Project 1871 | August 2019

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Developing a Fair Accessibility Framework through Green (Non-Auto) Transportation Modes for Fresno, California

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CSUTC California State University Transportation Consortium

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REPORT 19-22

DEVELOPING A FAIR ACCESSIBILITY FRAMEWORK THROUGH GREEN (NON-AUTO) TRANSPORTATION MODES FOR FRESNO, CALIFORNIA

Chih-Hao Wang, PhD
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August 2019

A publication of
Mineta Transportation Institute
Created by Congress in 1991

College of Business
San José State University
San José, CA 95192-0219

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
19-22

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Developing a Fair Accessibility Framework through Green (Non-Auto) Transportation Modes for Fresno, California

5. Report Date
August 2019

6. Performing Organization Code

7. Authors
Chih-Hao Wang, https://orcid.org/0000-0003-4200-9153
Na Chen

8. Performing Organization Report
CA-MTI-1871

9. Performing Organization Name and Address
Mineta Transportation Institute
College of Business
San José State University
San José, CA 95192-0219

10. Work Unit No.

11. Contract or Grant No.
ZSB12017-SJAUX

12. Sponsoring Agency Name and Address
State of California SB1 2017/2018
Trustees of the California State University
Sponsored Programs Administration
401 Golden Shore, 5th Floor
Long Beach, CA 90802

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract
Fresno, California has been regarded as a city with a high concentration of poverty. Therefore, it is extremely important to examine whether transportation inequality exists in this city because transportation shapes residents' economic opportunities, physical activities, and social interactions. This study is to address this issue by looking at whether a resident of Fresno would have an equal opportunity to access a variety of urban opportunities, such as jobs, physical activities and dining, social interactions, and public facilities. Two non-auto (green) transportation modes (i.e. transit and cycling) were considered in this study since not everyone can afford for a private vehicle. GIS (Geographic Information System) was first used to illustrate the service area by using these two green transportation modes for each block group in the city. With the recently completed "open street" data, we then used the service area to count the number of various urban opportunities (jobs, restaurants, parks, multi-use paths, schools, libraries, and schools) that a resident from a block group can access within a 10-, 20-, 30-, 45-, and 60-minute travel time by transit or cycling. This is based on the will-known cumulative opportunity approach to measure the accessibility of a community to various opportunities in a city. To examine whether there exist difference in accessibility between a group of communities and the other group of the rest, we compared an array of computed accessibilities between two divided groups. Several economic and social-demographical factors were considered to divide the communities into two groups, including income, property value, school enrollment, vehicle ownerships, race, and age. This allows for a more comprehensive way to compare accessibility from varied socio-economic aspects. Another innovation in this study is to create a platform to flexibly group communities into two for the accessibility comparison. This helps reveal whether the results are sensitive to the threshold used for grouping. The comparison results suggest that the current green transportation network do help with the accessibility in terms of economic opportunities for economically disadvantaged neighborhoods. However, the city might need to focus on improving the efficiency of the bus system to provide a faster and wider service area for more urban opportunities. Students might be a good target for further study to better understand their needs because no consistent accessibility patterns were found. Finally, the findings point out that more efforts on providing multi-use paths need to be done to improve the accessibility by cycling for non-white and adolescent groups.

17. Key Words
Nonmotorized transportation, public transportation, bicycling, equity (justice), accessibility

18. Distribution Statement
No restrictions. This document is available to the public through The National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
43

22. Price

Form DOT F 1700.7 (8-72)

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ACKNOWLEDGMENTS

This research was supported by the 2018 research grant awarded by the Fres-no State Transportation Institute (FSTI) at California State University, Fresno.

The authors thank Editing Press, for editorial services, as well as MTI staff, including Executive Director Karen Philbrick, PhD; Deputy Executive Director Hilary Nixon, PhD; Graphic Designer Alverina Eka Weinardy; and Executive Administrative Assistant Jill Carter.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

- This study aims to examine whether transportation inequity exists in Fresno, which aligns with the SB 1 Objective 4 that "everyone should share the same opportunities for learning, living, labor, and leisure."

- A GIS-based cumulate opportunity approach was developed to measure the accessibility to a variety of urban opportunities (jobs, physical activities and dining, social interactions, and public facilities) by two non-auto (green) transportation modes (public transit and cycling).

- The service area for each block group in the city was defined, using the recently completed "open street" data, in a 10-, 20-, 30-, 45-, and 60-minute travel time by transit or cycling.

- The defined service area was then used to count the number of each type of urban opportunities (jobs, restaurants, parks, multi-use paths, schools, libraries, and schools).

- The two sample t-test approach was used to compare accessibility between better- and worse-off neighborhoods, using the 25th, 50th, and 75th percentile as thresholds for a set of socioeconomic factors (income, property value, school enrollment, vehicle ownerships, race, and age). We consider that this is an innovation in this study because it creates a platform to flexibly group neighborhoods into two for comparison.

- The mapping of the accessibility points to a need to improve the efficiency of the current bus service in Fresno to be at the same level of cycling.

- The comparison results suggest that the current green (non-auto) transportation network do help with the accessibility for economically disadvantaged neighborhoods.

- This study suggests to focus on students for further study to better understand their needs because the calculated accessibility for them did not show a consistent pattern.

- The results also suggest that there is a need to put more efforts on providing multi-use paths to improve the accessibility by cycling for neighborhoods with a high share of non-white and adolescent populations.

I. INTRODCTION

The subject of this study is the city of Fresno, CA, which is one of the cities with the highest concentration of poverty in the United States (Cytron, 2009). Residents of Fresno, particularly those living in socially-disadvantaged neighborhoods, are beset with an array of economic, educational, and health challenges. Transportation shapes human interactions, economic mobility, urban sustainability, and social equity (Delmelle and Casas, 2012; Klein, 2007). Social equity broadly refers to equally-distributed social benefits and costs, which is essentially affected by transportation accessibility. Fresno has been regarded as a car-oriented city and as a large agricultural base in California. Residents who do not have a private vehicle can only access urban opportunities (e.g. jobs, education, dinning, and physical and social activities) through public transit, cycling, or walking. The purpose of this study is to investigate the possible existence of transportation inequity in the city under the current transportation network.

The purpose described above stems from a longstanding belief that planning can help reduce social inequity through capital investments, such as the allocation of land uses, transportation infrastructure, and public facilities (Wang and Chen, 2015; Wang, 2019). The concept of cumulative opportunity is used to measure the number of an urban opportunity that can be reached from a neighborhood through transit or cycling respectively. The computed results are called “accessibility” in this study and are compared between two groups divided by a set of socioeconomic factors, including income, property value, school enrollment, vehicle ownership, race, and age. Thus, it becomes possible to examine whether transport inequity exists between socially advantaged and socially disadvantaged neighborhoods.

The comparison can help develop a fair accessibility framework through allocating future green (non-auto) transportation infrastructure and public facilities to the locations that could effectively improve the accessibility of socially-disadvantaged neighborhoods. The results will also provide information for targeting a specific group to promote the use of public transit and cycling. This study aligns with the SB 1 Objective 4 that “everyone should share the same opportunities for learning, living, labor, and leisure.” The outcome of this project would also align with two critical local needs: (1) improved transit and (2) cyclist safety project. For instance, the results would facilitate the allocation of new bus stops/routes that will increase transit ridership, and the improvement of current commuting cycling system that could help reduce greenhouse gas emissions, improve air quality, and relieve social inequity. Currently, none of these projects have been found in the SB1 project map for Fresno.

II. BACKGROUND

Accessibility is typically defined as the ease of people to reach activities using one or more transportation modes under certain constraints (Bhat, 2000; Geurs and van Wee, 2004; Shen, 1998). This concept has been measured from four different perspectives: infrastructure-, location-, person- and utility-based measures (Geurs and van Wee, 2004). Each of these measures and approaches has its own merits and demerits. Geurs and van Wee (2004) developed four criteria for selecting appropriate accessibility measures: theoretical basis; operationalization; interpretability and communicability; and usability in social and economic evaluations. Among those measures, the cumulative opportunity approach, which is a location-based accessibility measure, has been widely used in accessibility studies (Castiglione et al., 2006; Fan et al., 2010). Relatively easy operationalization, interpretation, and communication are the major advantages of selecting this cumulative opportunity approach, based on its definition as the count of the number of opportunities which can be reached within a given travel time or distance (Geurs and van Wee, 2004).

For instance, Wang and Chen (2015) analyzed job accessibility at the block group level using the cumulative opportunity approach, which counts potential jobs within certain travel times by auto, public transit, and walking. Fan et al. (2010) used the same approach to identify job accessibility and then assess the impact of transit investment on job accessibility in the Twin Cities among workers of different wage categories. Chen and Akar (2017) applied the cumulative opportunity approach based on the concept of activity space in order to calculate accessibility to a variety of urban opportunities (e.g., jobs and land uses by sector) at the individual level. The calculated accessibility results were utilized to compare and model for transportation equity concern.

The basic assumption is that the transportation network of a city would influence individuals' mobility and therefore facilitate or deter their social, economic, and physical activities (Gilliland et al., 2006). The physical setting of a transportation network in terms of transportation infrastructure and facilities in a city is determined through a series of policy-making and planning decisions based on local conventions, economic efficiency and environment justice considerations, and lobbying (Sampson et al., 2002; Witten et al., 2003). Wang (2019) developed an optimization model embedded with a set of local estimated relationships in order to find out the optimal decision of allocating future land uses and capital investments that would effectively increase community opportunity while minimizing socioeconomic inequity. To understand how those decisions may be related to people's accessibility and thus social equity and then to promote a fair accessibility framework for Fresno, it is urgently important to evaluate how the existing transportation network affects accessibility among differential social groups, especially those who are conceptually conceived as transportation disadvantaged.

III. METHODOLOGY

This study applied the cumulative-opportunity approach, a typical location-based accessibility measure, to count the number of urban opportunities (e.g., jobs, schools, etc.) reachable within a certain space by a transportation mode (Fan et al., 2010). This "space" can be specified in a variety of ways as a service area through different transportation modes, such as driving a private vehicle, riding a bus, cycling, or walking. As this study focuses on green (non-auto) transportation, the following section describes how the service area is delineated in these two cities (Fresno and Clovis) at the block group level by using public transit and cycling respectively.

