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Does green transportation promote accessibility for equity in medium-size U.S. cites?

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ABSTRACT

The link between accessibility and social equity attracts much attention for promoting sustainability. However, there is no comprehensive approach to elevate the role of accessibility in evaluating transportation system over social equity by considering the variety of urban opportunities and population groups from green transportation perspective. Our goal is to develop such a framework to evaluate transportation equity by focusing on accessibility via transit and cycling. Applying the framework to Fresno, California, and Cincinnati, Ohio with different development patterns, we delineate service areas at block-group level with five time-thresholds. The service area is used to count the number of urban opportunities: jobs, dining, churches, libraries, parks, multi-use paths, schools. We then use statistical comparison and geographical mapping to identify accessibility gap to these opportunities between advantaged and disadvantaged groups defined by income, property value, education, vehicle ownership, race, and age. The results indicate the extent of differences in accessibility is sensitive to threshold specification of grouping population. The findings suggest that the efficiency of transit service needs to be improved to reach the same level of cycling, while they do help with the accessibility for economically disadvantaged neighborhoods. Considering school enrollment, the accessibility to opportunities in Fresno performs differently while students in Cincinnati benefit from good accessibility to most resources. The results of accessibility to multi-use paths highlight the need of providing more efficient green transportation facilities for less wealthy neighborhoods. Variation in accessibility between groups underscores the importance of developing policies to meet the needs of diverse social groups.

1. Introduction

A paradigm shift from mobility-based to accessibility-based planning is extensively praised in literature to address the conflicts between physical movement, people, and places (Cervero et al., 2017; Levine, 2013; Levine et al., 2019). While there are efforts to explore accessibility to support this shift (Chen and Akar, 2017; Bocarejo and Oviedo, 2012), debates and arguments of measuring and analyzing accessibility and advancing its practical connection with social equity still remain. Geurs and van Wee (2004) and Bocarejo and Oviedo (2012) synthesized the debates and arguments based on four components including transport, land-use, temporal, and individual. Different consideration of these components and their relationships decide the measurement techniques and corresponding indicators.

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Our goal is to develop an analytic framework to comprehensively evaluate transportation equity by focusing on accessibility to a variety of urban opportunities via green transportation in terms of transit and cycling. The main idea of developing such a comprehensive framework is to highlight the importance of examining different urban opportunities for different social groups using multiple thresholds for equity concerns through the lens of green transportation, rather than providing exhaustive lists of different opportunities by different social groups and the designed thresholds. Broadly, green transportation is defined as a type of transportation service that "has a lesser or reduced negative impact on human health and the natural environment when compared with competing transportation services that serve the same purpose" (Björklund, 2011). Based on this definition, green transportation modes available in this era mainly include bicycle, pedestrians, public transit with green energy, electric bikes/vehicle/motorcycle, scooter, hybrid car, etc. As compared to driving a private vehicle, using transit or cycling is more affordable, feasible, and sustainable from the perspective of equity. This study therefore focuses on public transit and cycling as two typical green transportation options for equity concern.

This study applies the framework to two U.S. cities, Fresno, California, and Cincinnati, Ohio which represent growing and declining development patterns respectively. At the block-group level as a proxy for community, we delineate service areas with the thresholds of 10-, 20-, 30-, 45-, and 60-minute based on street network datasets built separately for transit, bicycle, and auto travel as a comparison. The resulting service area is used to count the number of three groups of urban opportunities selected for transportation equity analysis. We then use statistical comparison and geographical mapping to examine the existence of spatial mismatch in the computed accessibility between socially advantaged and disadvantaged neighborhoods defined by income, education, property value, vehicle ownership, race, and age. People with different socio-economic status in different urban contexts may suffer from different types of transport exclusion in terms of low accessibility to an urban opportunity by using transit, cycling, and auto. Most studies show that automobiles provide better access to opportunities than other modes (Levinson, 1998; Wang and Chen, 2015). However, the accessibility gap may be narrowed down between auto and non-auto when more efficient green transportation infrastructure and services are provided. The differences in accessibility by using green transportation modes imply the importance of developing policies to satisfy various needs of social groups without using auto as the primary mode. The "market" of accessibility analysis by public transit is prolific along with maturing data collection and editing on transit (e.g., General Transit Feed Specification) and activity destinations (e.g., GPS tracking through smartphone apps) (Chang et al., 2019; El-Geneidy et al., 2016; Farber et al., 2014). Analysis results vary significantly due to the application of different criteria in the definition and measurement of all the key concepts. This calls for a comprehensive framework to highlight the importance of capturing these varieties. Therefore, we develop the accessibility framework to address the following two research questions: (1) whether accessibility by green transportation modes to urban opportunities is equal between advantaged and disadvantaged groups defined by a variety of social status, and (2) whether green transportation is efficient enough to access urban opportunities. This framework not only contributes to evaluate transportation equity from a more comprehensive perspective by considering a variety of dimensions to divide population and define urban opportunities, but also contributes to integrate green transportation and social equity in a quantitative analysis approach.

2. Literature review

With the notion of sustainable transportation, the relationships between green transportation, equity and accessibility have been gaining attention from different fields such as transportation planning and transport geography (Bocarejo S and Oviedo H, 2012; Lucas et al., 2016). This progressive trend is particularly supported and promoted by the legislation and regulations like the Transportation Equity Act for the 21st Century (TEA-21), emerging technologies in transportation for collecting and analyzing more data and increasing positive knowledge on the adoption of green transportation. However, there are three key challenges arising in this trend. First, there is no consistent definition and measurement of transportation equity in both research and practice. For instance, people can be grouped from various perspectives to reflect the dimension of social equity. Second, there are a variety of approaches to identify the "space" in operationalizing accessibility to reflect people's mobility using different transportation modes. Green transportation modes in terms of transit and cycling in this study have not been comprehensively and broadly examined in this operationalization process by considering those varieties. Third, the ways that select urban opportunities for accessibility analysis significantly vary to represent people's different needs for a quality of life and equity concern. These issues have challenged the inclusion of accessibility-related indicators in promoting social equity in transportation planning process and corresponding policy adoption and implementation.

Based on these key challenges, the remaining sub-sections of this literature review summarize and discuss the concept of transportation equity, how accessibility has been measured with a focus on green transportation, and the relationships between transportation equity, accessibility, and green transportation. These discussions highlight the significance of developing a relatively comprehensive framework to enhance the incorporation and implementation of equity-based accessibility indicators in transportation planning.

2.1. Transportation equity

There are generally two perspectives to define social equity in literature. The first perspective is based on three equality approaches, including equality of welfare, equality of resources, and capability approach (Cohen, 1990; Gosepath, 2011; Sen, 1995). The first two approaches do not consider different social groups' variability in their final travel need which is not physical movement itself but what they can access through physical movement (Martens and Golub, 2011). Therefore, Chen (2016), Beyazit (2011), Rashid et al. (2010), and Smith et al. (2012) switched their attention to the capability approach which explains transportation equity as travelers' capability to access social resources under their constraints.

The other perspective emphasizes "equity" from horizontal and vertical approaches which were comprehensively defined and discussed by Litman (2002) for transportation equity. For instance, horizontal equity in transportation treats everybody equally in transportation planning process and transportation service distribution. Vertical transportation equity is defined regarding income and social class, mobility needs and ability. Progressive policies based on vertical equity regarding income and social class concern about economically and socially disadvantaged groups' affordability in traveling (Blumenberg, 2017). Comparatively, vertical equity regarding mobility needs and ability extends people's concern from traditional socio-economic groups to all travelers with mobility impairments like seniors (Carleton and Porter, 2018).

The selection of any equality or equity approach for transportation would influence the categories of impacts placed from transportation systems, the methods to measure these impacts, and the ways to categorize people (Litman, 2002). The variances of these influence could be aggregated into mobility- and accessibility-based transportation planning as two main planning paradigms for transportation equity. Conventional planning based on mobility favors faster and longer auto-dependent traveling through increasing vehicle traffic speeds and volumes to justify roadway expansion projects (Litman, 2012). In the past decades, accessibility-based planning has gradually dominated the trend due to its advantage on capturing a variety of travel groups' needs based on their own capabilities and the consideration of green transportation modes relative to auto driving (Sanchez et al., 2003). Grengs (2015a, b, 2019) has been devoting significant efforts in elevating accessibility in social equity analysis of transportation policies from both qualitative and quantitative perspectives. Despite all that, there is limited argument in these analyses and discussions with a focus of green transportation. Residents' quality of life, particularly who have limited access to private automobiles, is more or less impaired by the auto-oriented urban structure (Akar et al., 2016; Wang and Chen, 2015). While there are studies suggesting a strong link between the economic outcomes of low-income adults and access to a car, the evidence on the relationship between green transportation modes and socio-economic outcomes within an accessibility framework is still limited. Particularly, limited attention has been paid to the significance of applying the nature of controversy in transportation equity itself to support a comprehensive framework that captures this nature as proposed in this study. This thus constitutes the main theoretical basis for our study, which is rarely addressed in most existing quantitative accessibility studies.

2.2. Accessibility measures

Accessibility is defined as the ease of reaching activities using different transportation modes under certain constraints (Bhat, 2000; Geurs and van Wee, 2004; Shen, 1998). However, there are debates about how to measure this concept. This is one major reason for the second challenge described above. The cumulative-opportunity approach as one typical location-based measure has been widely used in existing studies with the advantage of relatively easy operationalization, interpretation and communication (Castiglione et al., 2006; Fan et al., 2012; Wang and Chen, 2015). This approach is specified as the count of the number of urban opportunities that can be reached within certain space. Such space (service area) could be delineated using Euclidean distance, or street network, or activity space (Chen and Akar, 2017; Tian et al., 2017; Wang and Chen, 2015). Among these methods, street network is the approach considering roadways that Euclidean distance approach does not but undertakes less burden on collecting activity-travel data like activity space approach.

