario; 3) the job accessibility score of the central city (1.17) is higher than the metropolitan benchmark score (1.11) while the job accessibility scores of both the inner-ring suburb (0.99) and the outer-ring suburb (0.97) are lower than the benchmark score, which indicates that Hispanic poor job seekers in the central city do not suffer from spatial mismatch when considering travel time and monthly fare and maintain only slightly better job accessibility than their suburban counterparts while the central city-suburb difference in job accessibility decreases compared to the travel time only scenario.

Furthermore, the comparison of job accessibility for poor job seekers living in the same area (e.g., central city) across difference races shows another aspect of the job accessibility differences. When considering travel time only, 1) in the central city, black (1.24) and Hispanic (1.22) poor job seekers have similar job accessibility, both of which are slightly higher than that of white (1.17) poor job seekers; 2) in the inner-ring suburb, Hispanic (0.95) poor job seekers have the highest job accessibility, which is significantly higher than black (0.79) and white (0.70) poor job seekers; 3) in the outer-ring suburb, black (0.58) poor job seekers have the lowest job accessibility, which is significantly lower than white (0.71) and Hispanic (0.86) poor job seekers. When considering both travel time and one-way fare, 1) in the central city, black (1.15) and Hispanic (1.12) poor job seekers still have similar job accessibility, both of which are slightly higher than white (1.07) poor job seekers; 2) in the inner-ring suburb, Hispanic (1.03) poor job seekers have the highest job accessibility, which is significantly higher than those of black (0.89) and white (0.72) poor job seekers; 3) in the outer-ring suburb, black (0.74) poor job seekers still have the lowest job accessibility but has become closer to that of white (0.79) poor job seekers, and job accessibility of both of these two groups is still significantly lower than that of Hispanic (1.08) poor job seekers. When considering both travel time and monthly fare, 1) in the central city, black (1.19) and Hispanic (1.17) poor job seekers have similar job accessibility, which is slightly higher than that of white (1.12) poor job seekers; 2) in the inner-ring suburb, Hispanic (0.99) poor job seekers have the highest job accessibility, which is significantly higher than that of black (0.85) and white (0.71) poor job seekers; 3) in the outer-ring suburb, black (0.66) poor job seekers again have the lowest job accessibility, which again is significantly lower than that of white (0.75) and Hispanic (0.97) poor job seekers. Overall, white poor job seekers have the worst job accessibility compared to black and Hispanic counterparts in both the central city and the inner-ring suburb. In the inner-ring suburb, Hispanic poor job seekers have significantly higher job accessibility than their white and black counterparts. In the outer-ring suburb, black poor job seekers have the worst job accessibility compared to their white and Hispanic counterparts and Hispanic poor job seekers maintain significantly higher job accessibility than white poor job seekers.

Fig. 6 is created to better illustrate the job accessibility differences before and after including transit fare and across different areas and races in the study area.

The percentage figures within Fig. 6 mean job accessibility score difference compared with metropolitan area benchmark job accessibility score. Positive bar indicates better job accessibility than metropolitan area average and negative bar indicates worse job accessibility than metropolitan area average. The length of positive/negative bar indicates the degree of difference (i.e., the longer the positive/negative bar, the better/worse the area's job accessibility than the metropolitan area average).

As shown in Fig. 6, poor job seekers in the central city generally do not suffer from spatial mismatch. In comparison, poor job seekers of all races in both the inner-ring suburb and the outer-ring suburb have lower job accessibility compared to their central city counterparts. Such a phenomenon can be explained by that the central city has better transit coverage compared to the inner-ring suburb and the outer-ring suburb, which provides central city poor job seekers with better transit-based access to low-pay jobs. It also reflects that although low-pay jobs are concentrated in the suburban areas, poor job seekers living in the suburb lack the transit-based access to those jobs. It is also noteworthy that job accessibility of the entire metropolitan area lowers slightly from 0.94 to 0.93 after taking transit fare into consideration. However, when considering different areas and races, the change in job accessibility presents both increases and decreases.