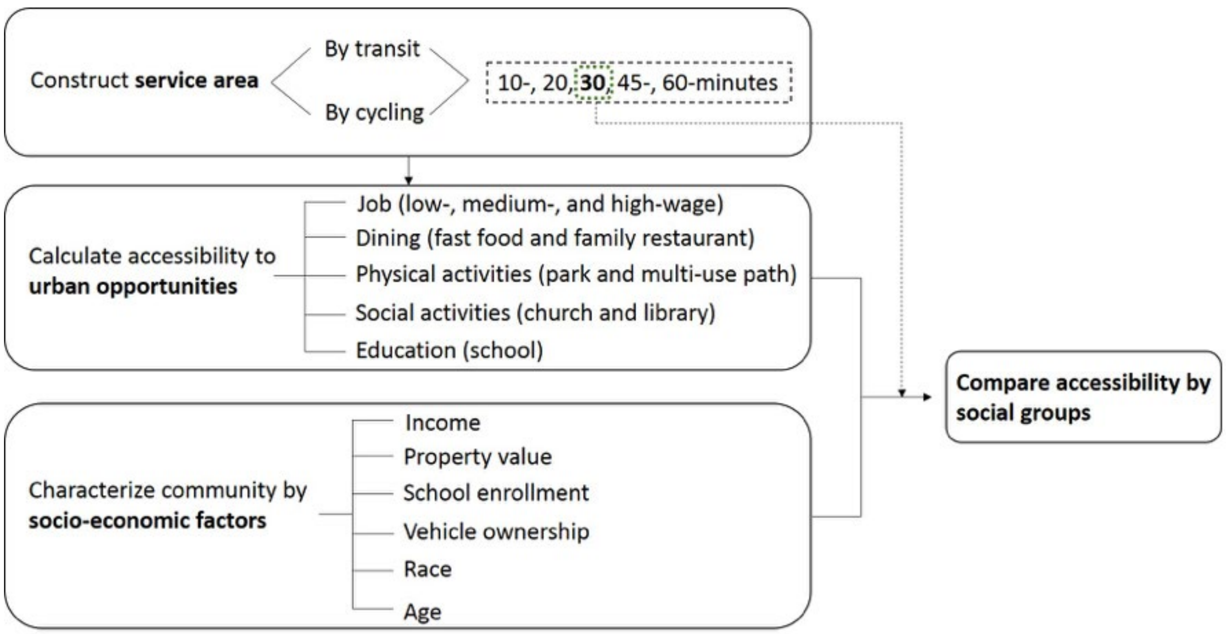

Figure 1. Research Design

Figure 1 presents the design of this study and its information flow. To compute the accessibility for each urban opportunity, each step in the process is explained as the follows.

Step 1: The service area was delineated based on one-way travel cost in terms of time in minutes on the street network with the following thresholds in minutes: 10, 20, 30, 45, and 60.

Step 2: The constructed service areas by public transit and cycling, respectively, for each of the 5 traveling-time thresholds were used to count the number of each urban opportunity within the defined service area, including jobs (low-, medium-, and high-wage), dining (fast food and family restaurants), physical activities (parks and multi-use paths), social activities (churches and libraries), and schools.

Step 3: This study also defined the level of socioeconomic disadvantage for each block group (as a proxy for a neighborhood) in the study region based on the following variables: income, property value, school enrolment, vehicle ownership, race, and age.

Step 4: The calculated accessibility to each urban opportunity was then divided into two groups by the above-defined socioeconomic factors. To avoid possible arguments on the threshold selected to divide groups, two groups of accessibility for each socioeconomic factor was divided, using the first-, the second-, and the third-quarter as the thresholds. Thus, the two-sample t-test approach was used to investigate whether each calculated accessibility is different between the first-quarter group and the rest, the second-quarter group and the rest, and the third-quarter group and the rest, respectively. The details of each step is elaborated in the following sections.

CONSTRUCTION OF SERVICE AREA

Service Area by Public Transit

Fresno and Clovis are served by the Fresno Area Express (FAX), which is a public transportation operator that provides over 100 buses on 16 fixed routes, as displayed in Figure 2.

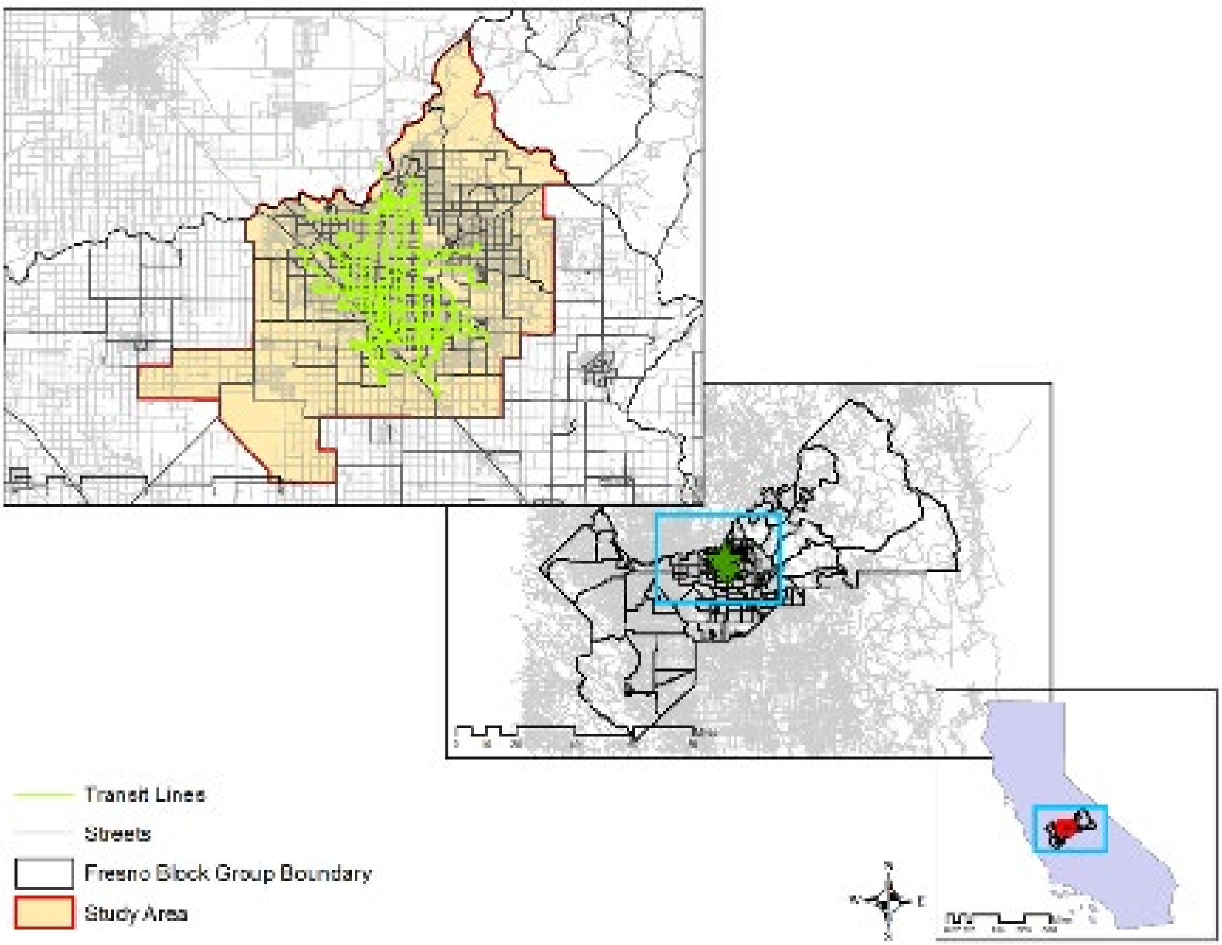

Figure 2. Public Transit in Fresno, California

The service area by public transit for the five thresholds (10, 20, 30, 45, and 60 minutes) was delineated using the transit-based network dataset, which is built in ArcGIS using the toolbox called “Add GTFS to a Network Dataset.” The key input data for this toolbox is the transit data in the format of General Transit Feed Specification (GTFS), which is the most widely-used format in terms of text files for public transportation schedules and associated geographic information, including stops, routes, trips, and other schedule data. The following software and data were used to set up the transit network dataset for the study area in this research:

- **ArcMap 10.6**. This version of ArcMap helps construct the network dataset much more easily using a template rather than having to manually set up each parameter step by step;
- **Street dataset** for the study area which was obtained from OpenStreetMap (OSM) which is a collaborative project that provides detailed street data;
- **GTFS dataset**, FAX Transit Data, which was assembled from the City of Fresno website.

These data and tools were assembled and edited to build the transit network dataset. The specific procedures of building this network dataset can be referred in ***Add GTFS to a Network Dataset User's Guide*** (Morang, 2018). After creating the GTFS-enabled transit network dataset using this toolbox, the Network Analyst toolbar in ArcMap were activated and then the function "New Service Area" was used to create a series of polygons which represent the distance in terms of travel time that can be reached from the centroids of block groups in the study area. As a result, 10-, 20, 30-, 45, 60-minute service areas for 410 block group centroids were constructed respectively.

Service Area by Cycling

As compared to the well-developed ArcGIS toolbox to identify service area by public transit, the approach to construct service area based on cycling networks is not consistent. One important reason is that it is relatively complicated to fix cycling routes for cyclists and difficult to construct all the spatial data for the bicycle network. In this research, we used the detailed street data from OSM to manually configure and construct a bicycle network dataset. The most distinct feature of the OSM street data is the inclusion of footway and cycleway attributes. Similar to public transit, the same five thresholds (10, 20, 30, 45, and 60 minutes) are used to identify the service space through cycling.