When applying the delineated "space" to capture urban opportunities, it is crucial to identify opportunity types for different equity concerns. Most existing accessibility studies focus on one single opportunity such as jobs and parks (Chang et al., 2019; Coombes et al., 2010; Dai, 2011; Fan et al., 2012; Wang and Chen, 2015). Fan et al. (2012)'s analysis of before-after job accessibility changes from a transit project in the Twin Cities shows that the magnitude of job accessibility increases among low-wage workers is larger than that of medium- and high-wage workers who live in areas near downtown and north light rail stations. Focusing on concern for physical activities. Chang et al. (2019) looked into the difference in urban park accessibility using walking, bus, and mass transit railway between urban residents living in large public and private housing estates in Hong Kong and reported the existence of spatial inequality of urban park accessibility by public transit. However, families' quality of life is predicated on access to a variety of destinations, not simply one. For instance, Chen and Akar (2017) reported differences in accessibility to four types of jobs and land uses by income, race, gender, and age. Specifically, adolescents and elderly have lower accessibility to commercial and industrial land uses and industrial jobs and individuals in low-income households access fewer office jobs. Accessibilities to some other non-work destinations have been also investigated, such as convenience stores, childcare facilities, religious organizations, and hospitals, which were compared by Grengs (2015b) to identify inequity in vulnerable social groups. Therefore, it is important to explore accessibility to diverse urban opportunities by considering different equity concerns. The findings would provide information for targeting a specific group to promote the use of certain transportation mode to access a specific type of urban opportunity.

2.3. Equity, accessibility, and green transportation

While it is theoretically recognized that sustainable policy focus should be on improving accessibility by green transportation for people with limited capability to own/use a car, the fact is that most people regardless of their limitations still rely on automobiles when living in a typical medium-size U.S. city. However, low usage of non-auto (e.g., transit and bike) does not downgrade the significance of studying accessibility by green transportation. Ignoring the potential accessibility by green transportation modes in a city dominated by auto travel would weaken the arguments for investing transit and bike related facilities. It is therefore better to understand whether promoting accessibility by green modes would help deal with social inequity issues even only for a small group of population currently using these modes.

For example, Guzman et al. (2017) calculated and compared average accessibility levels per capita and income groups by car, regular bus, and BRT. The interesting result is not the accessibility gap between modes but the increased differences in accessibility by transit between low-, medium-, and high-income groups. Li et al. (2019) incorporated perceptions and attitudes toward residents' community as a subjective accessibility concept to explore its impact on walking behavior. The results called for the importance of promoting more walkable communities for socially disadvantaged groups like low-income people and the elderly to increase their community participation. Braun et al. (2018) investigated the existence of social inequity in access to cycling infrastructure at the block-group level using data from 23 large U.S. cities. With or without adjusting cycling demand in the exploration of the associations between bike lanes and socio-demographic variables, distributional inequities in the provision of cycling facilities were found for certain disadvantaged groups. The difference before and after adjustment is because that the disadvantage status was defined by different socio-demographic variables.

With an attempt to fill the gap in understanding how newcomers, particularly low-income immigrants, access jobs and services using public transit, Barajas et al. (2018) explored low-income immigrant public transit riders' travel demand, attitudes, and perceptions as compared to those of others using an intercept survey for the central San Francisco Bay Area. This concerned population group was found to be less likely to have a bus pass or to have a bicycle. Moreover, they were not willing to use transit when driving is an available option. The authors identified the main reasons as the lack of access to the fare information and the spatial mismatch between where transit services are provided and what low-immigrants need. From a perceptual perspective, this finding supports the spatial mismatch hypothesis which has been broadly discussed in the literature as an inequality argument against many current public transportation systems and urban development structures. Without data on travel attitudes and perceptions but using objective approaches to measure accessibility (e.g., geographical accessibility), results regarding spatial mismatch might differ significantly. For instance, Chen and Akar (2017) did not find significant difference in accessibility to most types of jobs between low-income population clustering in urban core areas and others in Cleveland.

Theoretically and politically, green transportation in terms of public transit and cycling has been strongly promoted to advance transportation equity from the standing points of safety, environmental sustainability, accessibility, and affordability. For instance, many state, regional, and local governmental agencies have launched strategic programs for improving transportation equity through funding alternative transportation options, such as California's Sustainable Transportation Equity Project and the City of Seattle's Transportation Equity Program. These strategies and equity goals are conceptually supported by some studies on the relationship between transportation equity and accessibility. For example, Karner et al. (2016) comprehensively reviewed and assessed transportation equity to provide transportation decision makers, planners, policymakers, advocates, and also the general public with a common language on an equitable transportation system. The authors not only found that race, ethnicity, and income are mostly considered in transportation policy and planning, but also reported that significant disparities exist in accessibility to jobs, opportunities for physical activity, healthy good, and health care. Many existing accessibility analysis results identify mismatch between what certain social disadvantaged groups need and where the transportation resources are provided. One problem is that most of them focus on one accessibility issue (e.g., jobs) and cannot comprehend all the specific equity concerns. One may suffer from one accessibility issue but not from another. One accessibility issue may exist in one city but not in another. It is therefore urgent to comprehensively and empirically understand how different concerned social groups experience accessibility to different destinations with green transportation modes as specified to transit and cycling in this study in different urban contexts.

3. Study areas and data

This study applies the analytic framework to two U.S. medium-size cities, Fresno, California, and Cincinnati, Ohio (Figs. 1 and 2), which represent urban growing and declining respectively in terms of population change trend (Table 1). As compared to Fresno locating in relatively flat region with hot weather, Cincinnati's hilly topography and lengthy cold winter might make the land-use and transportation system and resulting travel and activity behavior differently. The main similarities and differences of these two cities are presented in Table 1. We examine how the accessibility patterns in these two comparable cities differ for the concerned social groups using this framework.

For this analysis, we assemble three types of data. First, street and transit datasets are collected and edited from the OpenStreetMap (OSM) and the General Transit Feed Specification (GTFS) with the tools in ArcGIS 10.6 to construct the service area by different transportation modes. The two transit authorities in the study areas provide the GTFS format data. Second, urban opportunities cover five categories, including jobs, dining (fast and family restaurants, physical activities (parks and multi-use paths), social activities (church and library), and schools. The *Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics* (LODES) provides job data at the workplace through 2015. The locations of restaurants, multi-use paths, church, library, and schools are extracted from the OSM street and amenity data. The GIS departments in two cities provided us with spatial data on parks. The data of socio-economic factors which are used to characterize neighborhoods are from the 2017 5-year American Community Survey, including median household income, median property value, school non-enrollment (a measure of the share of students of a neighborhood), vehicle ownership, race, and age (Table 2).

4. Methods

We present the overall study design in Fig. 3, including four parts which we specifically discuss in this section.

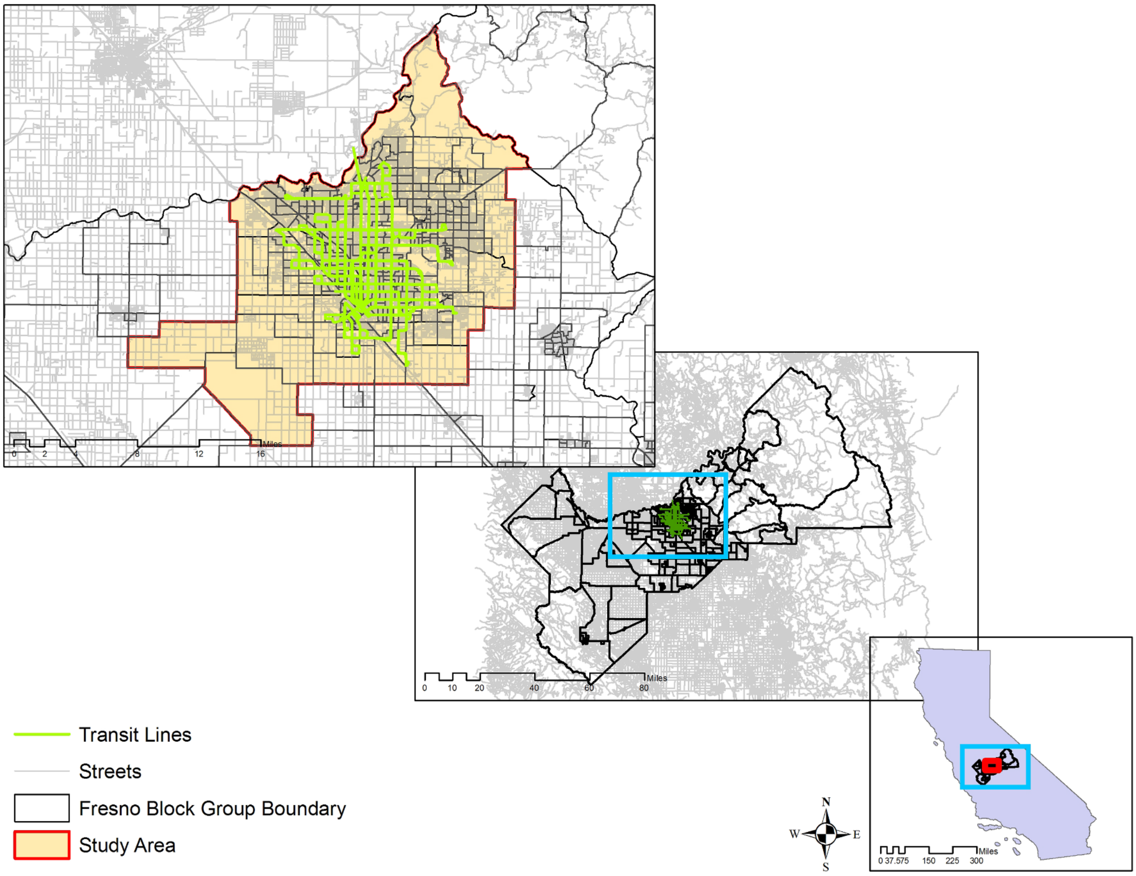

Fig. 1. Transportation network in Fresno, CA.