For poor job seekers of all races in the central city, the job accessibility score decreases significantly after taking transit fare into account. In contrast, for poor job seekers of all races in both the inner-ring suburb and the outer-ring suburb, the job accessibility score increases significantly after considering transit fare. Although taking transit fare into account can increase travel impedance to low-pay jobs, it also increases the travel impedance for potential poor job seekers and reduces the number of poor job seekers who are able to access those jobs. As the low-pay jobs are geographically concentrated in the suburban areas, the reduced competition is more helpful for people living in proximity to these job opportunities. The results show that 1) for poor job seekers in the inner-ring suburb and the outer-ring suburb, the benefits (i.e., reduced number of poor job seekers competing for low-pay jobs) outweigh the disadvantage (i.e., increased barrier to access low-pay jobs) brought by increased travel impedance from including transit fare; 2) for poor job seekers in the central city, the disadvantage (i.e., increased barrier to access low-pay jobs) outweigh the benefits (i.e., reduced number of poor job seekers competing for low-pay jobs) brought by increased travel impedance from including transit fare as the low-pay jobs are concentrated in the suburban area. Although central city poor job seekers do not suffer from spatial mismatch regardless whether transit fare is considered or not, we can see that, based on the job accessibility score, metropolitan area and central city job accessibility for poor job seekers are overestimated without considering transit fare while inner-ring suburb and outer-ring suburb job accessibility for poor job seekers are underestimated without considering transit fare. Nevertheless, it is still obvious that job accessibility for poor job seekers of all races in the central city is better than their counterparts in the inner-ring suburb and the outer-ring suburb.

The comparison of job accessibility of the inner-ring suburb and the outer-ring suburb presents a more complicated picture. When considering travel time only, white poor job seekers in the outer-ring suburb have slightly better job accessibility than their inner-ring counterparts while black and Hispanic poor job seekers in the inner-ring suburb have significantly better job accessibility compared to their outer-ring suburb counterparts. When considering travel time and transit fare, white poor job seekers in the outer-ring suburb have significantly better job accessibility than their inner-ring counterparts, while black poor job seekers in the inner-ring suburb maintain significantly better job accessibility compared to their outer-ring suburb counterparts. Interestingly, when one-way fare is included, Hispanic poor job seekers in the outer-ring suburb have better job accessibility than their inner-ring suburb counterparts, which is in reverse of the results obtained with considering travel time only. When including monthly fare, Hispanic poor job seekers in the inner-ring suburb have slightly better job accessibility than their outer-ring suburban counterparts, which narrows the difference compared to considering travel time only.

Overall, in terms of job accessibility based on race, Hispanic poor job seekers in all three areas have better job accessibility scores than the average metropolitan area benchmark after considering transit fare. White and black poor job seekers in the central city also have better job accessibility scores than the average metropolitan area benchmark after considering transit fare. However, white and black poor job seekers living in the inner-ring suburb and the outer-ring suburb have lower job accessibility than the average metropolitan area benchmark after considering transit fare, while black poor job seeks have relatively better job accessibility than white poor job seekers in the inner-ring suburb but worse job accessibility than white poor job seekers in the outer-ring suburb.

5. Discussion and conclusions

This study improves the measurement of spatial mismatch by considering both the attraction of low-pay jobs weighted by poor job seekers and the friction of travel impedance of travel time and transit fare when measuring transit-based job accessibility.

Our results present a complicated picture before and after considering transit fare when measuring transit-based job accessibility for poor job seekers of different races living in different areas of the city. Overall, poor job seekers living in the central city do not suffer from spatial mismatch and have better job accessibility compared to their counterparts living in the inner-ring and outer-ring suburbs. Nevertheless, there is a clear concentration of poor job seekers residing in the central city, which indicates that there are probably other reasons behind the high concentration of poor job seekers in the central city as poor job seekers in the central city do not suffer from spatial mismatch.

In summary, in terms of job accessibility based on area, central city poor job seekers have better job accessibility compared to their counterparts living in the inner-ring suburb and the outer-ring suburb as evaluated by all three accessibility measures. With regard to job accessibility based on race, black and Hispanic poor job seekers have better job accessibility than white poor job seekers relative to the average metropolitan area job accessibility. Nevertheless, white poor job seekers living in the inner-ring suburb, as well as white and black poor job seekers living in the outer-ring suburb, have the worst transit-based job accessibility as assessed by all three accessibility measures. Therefore, future polices regarding transit improvement should be more concerned with white and black poor job seekers living in the suburbs.

We acknowledge the limitation of estimating travel costs based on the centroid-to-centroid travel time in this paper and intend to address this limitation by exploring alternative methods for estimating more accurate travel costs in future studies. Future work should also explore the effectiveness of different measures (e.g., concessionary fare to lower travel cost, speed rise to reduce travel time) for improving job accessibility for poor job seekers based on their areas of residence as well as race. Besides, future work could try to study job accessibility under spatial units that are easier for policy makers of different tiers of government agencies to interpret in order to facilitate the decision-making process.