To build the bicycle network dataset in ArcGIS, the following types of street links were extracted from the OSM street dataset which were downloaded from the previous task for public transit: *'primary', 'primary_link', 'secondary', 'secondary_link', 'tertiary', 'tertiary_link', 'unclassified', 'residential', 'living_street', 'service', 'track', 'cycleway', 'footway', 'bridleway', 'pedestrian', 'path'*. Once these street links were extracted as a separate shapefile dataset, the procedures and specifications of building the cycling-based network dataset were similar to the ones used for auto vehicles using the *New Network Dataset wizard* in ArcGIS. One major difference is the travel time on each street segment was calculated by considering cycling speed. This study calculated the travel time field for street segments using the street length and the average cycling speed 15.5 km/h (9.6 mph) based on the cycling statistics in Copenhagen (City of Copenhagen, 2013). Based on this bicycle network dataset, the steps to construct the service area using the 5 thresholds for the 410 block group centroids are the same as those for public transit using the “Network Analysit-New Service Area” tool in ArcGIS.

CALCULATION OF ACCESSIBILITY

Using the method described in the previous section, the service area by using public transit and cycling for the 5 thresholds (10-, 20-, 30-, 45-, and 60-min) based on each block group centroid was constructed. After constructing service areas, accessibility was calculated for two categories: (1) number of block groups (in terms of centroids) falling inside each service area; and (2) number of urban opportunities falling inside each service area, including job by wage level, restaurants, parks, multi-use paths, churches, libraries, and schools. Each of these two categories of accessibility was calculated using the spatial overlay function in ArcGIS.

The first category of accessibility is illustrated as:

$$A_i^m = \sum_{j=1}^{J} B_j,$$

- A_i^m : the number of block group centroids that falls inside the service area by using a transportation mode m for a block group i;

- B_j : a binary value, 1 if the centroid of block group j falls within the service area and 0 otherwise.

The results on the one hand can display the spatial range that residents could potentially reach by using public transit or by cycling from the block group where they live within different time thresholds. On the other hand, the overlaid results will be used to calculate accessibility to different urban opportunities, such as jobs, parks, etc.

For the second category, the calculation depends on the type of urban opportunity. For instance, the accessibility to jobs by wage level is calculated as:

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

- $A_i^{emp\_m}$: 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.

According to the LEHD Origin-Destination Employment Statistics (LODES), which is developed by US Census Bureau, the wage level is defined as:

- Low wage: $1,250/month or less;
- Medium wage: $1,251/month to $3,333/month;
- High wage: greater than $3,333/month.

The urban opportunity for dining is classified into fast food and family restaurants, calculated as:

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

- $A_i^{din\_m}$: 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 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 serve area. Some other urban opportunities, such as grocery stores, which are related to health, were not included in this study due to the issue of data availability.

IDENTIFICATION OF SOCIALLY DISADVANTAGED COMMUNITIES

One challenge in evaluating transportation equity in the literature is that the status and level of social disadvantage could be identified by a variety of demographic and geographic factors (Chen and Akar, 2016; Litman, 2019). This research categorizes communities based on the variables described in Table 1 to capture transportation disadvantaged status from a comprehensive perspective. These sociodemographic variables were selected based on the criteria of social concern, literature review, and data availability. For instance, household income and property value are broadly used in equity-related research in order to capture the economic gap between social groups (Chen and Akar, 2017). Education in terms of school non-enrollment represents potential limitations on gains in revenue and improvements in quality of life. Initially school drop-rate was preferred but not available. Mobility is specified through vehicle ownership in our study, where zero-vehicle ownership implies the reduced possibility of reaching resources which are not accessible by using non-auto transportation modes. Similar to household income, race is a traditional variable used to evaluate social equity. In most auto-oriented urban areas, the youth and elderly have been suffering from limited mobility and accessibility due to their limited economic or physical capability. Figures 2 to 4 show the spatial distributions of block groups based on the classifications in Table 1.

Table 1. Variables of Defining Transportation Disadvantaged Status

Variable	Description	Mean	S.D.	25%	50%	75%
Economics						
Income	Median household income	49869.7	28389.5	27974	41185	67500
Property Value	Median property value	190494.9	101472.8	119000	160050	237400
Education						
School non-enrollment	Percentage of people not enrolled in school	69.5	9.1	64.5	69.4	75.5
Transportation						
Vehicle Ownership	Percentage of households with zero vehicle	10.9	11.4	2.0	7.5	16.0
Social conditions						
Race	Percentage of non-white	36.1	18.6	20.9	35.0	50.1
Age	Percentage of adolescent (under 19 years)	30.2	9.6	23.4	30.6	37.0
	Percentage of elderly (at least 65 years)	12.5	8.7	6.8	10.5	15.6
# of Observations (Block groups)						410

From Figure 3, the median household income shows a very similar spatial pattern with the median property value that higher income/property value cluster in the outskirt areas, especially those in northeast Fresno and Clovis. However, the rates of those not enrolled in school do not show any specific spatial pattern in Figure 3. Similarly, zero vehicle ratios and non-white population shares have a very similar spatial pattern that most of them cluster around the city center and along Highway 99 (see Figure 4). Note that non-white groups are seen as a social demographical factor, but not necessarily a socially disadvantaged group. Finally, adolescent shares show an opposite spatial pattern with elderly shares in Figure 5 that more elderly population live in north Fresno.

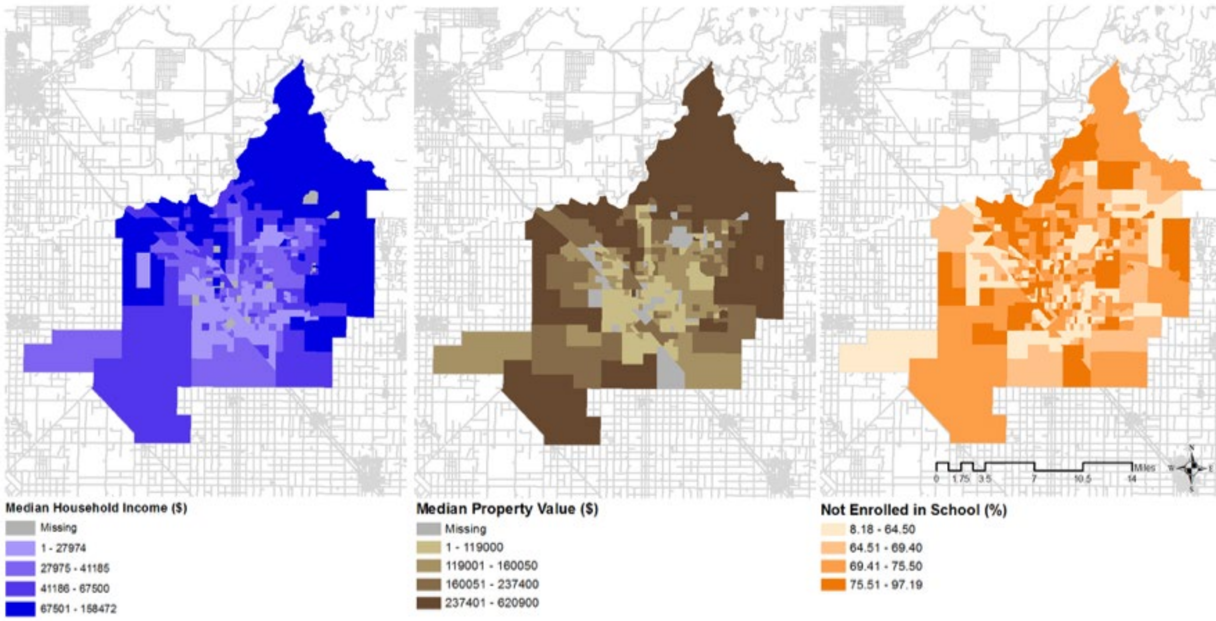

Figure 3. Spatial Distribution of Communities by Socio-Demographics (I)

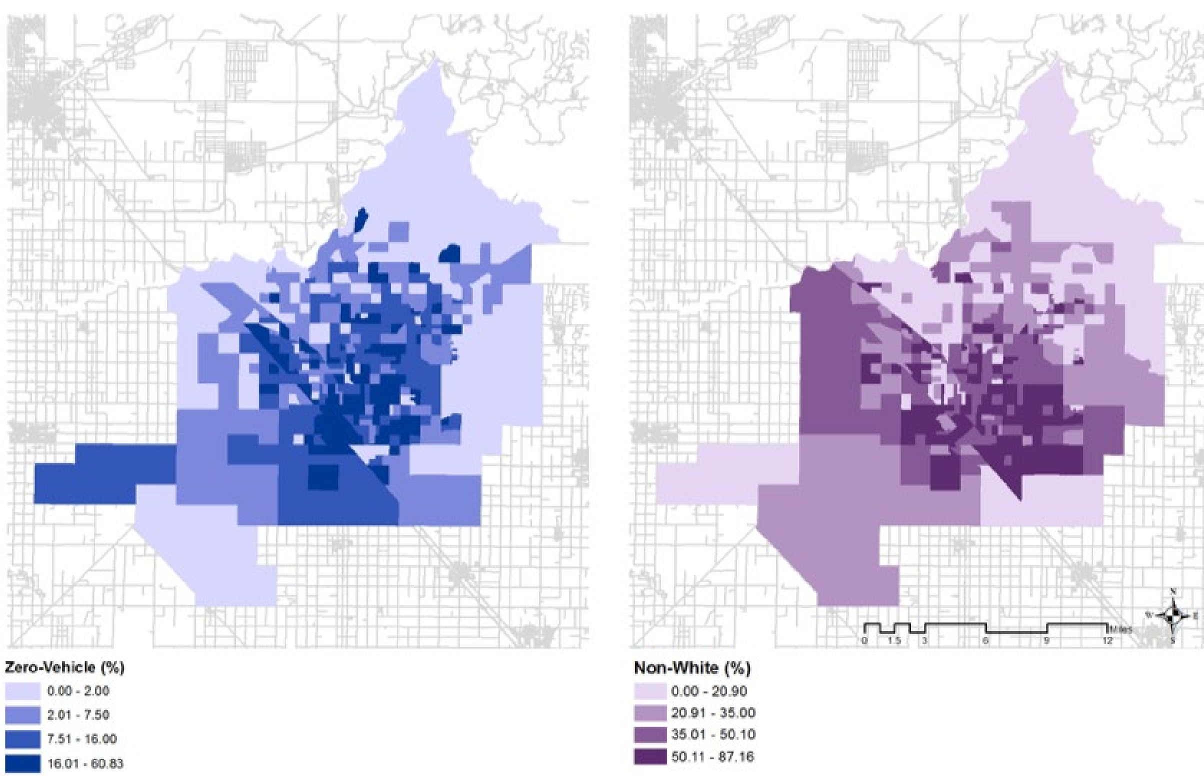

Figure 4. Spatial Distribution of Communities by Socio-Demographics (II)