4.1. Construction of service area

Using the cumulative-opportunity approach, this study firstly delineates the service area based on street network with five thresholds (10-, 20-, 30-, 45-, and 60-minute) by transit and cycling. For auto, 60-minute threshold is not necessary for Fresno and Cincinnati where driving one hour for daily commuting is quite rare. Transit and cycling are the focus of this study and accessibility by auto is calculated only as a benchmark. For accessibility by transit, the service area is delineated using the transit-based network dataset in ArcGIS built through the toolbox "*Add GTFS to a Network Dataset*". For cycling accessibility, this study uses the selected street data from OSM to manually configure and construct a bicycle network dataset. As a result, service areas for the five thresholds are constructed for block group centroids in two cities.

4.2. Calculation of accessibility

Accessibility is calculated as the number of urban opportunities falling inside each service area, including the five categories listed in Fig. 3. The accessibility to jobs at three wage levels is calculated as:

$$A_i^{emp\_m} = O_i + \sum_{j=1}^{J} B_j O_j \tag{1}$$

- $A_i^{emp\_m}$: the number of jobs (low wage, medium wage, high wage) accessible by using a transportation mode m for a block group i;
- O_i: the number of jobs (low wage, medium wage, high wage) in block group i;
- B_j: a binary value, 1 if the centroid of block group j falls within the service area and 0 otherwise;
- O_j: the number of jobs (low wage, medium wage, high wage) in block group j.

The wage level is defined by the LEHD LODES as follows.

- Low wage: $1,250/month or less;

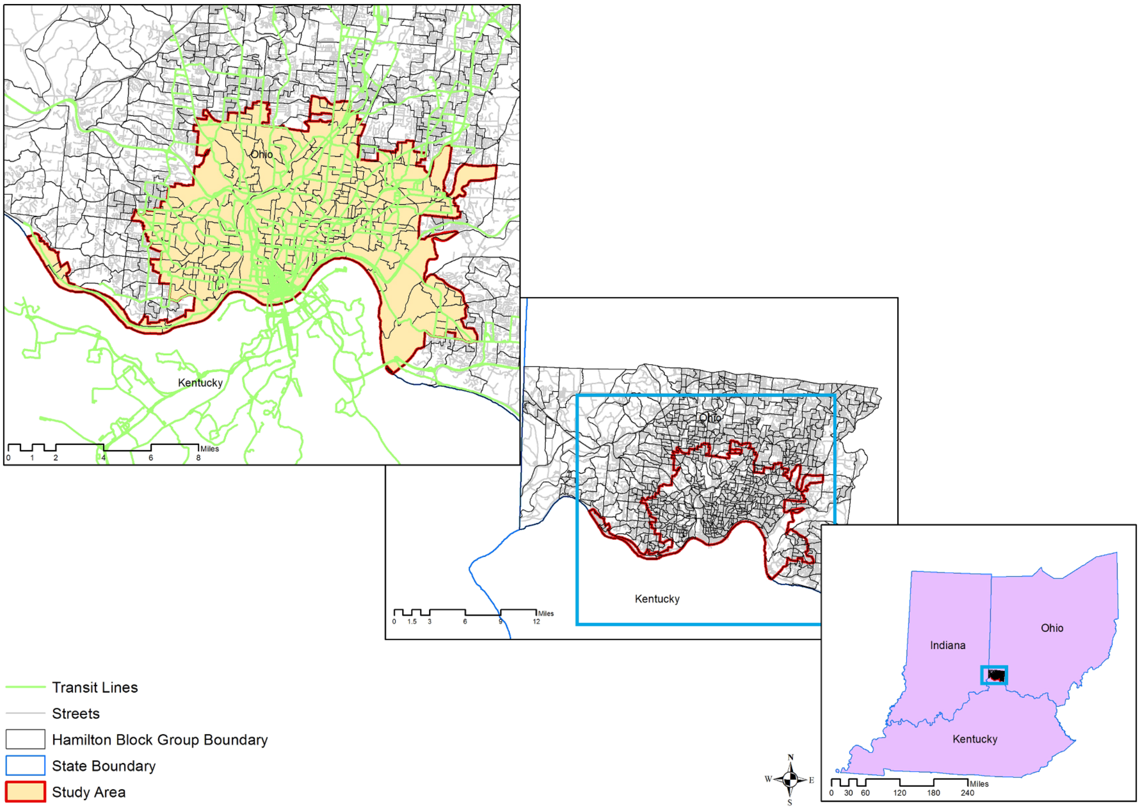

Fig. 2. Transportation network in Cincinnati, OH.

Table 1
Study region comparison: Fresno, CA vs. Cincinnati, OH.

	Fresno, CA	**Cincinnati, OH**
Population (2017 ACS)	527,438	298,957
Population change (2000 census-2017 ACS)	23%	−9%
Median household income (2017)	\$44,853	\$36,429
Topography	Flat	Hilly
Average annual temperature	64.1°F	54.7°F
Mean commuting time by transit (minute) (2016 ACS)	47.5	43.9
Mean commuting time by bike (minute)	21.3	16.1

- Medium wage: \$1,251/month to \$3,333/month;
- High wage: greater than \$3,333/month.

The urban opportunity for dining is calculated as:

$$A_i^{din\_m} = \sum_{j=1}^{J} D_j, \tag{2}$$

- $A_i^{din\_m}$: the number of dining places (fast food, family restaurant) accessible by using a transportation mode m for a block group i;
- D_j: a binary value, 1 if the dining place (fast food, family restaurant) j falls within the service area and 0 otherwise.

The classification of dining into fast food and regular family restaurants reflects people's potential economic capability and health status. The same approach is applied to calculate the accessibility to church $A_i^{chu\_m}$, library $A_i^{lib\_m}$, and school $A_i^{sch\_m}$. The accessibility to parks $A_i^{pak\_m}$ by using a transportation mode m for a block group i is calculated as the total land area (sq. mile) of parks falling inside the serve area. Similarly, the accessibility to multi-use path $A_i^{pth\_m}$ is calculated as the total length (mile) of all multi-use paths (including footways, cycleways, paths, and pedestrian sidewalks) falling inside the service area.

Table 2
Socio-demographic variables of defining transportation disadvantage status.

		Fresno, CA					Cincinnati, OH				
Variable	Description	Mean	S.D.	25%	50%	75%	Mean	S.D.	25%	50%	75%
Economics											
Income	Median household income	49869.7	28389.5	27,974	41,185	67,500	44228.7	25958.1	26,400	37,938	56,782
Property Value	Median property value	190494.9	101472.8	119,000	160,050	237,400	150648.2	111867.3	83,550	108,650	170,100
Education											
School non-enrollment	% of people not enrolled in school	69.5	9.1	64.5	69.4	75.5	73.9	14.5	69	76.7	82.9
Transportation											
Vehicle Ownership	% of households with zero vehicle	10.9	11.4	2	7.5	16	20.3	16.7	8.1	16.2	28.7
Social conditions											
Race	% of non-white	36.1	18.6	20.9	35	50.1	45.1	30.5	18.7	38.8	72.3
Age	% of adolescent (under 19 years)	30.2	9.6	23.4	30.6	37	24	12.1	15.5	23.6	30.8
	% of elderly (at least 65 years)	12.5	8.7	6.8	10.5	15.6	12.5	8.1	6.4	11	16.8
# of Observations (Block groups)		410					319				

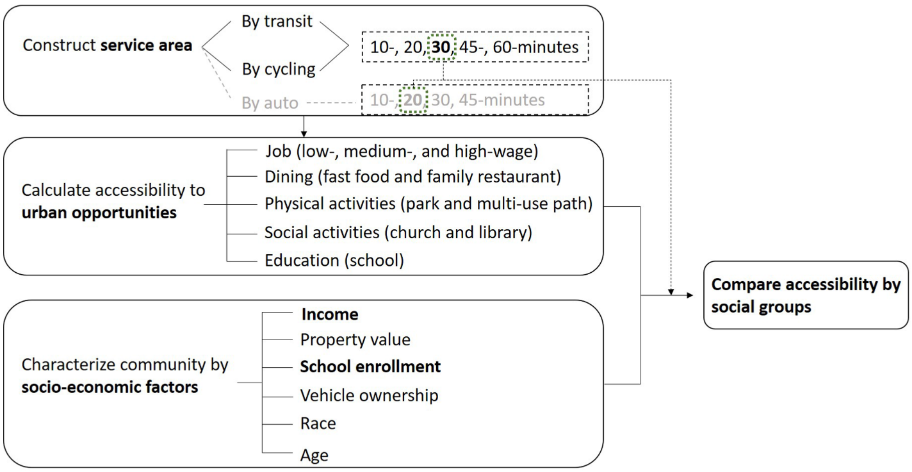

Fig. 3. Conceptual diagram of the research.

4.3. Identification of socially disadvantaged communities

The ways to categorize people might affect transportation equity analysis results (Chen and Akar, 2017; Litman, 2019). Table 2 describes the variables as well as the descriptive statistics used to categorize communities in Fresno and Cincinnati, based on the criteria of public concern, literature review, and data availability.

Fig. 4 displays the spatial distribution of income and school non-enrollment by quantiles at the block group level in two cities. In Fresno, median household income (Fig. 4a) shows a spatial pattern that higher-income communities cluster in the outskirt areas, especially those in northeast Fresno. Most higher-income communities in Cincinnati (Fig. 4c) concentrate in the areas away from urban cores, mostly in the east of Cincinnati. Relatively, the rates of those not enrolled in school do not show any specific spatial distribution pattern as displayed in Fig. 4b and 4d. While other socio-economic factors are not displayed in text by considering the paper length limit, property value, non-white, vehicle ownership, and age show similar spatial patterns as income. This study only presents results by income and student enrollment because the first one has a similar pattern with many other factors as mentioned and students is the group this research is interested in for their potential influence on travel behavior change based on their educational and social networking.