References

Blumenberg, E., 2004. En-gendering effective planning: spatial mismatch, low-income women, and transportation policy. J. Am. Plann. Assoc. 70 (3), 269–281.
Blumenberg, E., Manville, M., 2004. Beyond the spatial mismatch: welfare recipients and transportation policy. J. Plann. Lit. 19 (2), 182–205.
Blumenberg, E., Ong, P., 1998. Job accessibility and welfare usage: evidence from Los Angeles. Journal of Policy Analysis and Management: The Journal of the Association for Public Policy Analysis and Management 17 (4), 639–657.
Blumenberg, E., Pierce, G., 2012. Automobile ownership and travel by the poor: Evidence

from the 2009 National Household Travel Survey. Transp. Res. Rec. 2320 (1), 28–36.
Blumenberg, E., Shiki, K., 2004. Spatial mismatch outside of large urban areas: an analysis of welfare recipients in Fresno County, California. Environ. Plann. C: Government and Policy 22 (3), 401–421.
Bocarejo S, J.P., Oviedo H, D.R., 2012. Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments. J. Transp. Geogr. 24, 142–154.
Brown, A.E., 2018. Fair fares? How flat and variable fares affect transit equity in Los Angeles. Case Stud. Transp. Policy 6 (4), 765–773.
Bureau, B., Glachant, M., 2011. Distributional effects of public transport policies in the Paris Region. Transp. Policy 18 (5), 745–754.
Carruthers, R., Dick, M. and Saurkar, A., 2005. Affordability of public transport in developing countries.
Cervero, R., 1990. Transit pricing research. Transportation 17 (2), 117–139.
Cervero, R., Rood, T. and Appleyard, B., 1995. Job accessibility as a performance indicator: An analysis of trends and their social policy implications in the San Francisco Bay Area.
Cohn, S., Fossett, M., 1996. What spatial mismatch? The proximity of blacks to employment in Boston and Houston. Soc. Forces 75 (2), 557–573.
Dickens, M. and Neff, J., 2011. APTA 2011 Public Transportation Fact Book.
El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., Loong, C., 2016. The cost of equity: Assessing transit accessibility and social disparity using total travel cost. Transp. Res. Part A: Policy and Practice 91, 302–316.
Ellwood, D.T., 1986. The spatial mismatch hypothesis: Are there teenage jobs missing in the ghetto? In: The black youth employment crisis. University of Chicago Press, pp. 147–190.
Fan, Y., Allen, R., Sun, T., 2014. Spatial mismatch in Beijing, China: Implications of job accessibility for Chinese low-wage workers. Habitat International 44, 202–210.
Farber, S., Bartholomew, K., Li, X., Páez, A., Habib, K.M.N., 2014. Assessing social equity in distance based transit fares using a model of travel behavior. Transp. Res. Part A: Policy and Practice 67, 291–303.
Florida, R., Mellander, C., 2015. Segregated city: The geography of economic segregation in America's metros. Martin Prosperity Institute.
Gabriel, S.A., Rosenthal, S.S., 1996. Commutes, neighborhood effects, and earnings: An analysis of racial discrimination and compensating differentials. J. Urban Econ. 40 (1), 61–83.
Garrett, M., Taylor, B., 1999. Reconsidering social equity in public transit. Berkeley Plann. J. 13 (1).
Geurs, K.T., Van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. J. Transp. Geogr. 12 (2), 127–140.
Giuliano, G., 2005. Low income, public transit, and mobility. Transp. Res. Rec. 1927 (1), 63–70.
Haddad, E.A., Barufi, A.M.B., 2017. From rivers to roads: spatial mismatch and inequality of opportunity in urban labor markets of a megacity. Habitat International 68, 3–14.
Hellerstein, J.K., McInerney, M. and Neumark, D., 2009. Spatial mismatch, immigrant networks, and Hispanic employment in the United States (No. w15398). National Bureau of Economic Research.
Holloway, S.R., 1996. Job accessibility and male teenage employment, 1980–1990: The declining significance of space? The Professional Geographer 48 (4), 445–458.
Holzer, H.J., Ihlanfeldt, K.R., Sjoquist, D.L., 1994. Work, search, and travel among white and black youth. J. Urban Econ. 35 (3), 320–345.