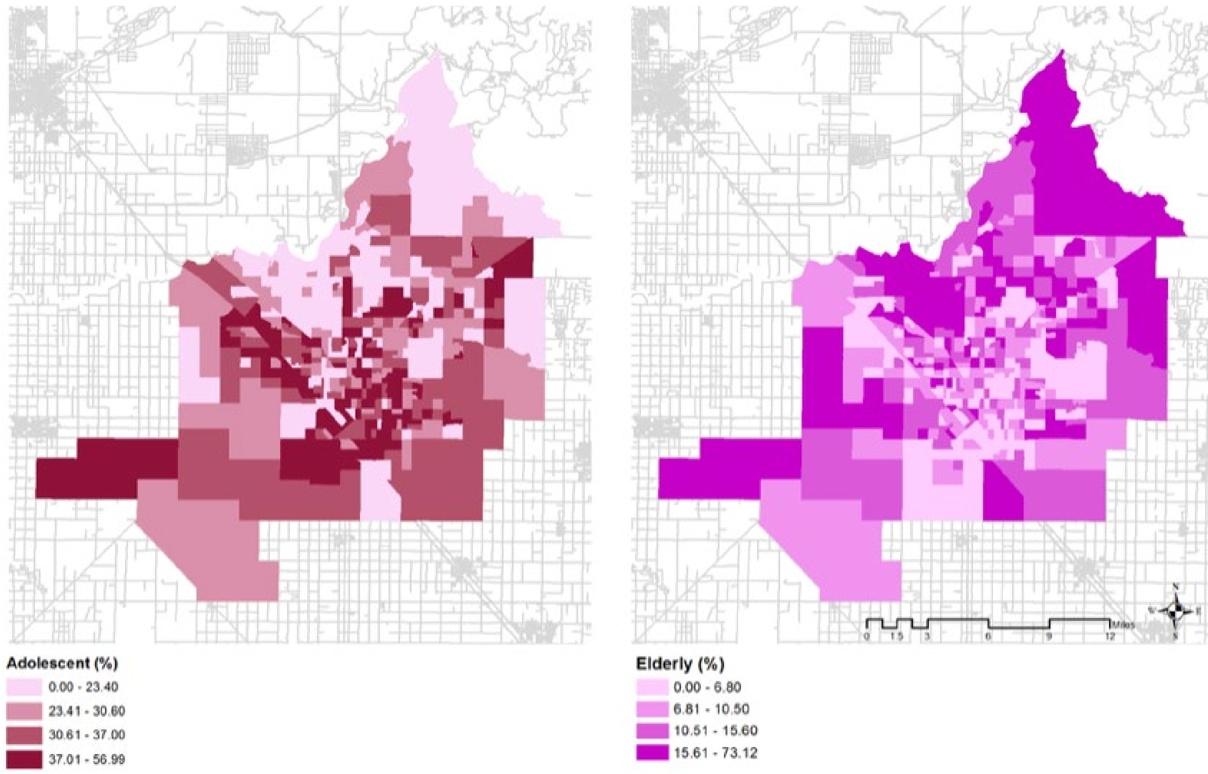

Figure 5. Spatial Distribution of Communities by Socio-Demographics (III)

COMPARRISON OF THE CACULATED ACCESSIBILITY

With the selected socioeconomic factors, the calculated accessibility to each urban opportunity can be divided into two groups in order to investigate if there is a difference in accessibility between them. Nevertheless, it might be arguable which threshold should be used to divide neighborhoods into two for each socioeconomic factor. To avoid such arguments, we proposed to divide neighborhoods into two groups using first- (25%), second- (50%), and third-quarter (75%) thresholds. Then, the two-sample t-test approach can be used to test whether each calculated accessibility is different between the two divided groups for each socioeconomic factor. Note that the difference between two groups might exist between the first-quarter group and the rest of the neighborhoods, but might not always be the case in the other group settings. This provides an interface to consistently compare accessibility between two groups using different thresholds. A potential advantage of this approach is that it might help target a specific group for promoting the use of transit and cycling. For instance, if the first-quarter neighborhoods of school non-enrollment have significant-lower accessibility than the rest of the neighborhoods, we could target these neighborhoods as the leverage to promote green transportation policies to increase their accessibility.

IV. RESULTS

SERVICE AREA

Based on the methods developed above for the service area by transit and cycling, the calculated results are presented in different travel-time thresholds (10, 20, 30, 45, and 60 minutes) in Figures 6–8 for public transit, and in Figures 9–11 for cycling. Figure 6 shows that one only can reach out a little from one's own neighborhood within a 20-minute bus ride (areas in brown in Figure 6). A 30- to 45-minute bus ride would allow a resident to reach further in space for a local destination (much larger brown areas in Figure 7), and it might need to take about an hour to access to some destinations that are on the other side of the city (see Figure 8).

From Figures 9–11, it is obvious that residents could have a much bigger reach-out area by cycling from their own neighborhoods, as compared to that by public transit. A 20- to 30-minute cycling would allow one to reach a destination within a large area (areas in brown in Figures 9–10), and a longer travel time by cycling beyond that would make it possible for one to reach most locations in the city (see Figure 11).

Table 1 presents an array of results pertaining to the varying accessibilities with 30-, 45-, and 60-minute travel times by both transportation modes. In general, the accessibility by a 45-minute bus ride would be the triple of that of a 30-minute one, while the accessibility by a 60-minute bus ride would be the double of that of a 45-minute one. In the case of cycling, the accessibility seems to show a linear trend with the travel time, meaning that a 45-minute cycle would double the accessibility of 30-minute cycling, and a 60-minute cycle would triple that of a 30-minute one.

More importantly, the accessibility by transit requires a 60-minute travel time to reach a similar quality of accessibility by cycling within a 30-minute travel time. In other words, it requires the double of the time to reach a similar number of urban opportunities across the city by transit as compared to cycling. This could discourage residents to rely on public transit for their daily activities. Improving the efficiency of the current FAX system to be at the same level as that of cycling could therefore be an extremely important task in convincing residents to use more public transit and hence to increase ridership. The following illustrates each of the computed accessibilities and their spatial distributions by transit and cycling respectively.

Table 2. Descriptive Statistics of Accessibility

	By transit						By cycling					
	30 minutes		45 minutes		60 minutes		30 minutes		45 minutes		60 minutes	
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Accessible block groups	18.42	14.47	57.77	41.38	**126.57**	76.82	**117.74**	46.84	221.90	68.78	314.49	66.42
Accessibility to low-wage jobs	2824.89	2644.81	10828.84	8134.32	**22732.85**	14317.97	**20570.80**	8596.79	39246.97	12790.84	55287.50	12016.97
Accessibility to medium-wage jobs	3796.80	4543.62	14446.14	11028.19	**30197.40**	19294.86	**27822.15**	10917.32	53196.00	17449.94	76095.55	17699.90
Accessibility to high-wage jobs	3521.96	5167.56	13350.70	11039.14	**27651.83**	18070.06	**25486.62**	11011.28	47901.05	16419.22	67841.27	16196.01
Accessibility to fast food	0.38	0.63	1.68	1.36	**3.75**	2.27	**3.93**	1.81	7.54	2.34	11.33	3.09
Accessibility to family restaurant	1.63	2.59	7.61	6.31	**14.74**	9.41	**13.78**	6.44	24.47	8.19	34.74	8.90
Accessibility to park	0.03	0.04	0.13	0.13	**0.31**	0.31	**0.39**	0.19	0.82	0.32	1.26	0.39
Accessibility to multi-use path	2.96	4.19	10.52	8.19	**21.53**	12.55	**22.71**	20.88	45.81	28.38	71.74	28.50
Accessibility to church	2.67	4.00	10.12	11.88	**24.93**	19.45	**26.72**	17.44	54.91	20.78	79.35	18.95
Accessibility to library	0.34	0.83	1.24	1.36	**2.18**	1.59	**1.85**	1.35	2.99	1.45	4.14	1.22
Accessibility to school	8.89	8.18	30.30	24.22	**69.41**	44.25	**70.60**	30.94	131.97	41.77	184.95	40.55