4.4. Geographical mapping and statistical comparison of accessibility

The calculated accessibility to the five groups of urban opportunities are analyzed using two approaches. First, we geographically map their spatial patterns. Then the two-sample *t*-test approach is used to statistically examine the existence of difference in accessibility between two groups for a number of social factors. This study divides neighborhoods into two groups using the first-

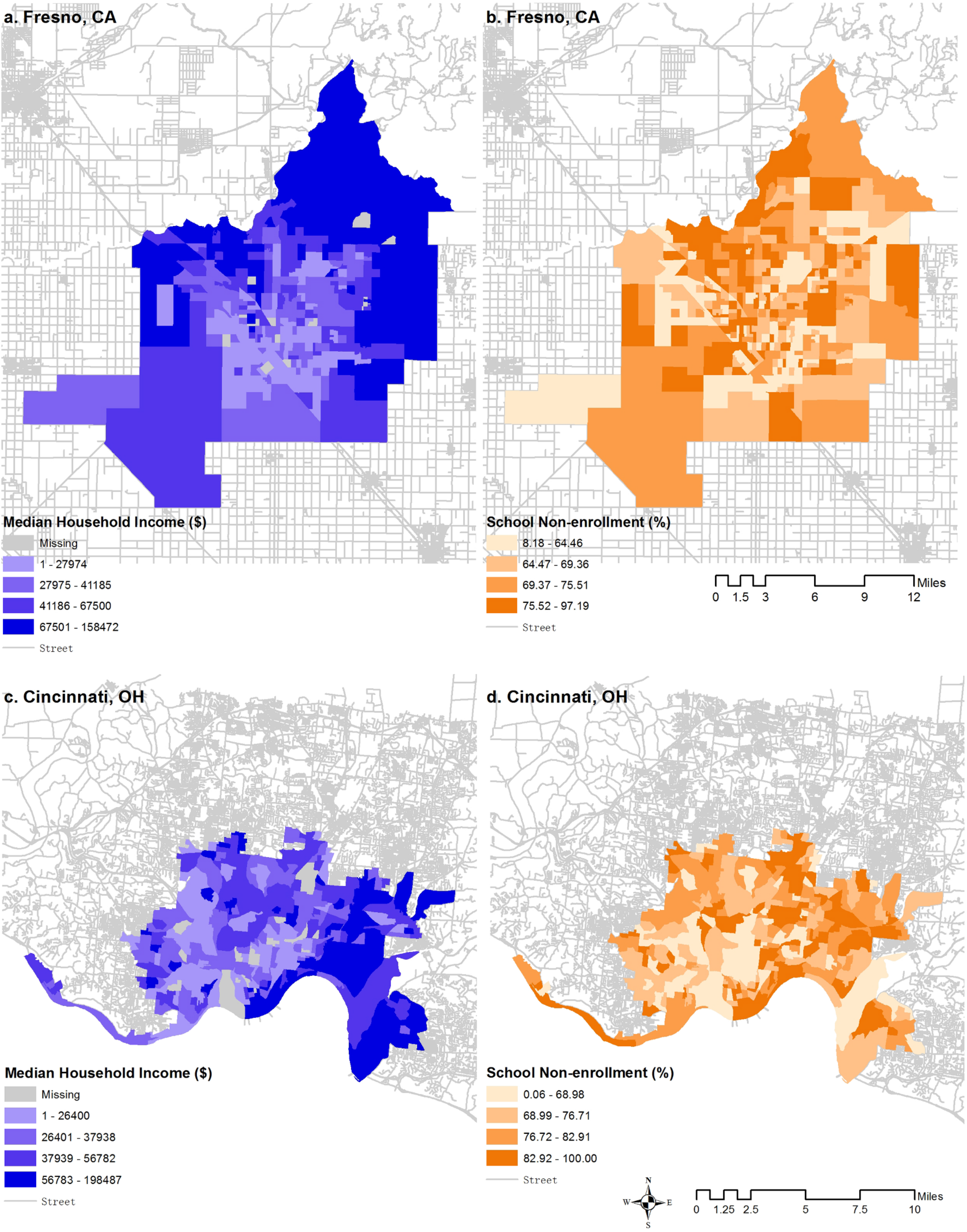

Fig. 4. Spatial distribution of communities by income and school non-enrollment.

(25%), the second- (50%), and the third-quarter (75%) as the divide thresholds. Accessibility is compared between every two groups based on the three quantiles. As compared to the traditional way of using one single arbitrary threshold in grouping social groups, this approach adopts the values of socio-demographic variables at these three percentiles to capture the sensitivity in accessibility comparison results. Note that the difference between two groups might exist between the first quarter group and the rest of the neighborhoods but might not be always the case in the other divisions. This approach might help target at specific groups for promoting the use of green transportation modes.

Table 3
Selected descriptive statistics of calculated accessibility results.

		min		Accessibility to Low-wage jobs	Medium-wage jobs	High-wage jobs	Fast food	Family restaurant	Park	Multi-use path	Church	Library	School
Fresno, CA	By transit	30	Mean	2824.9	3796.8	3522.0	0.4	1.6	0.0	3.0	2.7	0.3	8.9
			S.D.	2644.8	4543.6	5167.6	0.6	2.6	0.0	4.2	4.0	0.8	8.2
		45	Mean	10828.8	14446.1	13350.7	1.7	7.6	0.1	10.5	10.1	1.2	30.3
			S.D.	8134.3	11028.2	11039.1	1.4	6.3	0.1	8.2	11.9	1.4	24.2
		60	Mean	22732.9	30197.4	27651.8	3.7	14.7	0.3	21.5	24.9	2.2	69.4
			S.D.	14318.0	19294.9	18070.1	2.3	9.4	0.3	12.5	19.4	1.6	44.3
	By cycling	30	Mean	20570.8	27822.2	25486.6	3.9	13.8	0.4	22.7	26.7	1.9	70.6
			S.D.	8596.8	10917.3	11011.3	1.8	6.4	0.2	20.9	17.4	1.4	30.9
		45	Mean	39247.0	53196.0	47901.1	7.5	24.5	0.8	45.8	54.9	3.0	132.0
			S.D.	12790.8	17449.9	16419.2	2.3	8.2	0.3	28.4	20.8	1.4	41.8
		60	Mean	55287.5	76095.6	67841.3	11.3	34.7	1.3	71.7	79.3	4.1	185.0
			S.D.	12017.0	17699.9	16196.0	3.1	8.9	0.4	28.5	18.9	1.2	40.6
	By auto	10	Mean	44340.2	60450.7	54846.6	9.4	29.2	1.0	55.0	61.7	3.6	144.3
			S.D.	14371.4	19931.0	18468.8	3.3	10.0	0.4	29.5	22.4	1.5	46.4
		20	Mean	70097.9	99252.0	88401.1	17.3	51.9	1.8	107.2	102.1	5.6	243.7
			S.D.	4955.6	6803.1	5908.5	1.3	5.9	0.1	8.9	7.2	0.8	16.6
		30	Mean	70841.3	100419.9	89291.8	18.0	59.3	1.9	109.0	102.9	7.7	246.8
			S.D.	404.4	891.5	811.4	0.2	1.4	0.0	1.0	1.3	1.3	2.5
Cincinnati, OH	By transit	30	Mean	4201.8	6995.8	13227.4	3.0	31.1	0.3	14.4	12.6	1.6	3.9
			S.D.	5901.6	10614.5	22750.5	5.5	45.0	0.2	15.2	12.1	3.0	3.1
		45	Mean	14115.3	22973.6	43001.3	11.0	93.8	1.5	50.1	40.1	5.7	12.5
			S.D.	10235.5	17236.8	33499.9	9.0	60.7	0.8	30.4	28.1	4.8	7.2
		60	Mean	26566.2	42600.6	76895.0	22.4	163.8	4.5	110.4	88.8	10.2	26.1
			S.D.	11113.6	17739.7	31573.0	10.5	65.1	2.5	52.1	41.3	5.3	10.3
	By cycling	30	Mean	19170.8	30642.2	51430.5	16.3	108.2	6.6	112.7	69.6	6.7	21.1
			S.D.	11470.7	19421.3	37011.9	13.2	75.0	4.6	66.6	37.7	5.2	9.2
		45	Mean	32701.6	52728.7	90179.6	34.3	194.1	14.9	222.4	137.4	12.2	40.0
			S.D.	12830.6	20791.0	37127.6	15.0	79.4	6.7	96.1	53.8	4.9	14.6
		60	Mean	39802.9	63430.1	107587.1	51.8	247.3	25.3	341.8	204.0	14.4	58.6
			S.D.	12595.9	20079.0	34087.2	20.6	81.5	9.2	129.8	67.0	4.7	20.0
	By auto	10	Mean	25726.5	41324.1	71181.5	25.7	154.0	9.1	156.0	94.0	9.3	27.4
			S.D.	12068.6	20599.3	39376.9	11.8	78.0	2.0	57.8	36.7	5.5	8.1
		20	Mean	46959.8	74335.8	123537.2	100.9	349.2	50.9	599.6	302.5	17.1	88.4
			S.D.	3176.1	4902.4	7049.2	22.3	40.7	10.3	127.2	39.3	1.0	11.9
		30	Mean	48360.4	76272.4	125676.2	155.6	431.6	122.5	1116.9	462.9	19.4	135.5
			S.D.	90.2	134.8	135.5	11.3	17.1	14.5	144.2	36.6	1.1	9.5

5. Results and discussions

The results of accessibility within 30, 45, and 60 min by transit and cycling, and within 10, 20, and 30 min by auto are presented in Table 3. For Fresno, a 45-minute transit ride would triple the accessibility as that of a 30-minute one, while a 60-minute transit ride would double the accessibility as that of a 45-minute one. By cycling in Fresno, the change trend of accessibility from 30-minute to 60-minute shows a linear pattern. It requires double time to reach a similar number of urban opportunities across Fresno by transit as compared to cycling.