Hu, L., 2015. Job accessibility of the poor in Los Angeles: Has suburbanization affected spatial mismatch? J. Am. Plann. Assoc. 81 (1), 30–45.
Ihlanfeldt, K.R., Sjoquist, D.L., 1990. Job accessibility and racial differences in youth employment rates. Am. Econ. Rev. 80 (1), 267–276.
Ihlanfeldt, K.R., Sjoquist, D.L., 1998. The spatial mismatch hypothesis: a review of recent studies and their implications for welfare reform. Housing Policy Debate 9 (4), 849–892.
Johnston-Anumonwo, I., 1997. Race, gender, and constrained work trips in Buffalo, NY, 1990. The Professional Geographer 49 (3), 306–317.
Johnson, D., Ercolani, M., Mackie, P., 2017. Econometric analysis of the link between public transport accessibility and employment. Transp. Policy 60, 1–9.
Kain, J.F., 1968. Housing segregation, negro employment, and metropolitan decentralization. Q. J. Econ. 82 (2), 175–197.
Liu, C.Y., Painter, G., 2012. Immigrant settlement and employment suburbanisation in the US: Is there a spatial mismatch? Urban Studies 49 (5), 979–1002.
McLafferty, S., Preston, V., 1992. Spatial mismatch and labor market segmentation for African-American and Latina women. Economic Geography 68 (4), 406–431.
Ong, P.M., Miller, D., 2005. Spatial and transportation mismatch in Los Angeles. J. Plann. Educ. Res. 25 (1), 43–56.
Páez, A., Farber, S., Mercado, R., Roorda, M., Morency, C., 2013. Jobs and the single parent: an analysis of accessibility to employment in Toronto. Urban Geography 34 (6), 815–842.
Painter, G., Liu, C.Y., Zhuang, D., 2007. Immigrants and the spatial mismatch hypothesis: Employment outcomes among immigrant youth in Los Angeles. Urban Studies 44 (13), 2627–2649.
Parks, V., 2004. Access to work: The effects of spatial and social accessibility on unemployment for native-born black and immigrant women in Los Angeles. Economic Geography 80 (2), 141–172.
Preston, V., McLafferty, S., 1999. Spatial mismatch research in the 1990s: progress and potential. Papers in Regional Science 78 (4), 387–402.
Qi, Y., Fan, Y., Sun, T., Hu, L., 2018. Decade-long changes in spatial mismatch in Beijing, China: Are disadvantaged populations better or worse off? Environ. Plann. A: Economy and Space 50 (4), 848–868.
Raphael, S., 1998. The spatial mismatch hypothesis and black youth joblessness: Evidence from the San Francisco Bay Area. J. Urban Econ. 43 (1), 79–111.
Sanchez, T.W., 1999. The connection between public transit and employment: the cases of Portland and Atlanta. J. Am. Plann. Assoc. 65 (3), 284–296.
Shen, Q., 1998. Location characteristics of central city neighborhoods and employment accessibility of low-wage workers. Environ. Plann. B: Planning and Design 25 (3), 345–365.
Stoll, M.A., Covington, K., 2012. Explaining racial/ethnic gaps in spatial mismatch in the US: The primacy of racial segregation. Urban Studies 49 (11), 2501–2521.
Taylor, B.D., Ong, P.M., 1995. Spatial mismatch or automobile mismatch? An examination of race, residence and commuting in US metropolitan areas. Urban Studies 32 (9), 1453–1473.
Tomer, A., Kneebone, E., Puentes, R., Berube, A., 2011. Missed opportunity: Transit and jobs in metropolitan America. Institute, Brookings.
Tyndall, J., 2017. Waiting for the R train: Public transportation and employment. Urban Studies 54 (2), 520–537.
U.S. Census Bureau, 2010. American Community Survey 5-Year Estimates.
U.S. Census Bureau, 2017. American Community Survey and Puerto Rico Community Survey 2017 Subject Definitions, pp. 66-67.
Yi, C., 2006. Impact of public transit on employment status: disaggregate analysis of Houston, Texas. Transp. Res. Rec. 1986 (1), 137–144.
Zhou, S., Wu, Z., Cheng, L., 2013. The impact of spatial mismatch on residents in low-income housing neighbourhoods: a study of the Guangzhou metropolis, China. Urban Studies 50 (9), 1817–1835.
Zhou, X., Chen, X., Zhang, T., 2016. Impact of megacity jobs-housing spatial mismatch on commuting behaviors: A case study on central districts of Shanghai, China. Sustainability 8 (2), 122.