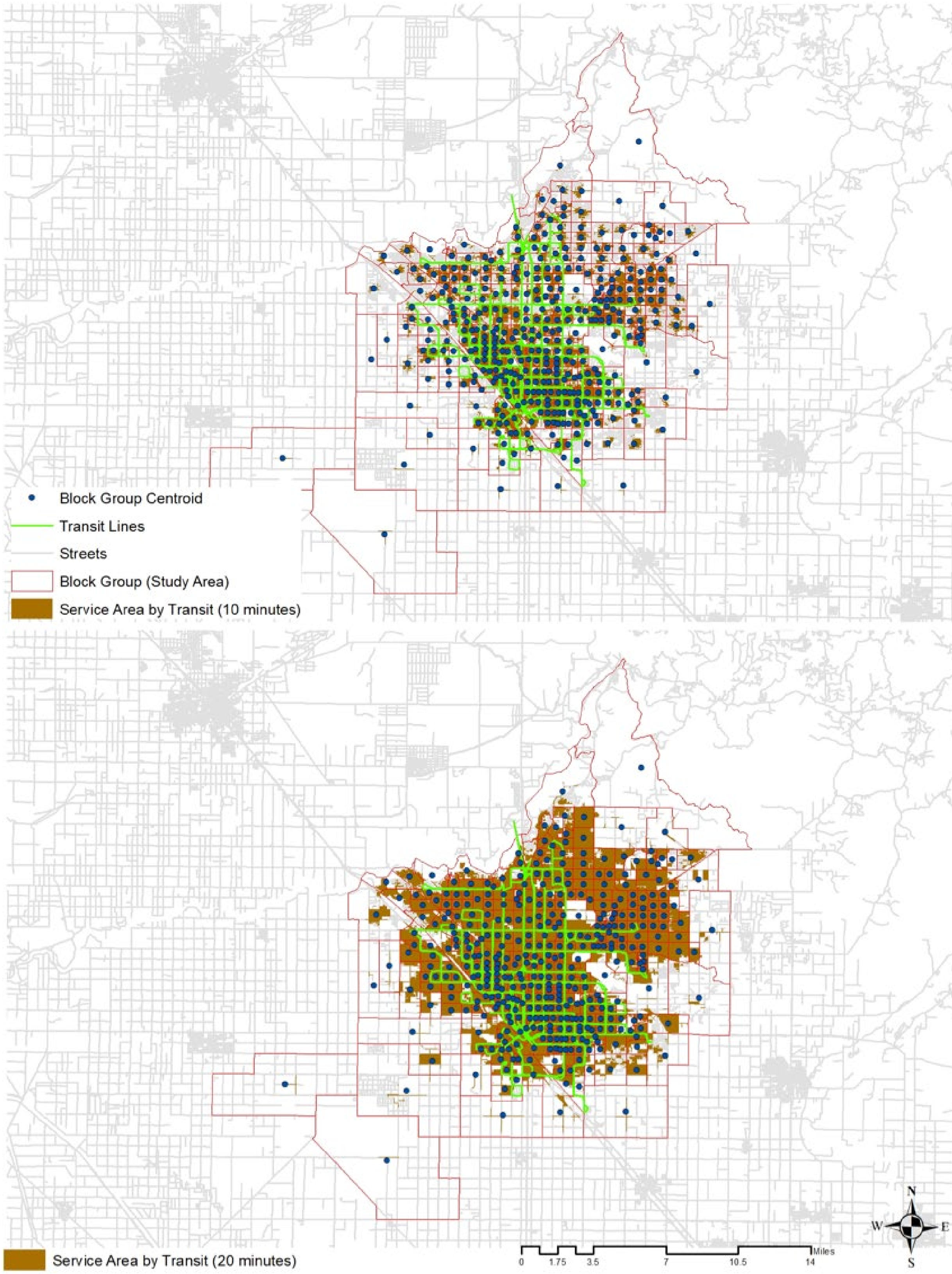

Figure 6. Service Area by Transit (10- and 20-minute)

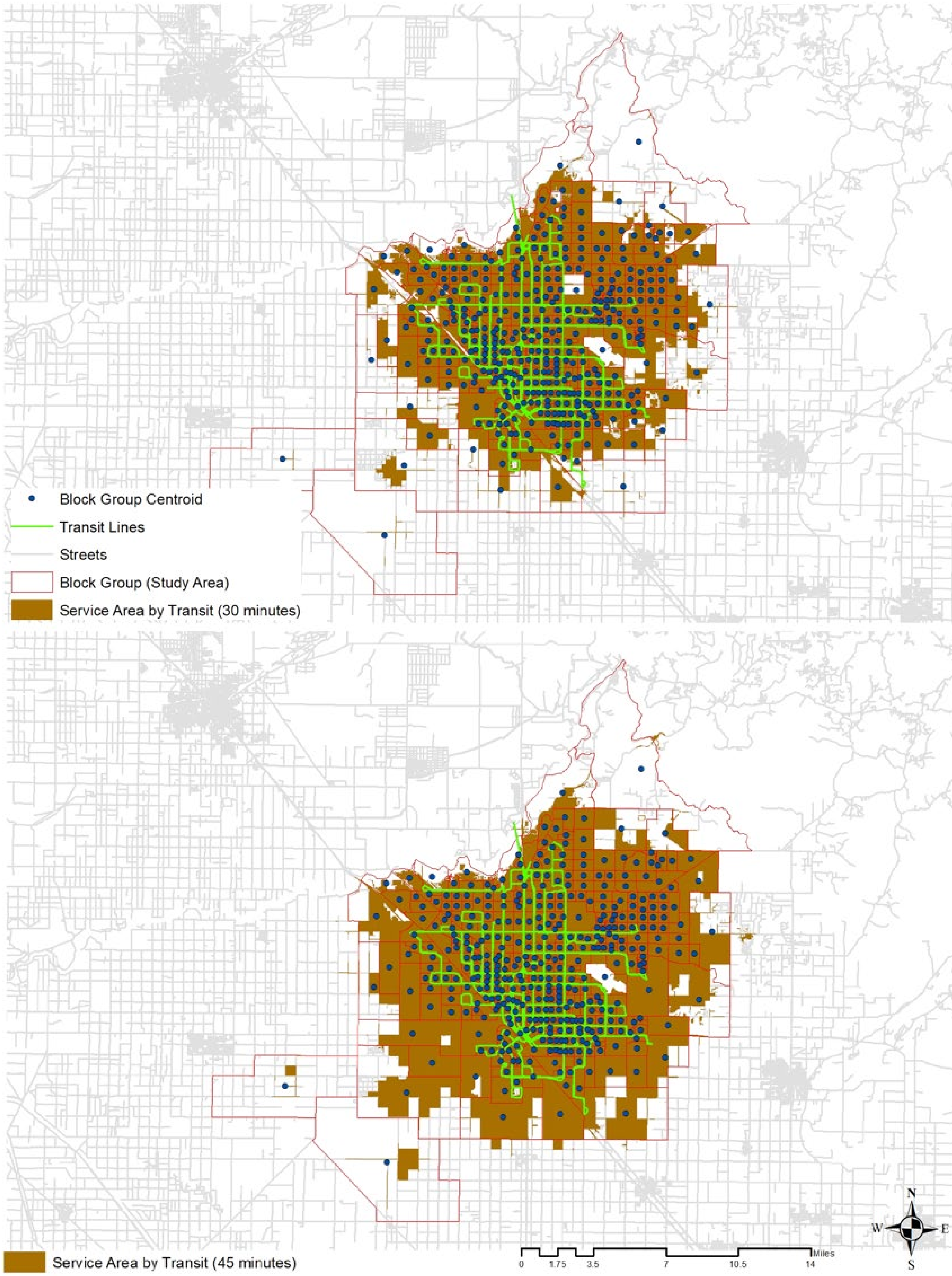

Figure 7. Service Area by Transit (30- and 45-minute)

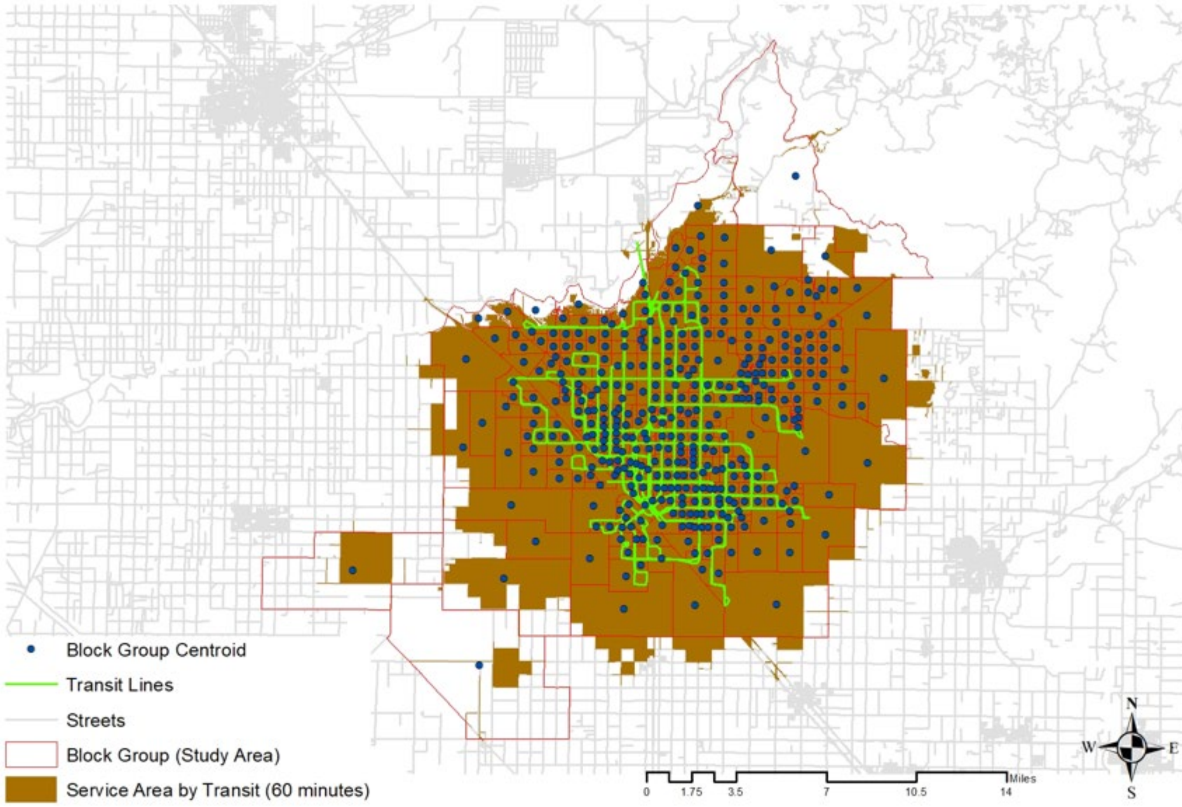

Figure 8. Service Area by Transit (60-minute)