In Cincinnati, the accessibility by transit shows the same pattern as Fresno. By cycling, the accessibility pattern between 30-minute and 45-minute is comparable as Fresno, but the gap is relatively smaller between 45-minute and 60-minute. Like Fresno, using the same amount of time, the accessibility by cycling is higher than the one by transit. The auto results in both cities are presented as a reference. These findings in both cities reveal that residents are discouraged to rely on public transit for their daily activities and suggest that transit ridership may be increased if the efficiency gap between by transit and other modes could be reduced.

The following sub-sections present the spatial and statistical comparison results and corresponding discussions on the differences in accessibility to economic, social, and physical opportunities with focus on income and student status.

5.1. Mapping results of calculated accessibility

This subsection reports the calculated accessibility to jobs and multi-use paths within the 30-minute travel time with the geographical maps. The main findings from other accessibilities are selectively highlighted without providing the maps by considering the paper length.

Figs. 5 and 6 display the accessibility to jobs in Fresno and Cincinnati respectively. The capability of accessing jobs at three wage levels implies the potential economic opportunity to gain different revenue. Fig. 5 (a., b., and c.) shows that residents living in

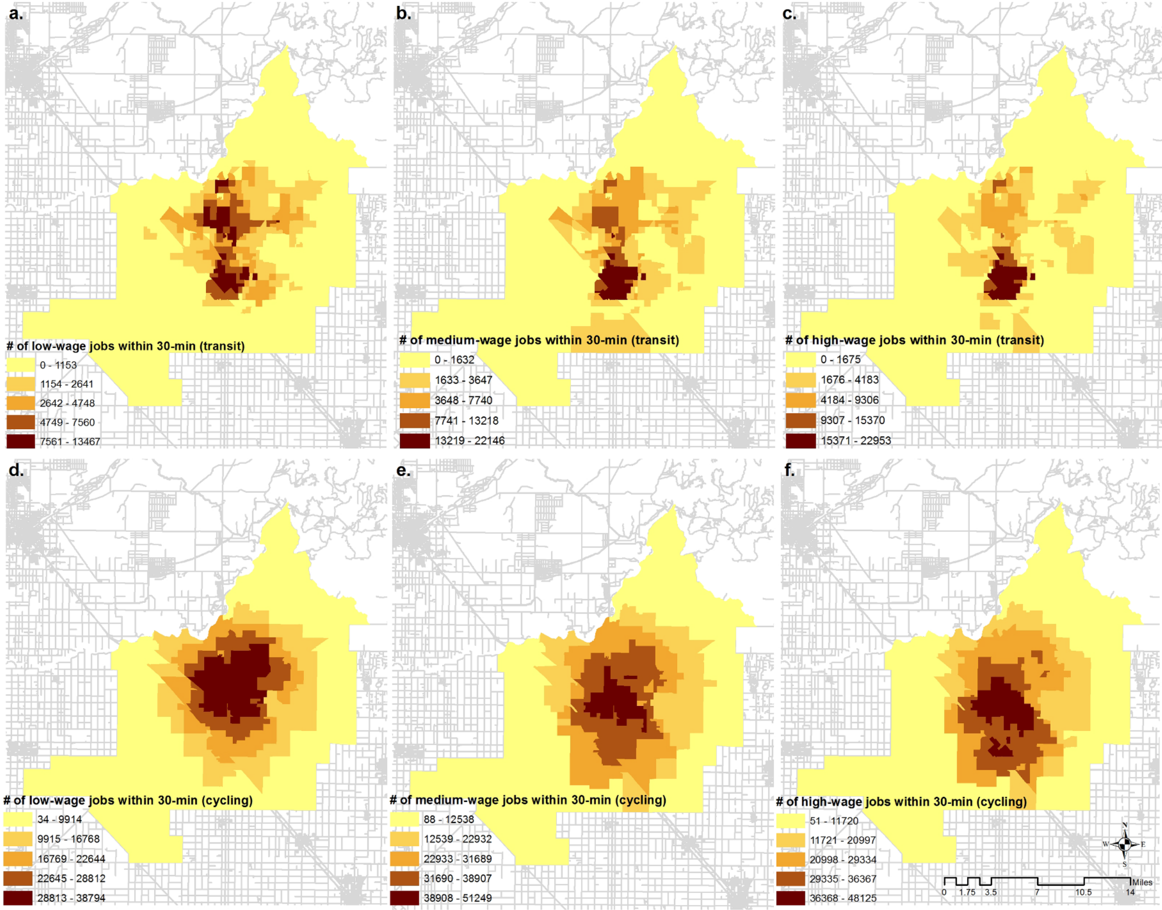

Fig. 5. Accessibility to jobs at three wage levels by transit and cycling (Fresno, CA).

Downtown Fresno can access more jobs by transit, except for low-wage jobs which are also accessible outward to the north. The accessibility to jobs at all wage levels by cycling shows a similar spatial pattern but with declining values in ring-pattern outward from the central urban areas where low-income residents concentrate (Fig. 4a). The disaggregation of accessibility by wage level points to variations in mapping results. For instance, a Fresno resident can access a low-wage job relatively easier than a high-wage job in central areas by transit and cycling. This finding is consistent with Chen and Akar (2017's) accessibility modeling results which suggest that low-income households only have lower accessibility to office jobs, but not the case to other types of jobs. Spatially, current transit and cycling networks seem to well serve the economically disadvantaged communities defined with low income and property value. This finding rejects the traditional spatial mismatch hypothesis as supported in some existing literature, such as Barajas et al. (2018). This might be explained that low-income households without automobiles tend to live in dense urban neighborhoods where they have better access to opportunities using transit and other non-auto modes with neither considering their qualification and affordability nor capturing their subjective accessibility. The central areas in Fresno have relatively high percentages in households without vehicle and with non-white race (figures not presented). However, it should be prudential to draw a conclusion that these communities are not suffering from low accessibility to jobs, supposing a 30-minute travel time good enough for access one, because the accessibility calculation method does not consider the qualification of jobseekers and job competition. Similarly, the values and distribution patterns of job accessibility by cycling in both cities suggest that cycling is more efficient than the transit network. Fig. 6a, 6c, and 6e present that high accessibility to jobs by transit cluster in Downtown Cincinnati and east areas. With cycling (Fig. 6b, 6d, and 6f), the clustering of high accessibility expands due to the flexible bicycle network and slightly moves to the east part. This is interesting and also different from Fresno when comparing with the distribution of social groups. The east Cincinnati is dominated by white households with high values in income, property, and vehicle ownership.

We measure the accessibility to multi-use paths as the length of paths within the time threshold. In Fresno, the accessibility results for both modes show a clear cluster in the northeast area with larger catchment areas and higher values by cycling (Fig. 7). Comparatively, the spatial patterns in Cincinnati by transit and cycling are more spreading out from downtown to the east (Fig. 8). In Fresno, the larger values in accessibility to dining places, churches, and parks move to the north, except for the accessibility to library and schools concentrating around downtown. In Cincinnati, the situation is sort of different. With transit and cycling, the accessibility to dining, church, and library are high in downtown and surrounding areas, with the exception to parks and schools which are less

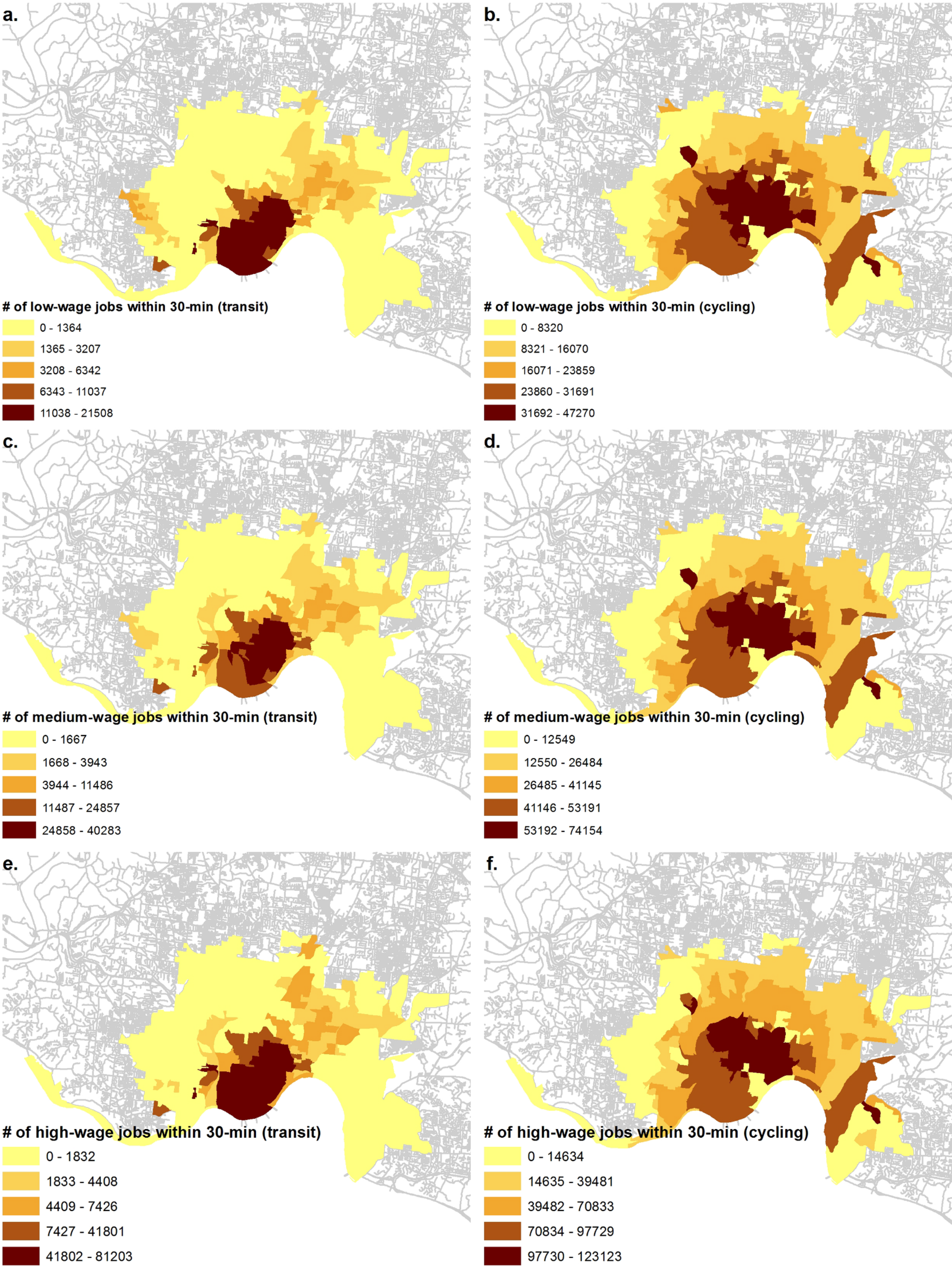

Fig. 6. Accessibility to jobs at three wage levels by transit and cycling (Cincinnati, OH).