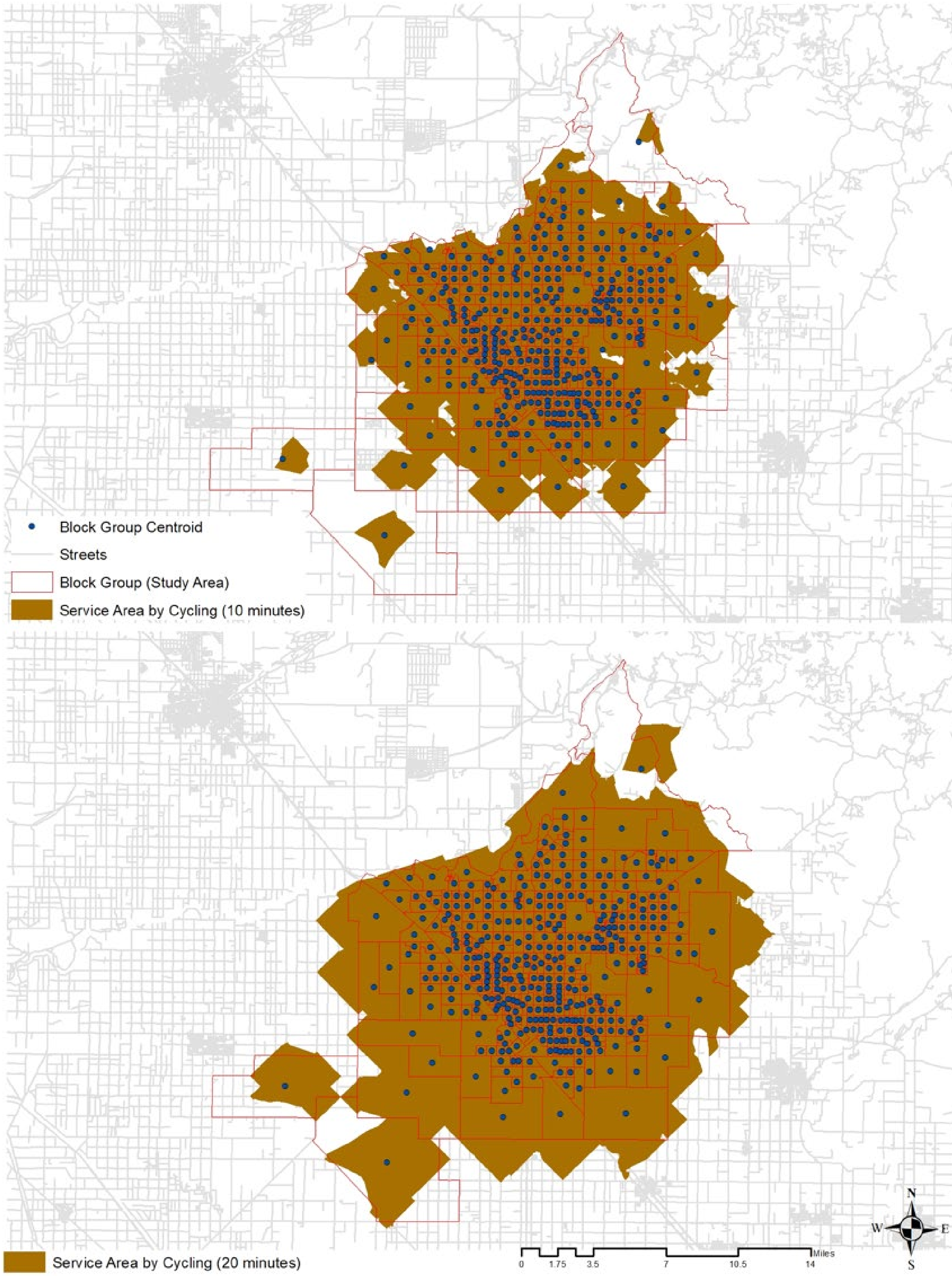

Figure 9. Service Area by Cycling (10- and 20-minute)

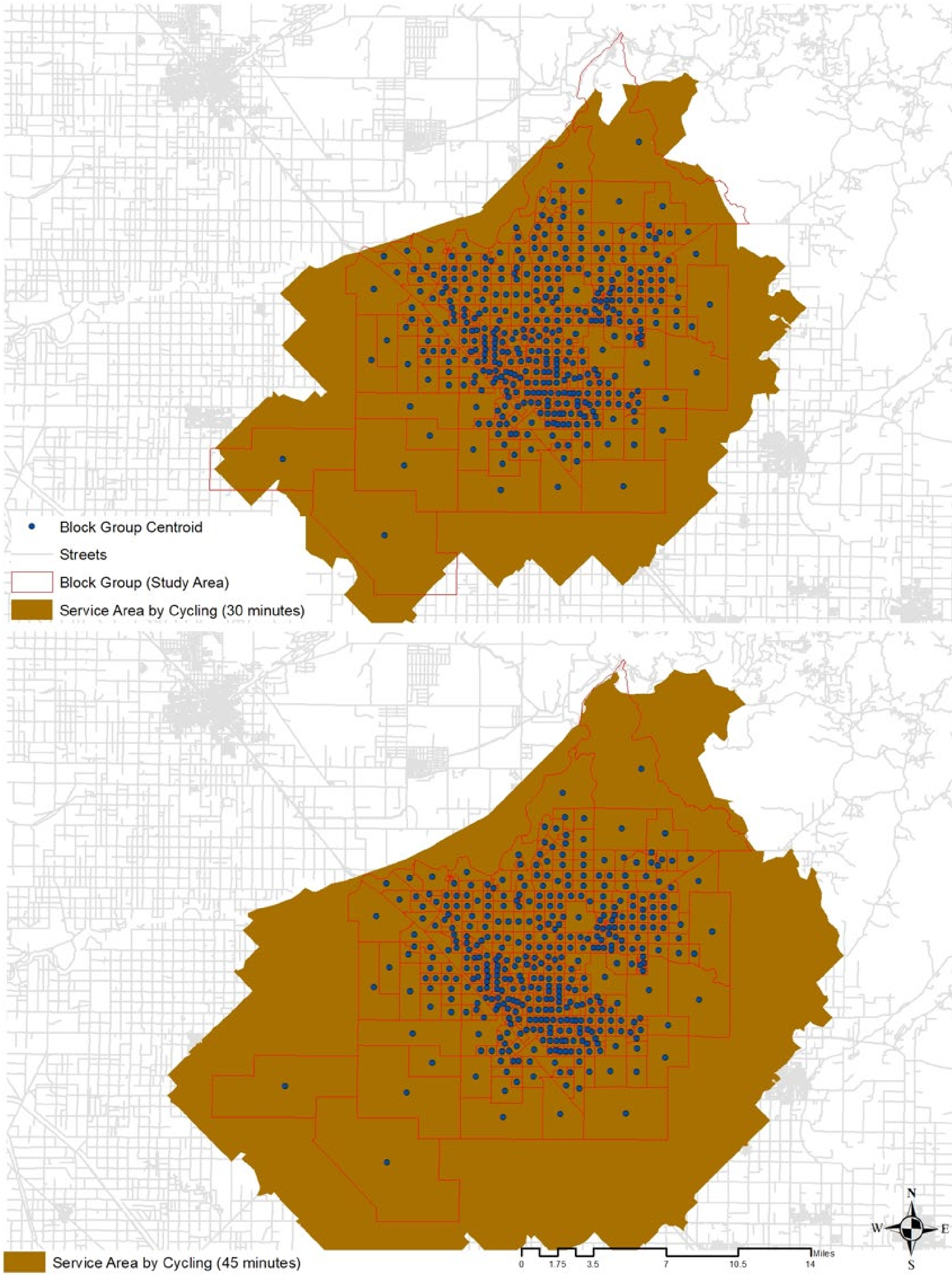

Figure 10. Service Area by Cycling (30- and 45-minute)

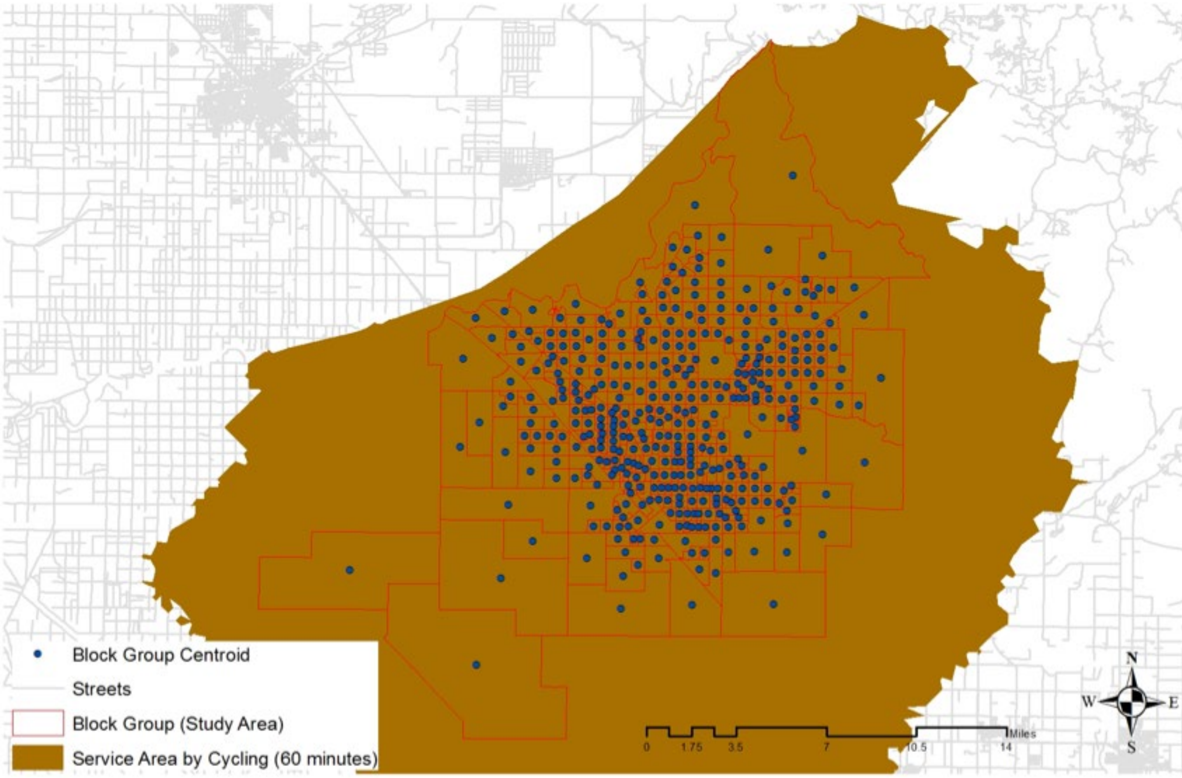

Figure 11. Service Area by Cycling (60-minute)

AALCULATED ACCESSIBILITY

Accessibility to Block Groups

The defined service area only shows how far in space one can access by public transit or cycling in a geographical sense. The calculated accessibility as presented in Table 1, however, can provide a quantitative way for measuring how many urban opportunities can be actually accessed by public transit or cycling. The accessibility to block groups (BGs) is defined as the number of block groups (in terms of centroid points) that fall inside the service area by using a transportation mode (public transit and cycling) for the thresholds of 10-, 20-, 30-, 45-, and 60-minutes. Therefore, the results provide a general look at accessibility by non-auto transportation modes for the city. The 30-minute travel time is selected for the comparison for the two transportation modes, as illustrated in Figure 12. The residents living around the city center would be able to reach more BGs than those living in the outskirt areas because the network of current bus routes and bike lanes are highly concentrated in the central area of the city. Also, one can reach more BGs by cycling than by transit because cycling typically creates a larger service area due to its time flexibility and route availability.

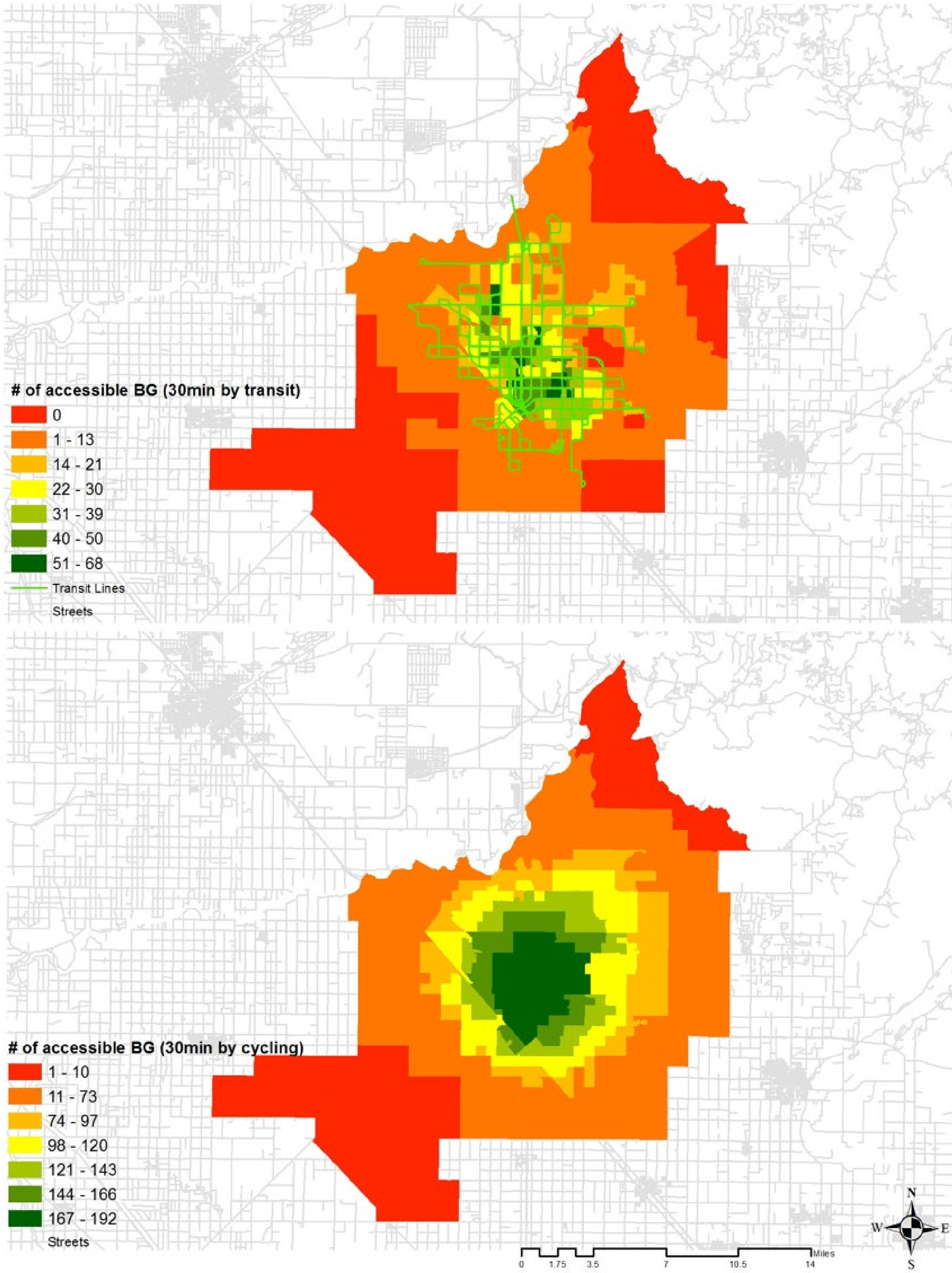

Figure 12. Number of Accessible Block Groups (30 minutes)

Accessibility to Jobs

At the block group (BG) level, the accessibility to jobs within 30 minutes by transit and cycling at three wage levels are displayed in Figure 13 and Figure 14. The capability of accessing jobs at these wage levels implies the potential economic-opportunity to gain different revenue. Figure 13 illustrates that those residents who live in the downtown area would be able to access more high-wage jobs by transit due to the limits of travel time and transit network setting. The three panels in Figure 14 show a similar spatial pattern that central area of the city has a higher job accessibility at all the three wage levels.

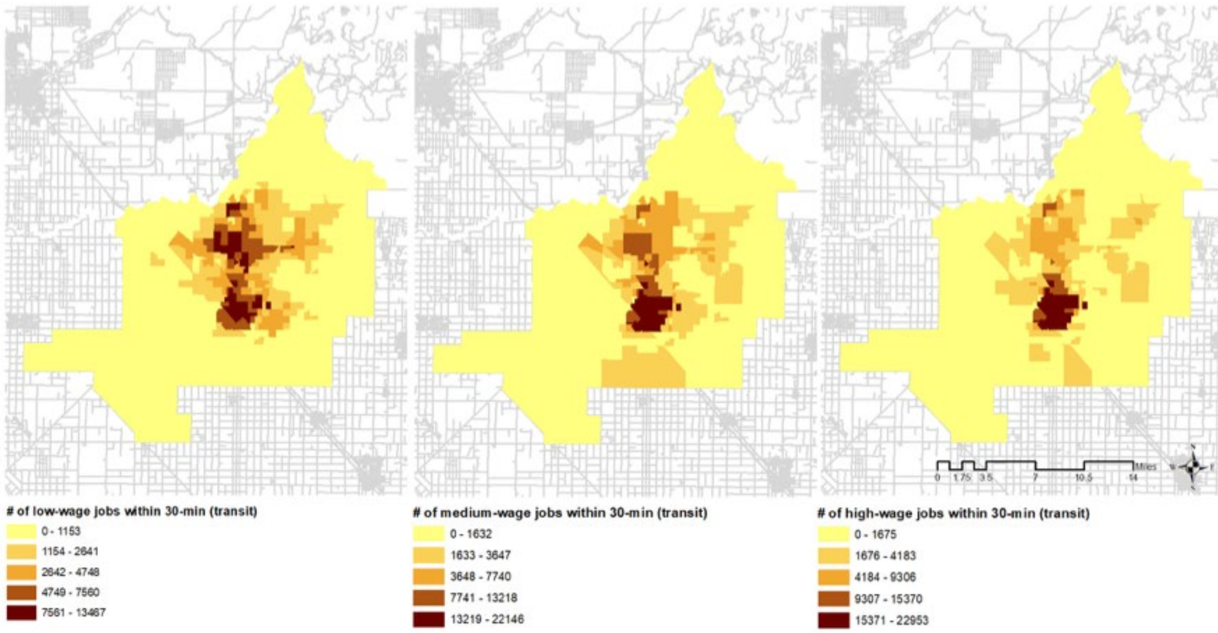

Figure 13. Accessibility to Jobs (30 minutes by Transit)

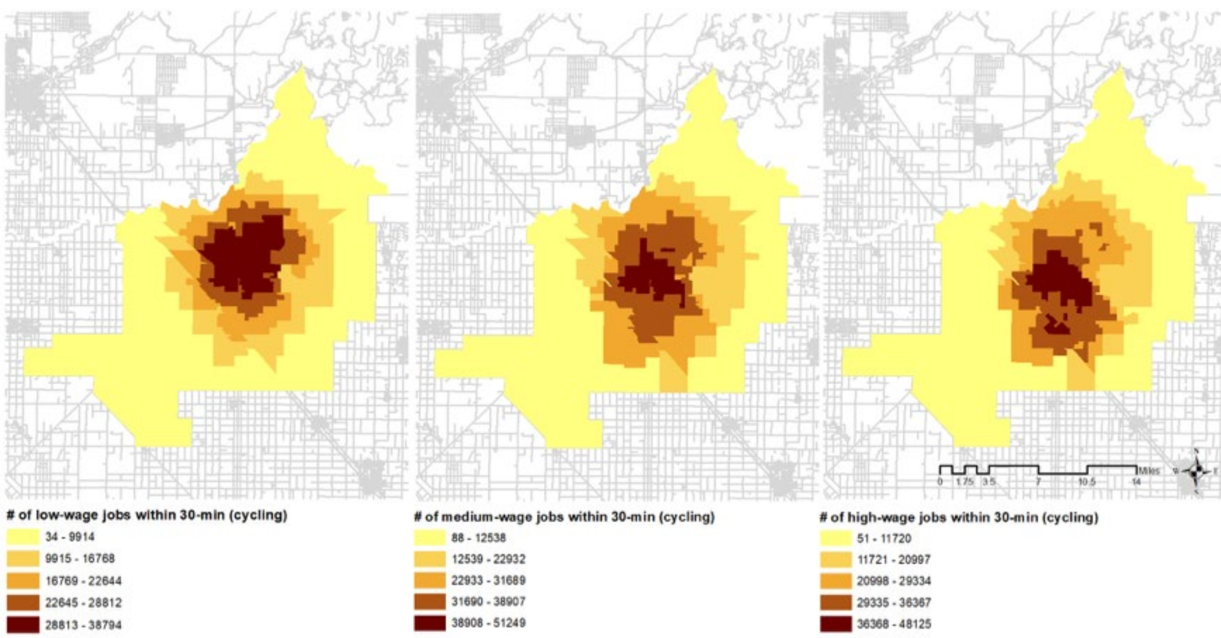

Figure 14. Accessibility to Jobs (30 minutes by Cycling)

Accessibility to Dining

This research classifies dining places into fast-food and regular family-restaurants which potentially reflect people's economic capability and health status. The accessibility to these two types of restaurants by transit and cycling within 30 minutes at the block group (BG) level are presented in Figure 15 and 16. Figure 15 shows that accessibility to dining (fast-food and family restaurants) is generally low by riding a bus for 30 minutes, except the downtown area. Comparatively, the flexibility of cycling in terms of time and routes makes the accessibility to these two types of dining is much better, even with a similar spatial pattern, than that by riding a bus in the same travel time.