concentrated with a spatial shift to the north and east parts. These results are most likely due to an extremely clustering allocation of corresponding facilities. It is worth noting that the outskirt areas might be defined as "service desert" in both Fresno and Cincinnati with relatively low accessibility to places for dining and social activities. This might explain the traffic congestion on Highway 41 in Fresno and on I-71 and I-75 in Cincinnati and explain the inefficiency of traveling long distance to access services.

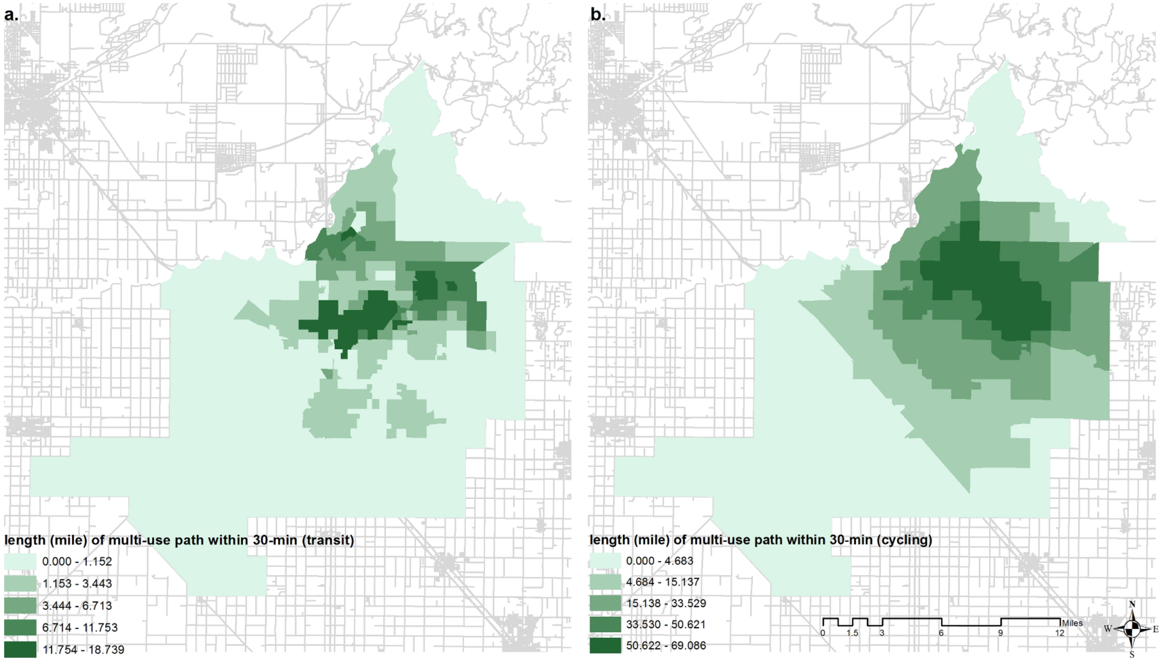

Fig. 7. Accessibility to multi-use paths by transit and cycling (Fresno, CA).

While accessibility by auto is not the focus of this study, the results are used as a reference for transit and cycling. In Fresno, the spatial patterns of accessibility by auto are like the ones by the other two modes, but with much larger service areas and thus more resources accessible within the typical commuting time such as 20-minute. However, the spatial patterns of accessibility results by auto in Cincinnati are quite different from the ones by transit and cycling, except for the accessibility to jobs. For instance, the accessibility to church and library by auto are higher in Northeast and East Cincinnati. These neighborhoods are better-off areas with more wealthy people and therefore have enough financial capability to invest developments for those social activities along with relatively high vehicle ownership.

Overall, the accessibility to most urban opportunities, particularly to economic opportunities and locations for physical activities, indicates a typical spatial pattern in medium-size U.S. cities like Fresno and Cincinnati, where the transit system is not efficient as compared to auto and bicycle, even though the system well serves people in urban centers which have higher densities of transit stops and routes. As compared to transit, cycling does a more efficient job in increasing accessibility from urban centers toward the wealthy areas because of the higher flexibility in departure time and route selection.

5.2. Statistical comparison results of calculated accessibility

To better understand whether transportation inequity exists between advantaged and disadvantaged neighborhoods, accessibility is statistically compared between higher-share and lower-share groups for the six socio-economic factors (Fig. 3). For each factor, this study uses each of the three percentiles (25%, 50%, and 75%) as the threshold to separate block groups into two groups. The purpose of comparing the accessibility using these percentiles is to find out whether the comparison results would be sensitive to the threshold specification. These comparisons would help better identify the specific groups for corresponding transportation and land-use policies which are used to address the issues where the difference exists.

While the accessibility to urban opportunities are compared by all factors, only the results for income and school non-enrollment are presented (Tables 4–7) and discussed by considering some similar results and the paper length. Tables 4 and 6 show the comparison results between the lower- and higher-income neighborhoods defined with the three percentiles. Most accessibility differences are statistically significant in Fresno, except for the accessibility to churches. Comparatively, in Cincinnati, there are fewer significant results and more variation in accessibility to different urban opportunities at different thresholds. In Tables 5 and 7, the significances of accessibility differences by school non-enrollment vary between the two cities. Considering the underlying connections between different types of urban opportunities and different social factors, the following parts summarize the interesting findings regarding the differences in accessibility to economic opportunities by income and accessibility to social and physical activities by student enrollment status.

5.2.1. Accessibility to economic opportunities

Job accessibility is a major measurement for transportation equity analysis in literature (Chen and Akar, 2017; Fan et al., 2012) mainly through examining the relationship between job accessibility and income or other economically related factors (e.g., property

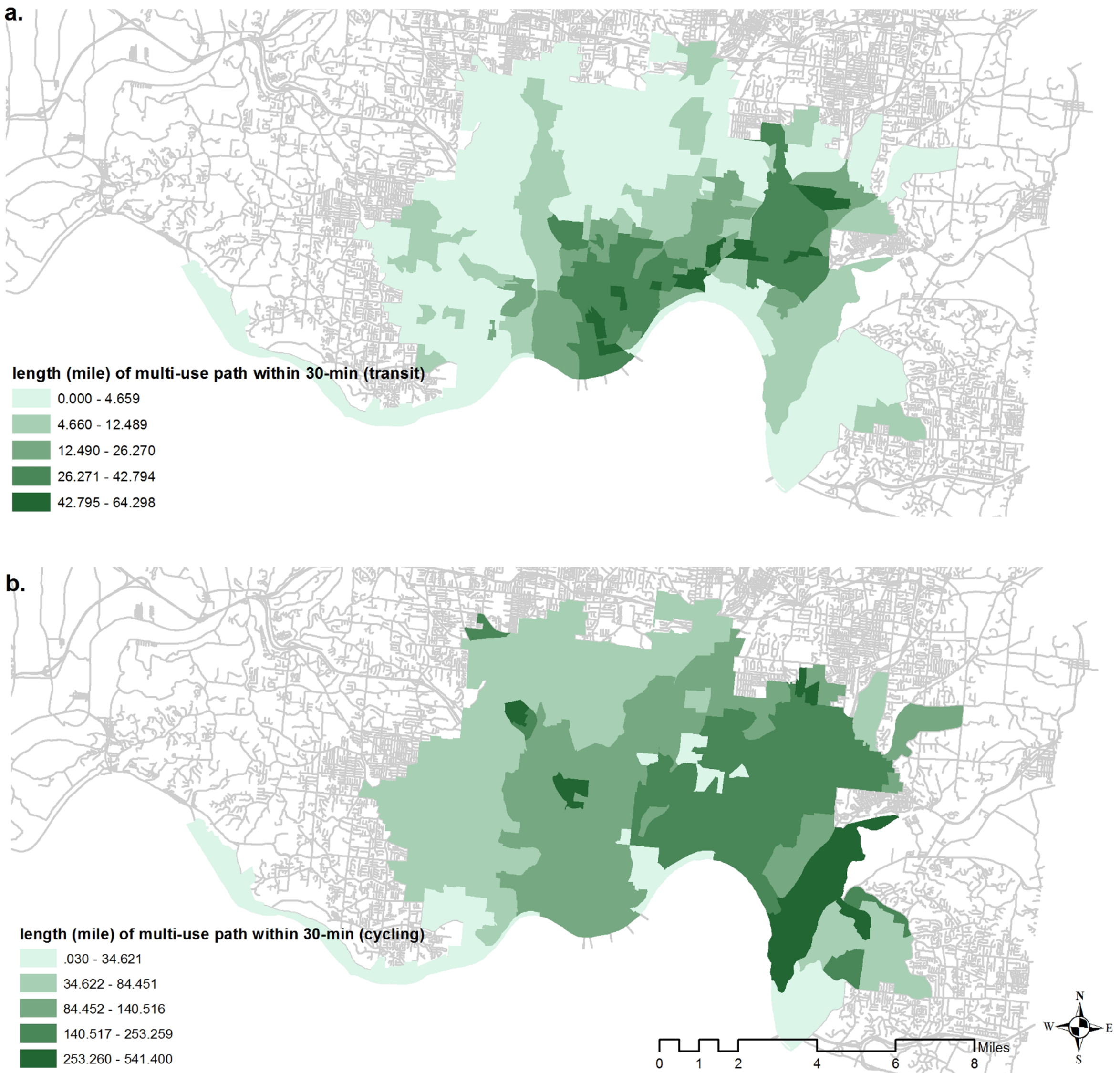

Fig. 8. Accessibility to multi-use paths by transit and cycling (Cincinnati, OH).

value, vehicle ownership, etc.). The different findings on their relationship reported by Chen and Akar (2017), Gao et al. (2008) highlight the importance of disaggregating the analysis. Different from these two papers without considering different transportation modes, this study finds that lower-income neighborhoods significantly have higher accessibility to jobs at all wage levels by both transit and cycling, except for Cincinnati at the 75% threshold. That means in Cincinnati there is no significance difference in job accessibility between neighborhoods with income below $56,782 and the ones above this value.

While not reported in this paper, the comparison results based on property value and vehicle ownership are consistent with the ones based on income. These findings imply that economically disadvantaged groups are not excluded by the current green transportation network in a medium-size U.S. city like Fresno and Cincinnati. In other words, the green transportation networks and facilities in the study areas seem to well take care of transportation inequity concern when grouping people based on economic factors. However, when looking at the absolute values in accessibility to jobs by transit and cycling, it is not difficult to find out that taking transit is much less efficient than cycling to access jobs, not to mention taking auto, due to its inflexible routes and unreliable schedule.

5.2.2. Accessibility to locations for social and physical activities

While accessibility to economic opportunities is a big concern for equity analysis, the potential capability to access locations for social and physical activities is increasingly attracting attention for both physical and mental health concerns, particularly for enrolled students. Enrolled students are the group with high potential that their travel behavior and accessibility could be influenced through advocating sustainable transportation strategies and might influence other people through their mutual learning and social

Table 4
Accessibility comparison by income (Fresno, CA).

	Accessibility to	Median household income								
		25% ($27974)			50% ($41185)			75% ($67500)		
		Below	Above	t*	Below	Above	t*	Below	Above	t*
By transit	***Jobs***									
	Low-wage	3637.32	2466.75	**4.05**	3505.27	2010.58	**6.13**	3245.87	1303.84	**7.00**
	Medium-wage	5486.37	3067.19	**4.94**	4983.25	2354.65	**6.32**	4360.83	1607.15	**5.70**
	High-wage	5573.00	2640.55	**5.27**	4856.72	1883.23	**6.26**	4071.91	1278.20	**5.02**
	Dining									
	Fast food	0.47	0.34	**1.91**	0.46	0.29	**2.77**	0.44	0.18	**3.63**
	Family restaurant	2.29	1.30	**3.51**	2.06	1.04	**4.19**	1.77	0.89	**3.09**
	Physical activities									
	Park	0.05	0.03	**4.50**	0.04	0.02	**3.71**	0.04	0.02	**4.19**
	Multi-use path	2.23	3.19	**−1.97**	2.65	3.25	−1.43	2.87	3.19	−0.65
	Social activities									
	Church	2.55	2.71	−0.35	2.51	2.83	−0.80	2.88	2.03	**1.85**
	Library	0.59	0.23	**3.93**	0.51	0.13	**4.90**	0.40	0.08	**3.46**
	Education									
	School	13.80	6.99	**7.92**	11.98	5.39	**9.07**	10.45	3.43	**8.25**
By cycling	***Jobs***									
	Low-wage	22180.92	19972.44	**2.22**	22623.75	18419.81	**5.01**	22123.11	15749.84	**6.75**
	Medium-wage	33081.86	25938.96	**5.88**	32117.31	23314.11	**8.79**	30433.72	19616.04	**9.49**
	High-wage	32185.80	23107.09	**7.62**	30459.31	20271.42	**10.43**	28296.73	16629.90	**10.34**
	Dining									
	Fast food	4.68	3.68	**4.85**	4.47	3.39	**6.18**	4.19	3.13	**5.21**
	Family restaurant	17.78	12.26	**7.99**	16.69	10.57	**10.84**	15.14	9.15	**8.84**
	Physical activities									
	Park	0.44	0.37	**3.00**	0.43	0.35	**4.30**	0.42	0.31	**5.20**
	Multi-use path	13.32	26.05	**−5.41**	16.52	29.25	**−6.34**	19.92	31.72	**−5.01**
	Social activities									
	Church	24.59	27.62	−1.49	26.46	27.27	−0.46	27.44	25.15	1.13
	Library	2.75	1.53	**8.49**	2.49	1.17	**11.14**	2.17	0.82	**9.58**
	Education									
	School	89.11	63.87	**7.54**	85.83	54.46	**11.78**	79.40	42.57	**12.08**

* The t-values at the significance level of 0.05 are highlighted in bold.

networking (Akar et al., 2013).

In Fresno, there is no significant difference in most accessibilities between low- and high-share school enrollment neighborhoods. However, the results do show a neighborhood with a higher share of enrolled students have lower accessibility to family restaurants by transit at all divide thresholds, and lower accessibility to parks and churches at 75% and 50% threshold respectively. By cycling in Fresno, significant differences are found for accessing dining, physical and social activity places. Furthermore, a neighborhood with more people enrolled in school would generally have lower accessibility to physical activity places (e.g., multi-use paths) and churches through cycling. This finding reveals an important signal for urban planners to explore the relationship between a transportation-land use network and students' physical and mental health, based on the concern about students' physical and social activities and their health status. It might be interesting to further investigate the travel behavior difference between school enrolled and non-enrolled travelers to promote their overall accessibility.

The comparison results for Cincinnati by school non-enrollment indicate more significances and similarity with both modes at 25% and 50% thresholds. In Cincinnati, we find that neighborhoods with more enrolled students have better accessibility to most urban opportunities. Both the mapping and comparison results highlight the need of investing multi-use paths and relevant facilities for neighborhood with more students to improve their health through walking and biking.

6. Conclusion

This study develops an analytic accessibility framework to examine transportation equity for Fresno, CA, and Cincinnati, OH, by focusing on green transportation. An array of accessibilities for each block group in both cities as a proxy for community have been calculated for a variety of urban opportunities within a catchment area constructed using the cumulative-opportunity approach at five travel-time thresholds. The calculated accessibilities by transit and cycling are geographically mapped and statistically compared to examine the existence of spatial mismatch of transportation inequity between socially advantaged and disadvantaged neighborhoods at different divide thresholds for six factors (income, property value, education, vehicle ownership, race, and age). This framework contributes to the accessibility analysis for transportation equity by focusing on the sensitivity of using different thresholds and urban contexts.

The analysis results based on a widely used 30-minute travel time are presented and discussed in this paper. Both descriptive

Table 5
Accessibility comparison by non-enrollment in school (Fresno, CA).

	Accessibility to	School non-enrollment rate								
		25% (64.5%)			50% (69.4%)			75% (75.5%)		
		Below	Above	t*	Below	Above	t*	Below	Above	t*
By transit	***Jobs***									
	Low-wage	2774.37	2841.62	−0.22	2711.74	2938.04	−0.87	2688.90	3230.20	**−1.80**
	Medium-wage	3590.86	3865.00	−0.53	3624.29	3969.31	−0.77	3622.79	4315.45	−1.34
	High-wage	3378.87	3569.34	−0.32	3359.71	3684.21	−0.64	3342.00	4058.33	−1.22
	Dining									
	Fast food	0.38	0.38	0.03	0.39	0.37	0.31	0.38	0.38	0.03
	Family restaurant	1.22	1.77	**−1.87**	1.30	1.96	**−2.61**	1.50	2.01	**−1.73**
	Physical activities									
	Park	0.03	0.03	0.13	0.03	0.03	−1.16	0.03	0.04	**−2.17**
	Multi-use path	3.14	2.90	0.51	3.06	2.86	0.49	2.93	3.02	−0.19
	Social activities									
	Church	2.30	2.80	−1.08	2.28	3.07	**−2.01**	2.51	3.17	−1.45
	Library	0.29	0.35	−0.63	0.32	0.36	−0.41	0.32	0.40	−0.83
	Education									
	School	9.92	8.55	1.47	9.34	8.44	1.12	8.90	8.85	0.05
By cycling	***Jobs***									
	Low-wage	20003.31	20758.73	−0.77	19809.90	21331.69	**−1.80**	20063.35	22083.29	**−2.07**
	Medium-wage	27964.90	27774.87	0.15	27321.42	28322.87	−0.93	27321.64	29313.94	−1.61
	High-wage	26105.36	25281.71	0.65	25417.54	25555.70	−0.13	25162.09	26453.89	−1.03
	Dining									
	Fast food	4.36	3.79	**2.78**	4.20	3.67	**2.95**	4.04	3.63	**1.97**
	Family restaurant	15.08	13.35	**2.37**	14.20	13.36	1.31	13.79	13.74	0.07
	Physical activities									
	Park	0.37	0.40	−1.45	0.36	0.42	**−2.92**	0.38	0.44	**−2.87**
	Multi-use path	17.86	24.32	**−2.73**	21.82	23.60	−0.87	22.43	23.54	0.47
	Social activities									
	Church	22.89	27.99	**−2.58**	23.44	30.00	**−3.87**	25.06	31.68	**−3.38**
	Library	2.09	1.77	**2.05**	1.92	1.79	0.99	1.84	1.87	−0.20
	Education									
	School	75.04	69.14	**1.67**	71.63	69.58	0.67	70.50	70.92	−0.12

* The t-values at the significance level of 0.05 are highlighted in bold.

statistics and geographical mapping results show that in general one may access more opportunities by cycling than by transit in both cities, due to the time and route constraints of public transportation. However, the accessibility by cycling may be overestimated because cycling may not always a good choice for some trips (e.g., long commuting trips) and population groups (e.g., the elderly). As compared to the accessibility by cycling and auto, the 30-minute service area by transit is not large enough for residents to reach resources that people need for a quality of life. For instance, it takes almost double the time to reach the similar accessibility level by transit as compared to cycling. This finding suggests the need of improving the availability, frequency, and efficiency of the current transit system in typical medium-size cities like Fresno and Cincinnati to support existing transit riders and encourage potential modal shift. For instance, an integrated bicycle-transit network could be invested to bridge the first-last-mile gap to improve accessibility by transit and therefore to provide a more equitable transit system for a variety of transportation disadvantaged groups. Especially, the increasing popularity of bike-sharing programs worldwide contributes to a more efficient network through integrating station design and payment mechanism.

The mapping results also point out that socially disadvantaged groups who mainly cluster in urban core areas are not always suffering from low accessibility, depending on the selection of divide thresholds, urban opportunities, and the specific urban context. This finding is consistent with some studies which reported that socially disadvantaged population may not always face spatial mismatch (Farber et al., 2016; Hu, 2015). It responds to the first and third challenges discussed in the literature review that transportation equity should be evaluated by considering the multi-dimensions in grouping population and classifying trip destinations to capture both horizonal and vertical equity. For instance, neighborhoods with relatively low income which are clustering in urban centers generally have good job accessibility. However, the mapping results for accessibility to parks and multi-use paths indicate that both cities have the spatial mismatch issue between physical activity need and social status. It is because communities in South Fresno and West Cincinnati with relatively low income, high zero-vehicle ownership, and more non-white are basically lacking the access to parks and multi-use paths to conduct their physical activities. It guides transportation investments to needed locations for providing a more accessible environment in doing physical activities.

These mapping results are supported by the accessibility comparison results using the two-sample *t*-test, suggesting that disadvantaged neighborhoods defined by lower income, lower property value, high zero-vehicle ownership, and high non-white share tend to have better accessibility to most urban opportunities by transit and cycling. Specifically, economic opportunities in terms of

Table 6
Accessibility comparison by income (Cincinnati, OH).

	Accessibility to	Median household income								
		25% ($26400)			50% ($37938)			75% ($56782)		
		Below	Above	t*	Below	Above	t*	Below	Above	t*
By transit	***Jobs***									
	Low-wage	6389.53	3215.28	**4.21**	5097.03	2922.64	**3.30**	4194.05	3450.07	0.96
	Medium-wage	11100.54	5213.88	**4.33**	8680.38	4694.23	**3.35**	7031.27	5642.59	1.00
	High-wage	22279.82	9364.44	**4.44**	17076.07	8118.91	**3.52**	13450.21	10013.75	1.15
	Dining									
	Fast food	3.89	2.45	**2.00**	3.20	2.42	1.25	2.68	3.20	−0.72
	Family restaurant	42.45	25.55	**2.92**	34.80	24.75	**1.99**	29.53	30.44	−0.16
	Physical activities									
	Park	0.35	0.25	**3.42**	0.30	0.25	**1.89**	0.29	0.25	1.23
	Multi-use path	15.05	13.90	0.56	12.63	15.73	**−1.75**	11.94	20.83	**−4.48**
	Social activities									
	Church	16.93	10.64	**4.02**	14.57	9.85	**3.46**	12.72	10.68	1.28
	Library	2.28	1.21	**2.84**	2.00	0.96	**3.20**	1.66	0.93	**1.93**
	Education									
	School	4.88	3.43	**3.61**	4.36	3.23	**3.27**	4.00	3.17	**2.06**
By cycling	***Jobs***									
	Low-wage	22485.05	17624.48	**3.25**	20667.84	17015.53	**2.81**	19481.01	16924.92	**1.69**
	Medium-wage	35796.45	28213.54	**2.98**	32941.69	27283.13	**2.56**	31075.19	27224.87	1.51
	High-wage	62992.20	46046.97	**3.53**	56836.99	43745.12	**3.14**	52606.71	43349.44	**1.91**
	Dining									
	Fast food	20.20	14.51	**3.28**	17.41	14.46	**1.94**	16.40	14.52	1.07
	Family restaurant	131.32	97.71	**3.44**	115.19	97.04	**2.12**	107.62	101.55	0.61
	Physical activities									
	Park	6.33	6.77	−0.70	6.19	7.13	**−1.75**	6.70	6.55	0.24
	Multi-use path	104.08	116.29	−1.35	101.56	124.85	**−3.01**	107.02	131.67	**−2.76**
	Social activities									
	Church	78.49	65.66	**2.55**	73.25	64.49	**2.00**	71.44	61.21	**2.03**
	Library	9.01	5.68	**4.97**	7.86	5.17	**4.60**	7.08	4.83	**3.29**
	Education									
	School	21.32	20.96	0.29	20.92	21.17	−0.23	21.32	20.23	0.88

* The t-values at the significance level of 0.05 are highlighted in bold.

jobs at three wage levels are well accessible for neighborhoods with high share of lower income by both transit and cycling. When considering other social factors, such as school enrollment and age, different results are found. For instance, enrolled students in Fresno are experiencing limited accessibility to multi-use paths and therefore would be discouraged to select green transportation modes and conduct physical activities. It is a concern not only about students' health status, but also their potential influence in shaping the culture in travel mode choice due to their education background and social networking pool. Therefore, strategies in promoting accessibility with a green transportation system need to be proposed based on transportation investment impact analysis by disaggregating activity types at the destinations and social status. Building and maintaining an integrated bicycle-transit network as proposed above could be an efficient strategy to enhance accessibility to both economic opportunities and locations for physical activities for social groups with limited access to auto.

The differences of accessibility results with different travel time thresholds in two cities indicate that the overall gap between by transit and by cycling is larger in Fresno than the one in Cincinnati. Moreover, the spatial distribution of accessibilities is more concentrative in Fresno while more spreading out in Cincinnati. Specifically, the main difference based on income between two cities lies in the accessibility to parks, that is, better-off neighborhoods in Cincinnati access more parks but not the case for Fresno, most likely due to its arid climate. Enrolled students in Fresno suffer from low accessibility to a few urban opportunities while students in Cincinnati are relatively better taken care of. These findings suggest that urban planners should group population and compare their travel behavior with considerable attention to the localization in urban structure, transportation facilities, and land-use resources to foster green transportation, rather than applying a uniform standard in the planning process.

It is acknowledged that limitations exist in this study. For example, the accessibility measurement would be improved when data become available to incorporate job competition and eligibility requirements. Furthermore, there are some other urban opportunities which were not included in the analysis such as retail stores due to data unavailability. Another limitation is the simple wage classification criterion that is applied to both Fresno and Cincinnati which actually have different economic levels (see Table 1). For future work, we plan to dig into more data to improve this analytic framework.

Table 7
Accessibility by non-enrollment in school (Cincinnati, OH).

	Accessibility to	School non-enrollment rate								
		25% (69.0%)			50% (76.7%)			75% (82.9%)		
		Below	Above	t*	Below	Above	t*	Below	Above	t*
By transit	***Jobs***									
	Low-wage	5565.01	3753.09	**2.38**	4696.46	3710.25	1.50	4054.53	4641.80	−0.77
	Medium-wage	9537.29	6159.20	**2.47**	7903.76	6093.47	1.53	6705.65	7862.53	−0.84
	High-wage	18377.10	11532.31	**2.34**	15057.51	11408.76	1.43	12489.03	15433.35	−1.00
	Dining									
	Fast food	3.57	2.76	1.13	3.30	2.63	1.08	2.72	3.69	−1.36
	Family restaurant	41.30	27.70	**2.35**	34.69	27.48	1.43	29.85	34.71	−0.84
	Physical activities									
	Park	0.34	0.27	**2.67**	0.31	0.26	**2.29**	0.28	0.30	−0.44
	Multi-use path	14.70	14.25	0.23	14.35	14.37	−0.01	13.98	15.51	−0.78
	Social activities									
	Church	15.00	11.85	**2.01**	13.42	11.85	1.16	12.22	13.86	−1.05
	Library	2.73	1.26	**3.87**	2.09	1.16	**2.78**	1.65	1.55	0.25
	Education									
	School	4.48	3.67	**2.07**	3.99	3.75	0.69	3.75	4.21	−1.17
By cycling	***Jobs***									
	Low-wage	22978.84	17917.35	**3.46**	20881.44	17470.90	**2.68**	19302.87	18776.33	0.35
	Medium-wage	37118.95	28510.30	**3.48**	33386.32	27915.28	**2.54**	30851.52	30016.94	0.33
	High-wage	65400.92	46831.86	**3.96**	57407.97	45490.32	**2.91**	52153.33	49270.93	0.60
	Dining									
	Fast food	20.18	14.97	**3.08**	18.36	14.18	**2.86**	16.53	15.46	0.62
	Family restaurant	132.01	100.40	**3.30**	118.57	97.95	**2.48**	108.60	107.11	0.15
	Physical activities									
	Park	6.64	6.58	0.10	6.65	6.53	0.23	6.62	6.49	0.23
	Multi-use path	109.13	113.87	−0.55	111.03	114.35	−0.44	110.85	118.20	−0.86
	Social activities									
	Church	79.22	66.45	**2.63**	74.57	64.69	**2.35**	69.94	68.65	0.26
	Library	9.03	5.92	**4.72**	7.85	5.54	**4.03**	6.79	6.38	0.62
	Education									
	School	21.28	21.00	0.23	21.45	20.69	0.73	21.03	21.20	−0.15

* The t-values at the significance level of 0.05 are highlighted in bold.

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