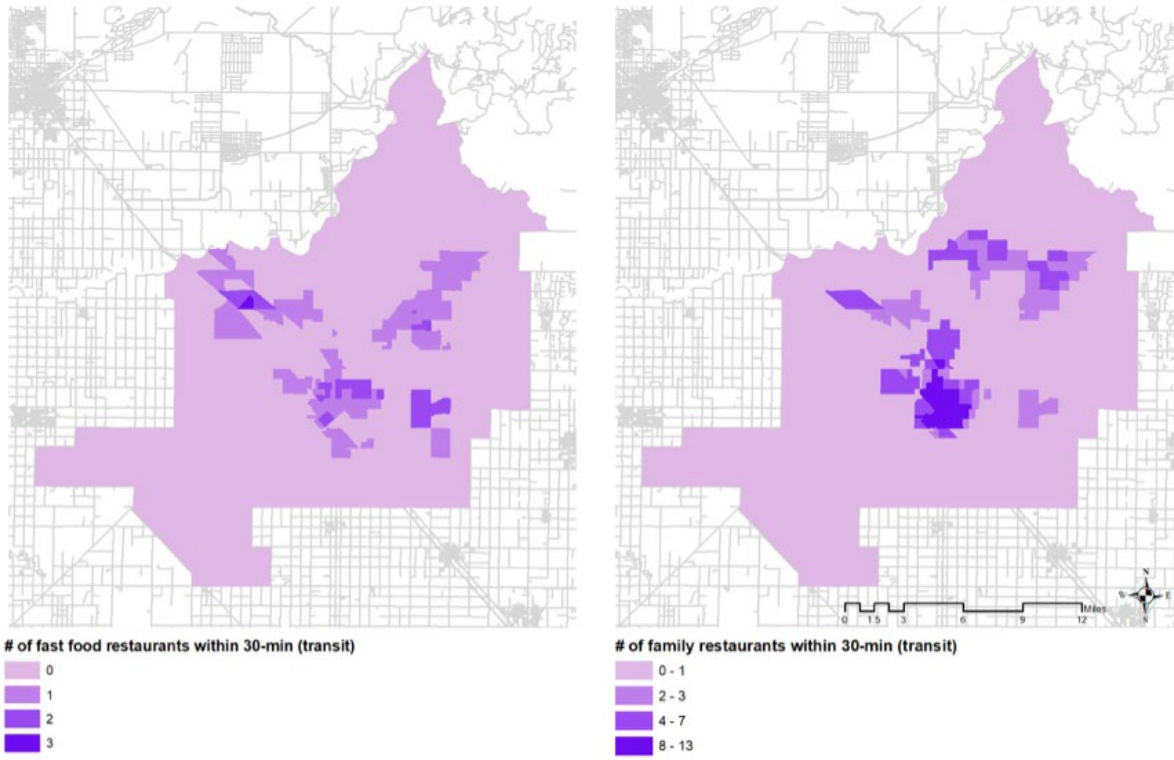

Figure 15. Accessibility to Restaurants (30 minutes by Transit)

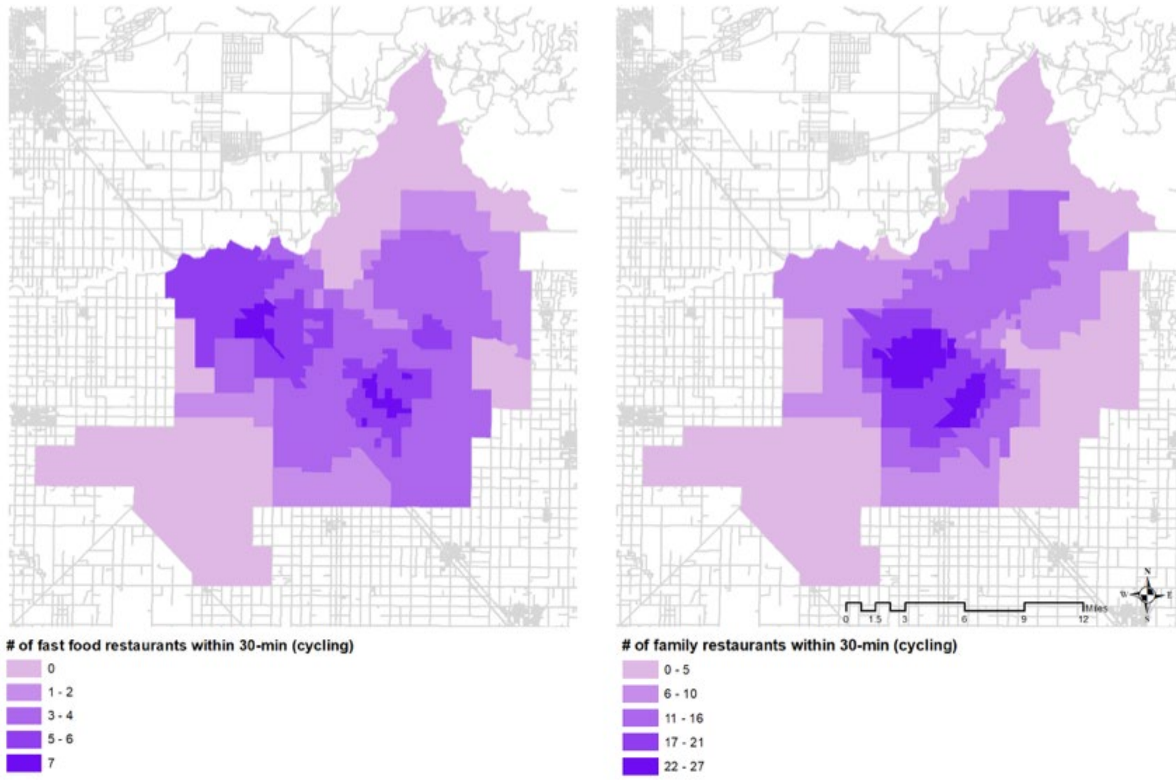

Figure 16. Accessibility to Restaurants (30 minutes by Cycling)

Accessibility to Social Activities

This study measures accessibility to social activities in terms of the number of reachable churches and libraries by non-auto transportation modes. Figure 17 and Figure 18 show the accessibility to churches and libraries by public transit and by cycling for a 30-minute ride. The results show that higher accessibility to churches for both transportation modes is concentrated in northern Fresno, while that to libraries is concentrated around the downtown area, most likely due to the allocation of these facilities. An extremely centralized pattern implies an unequal spatial distribution of land uses and transportation network to connect to these services.

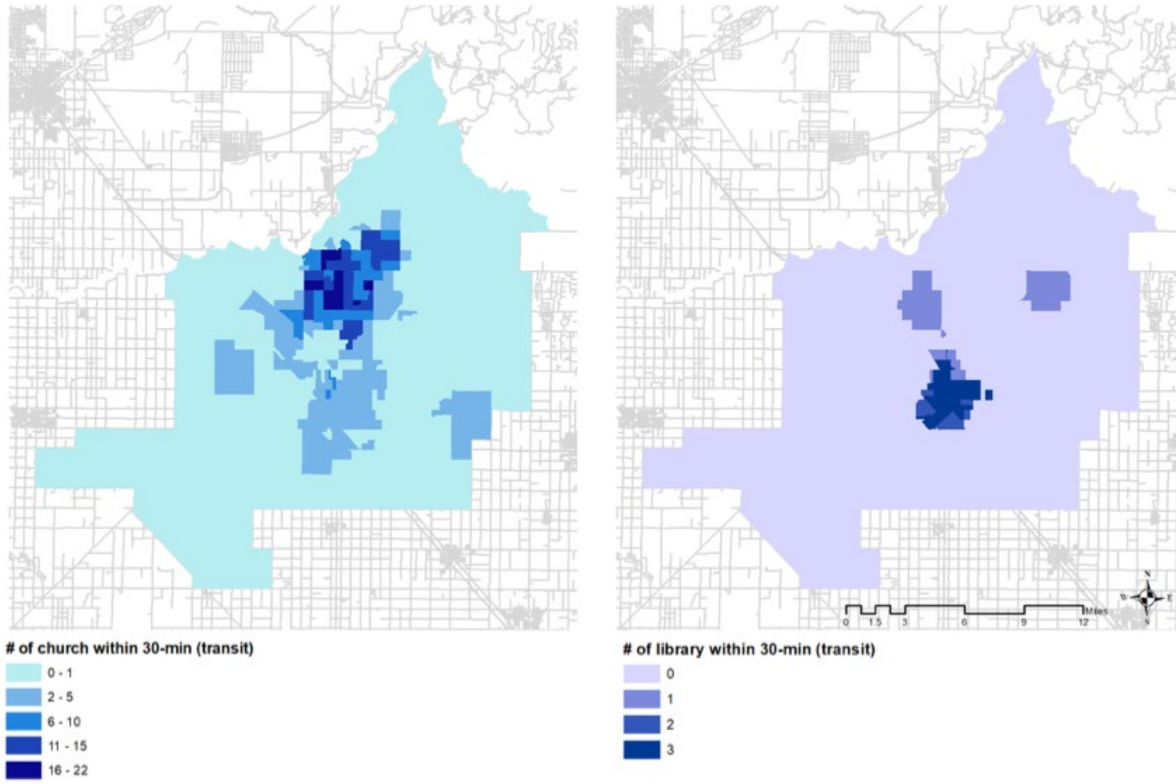

Figure 17. Accessibility to Social Activities (30 minutes by Transit)

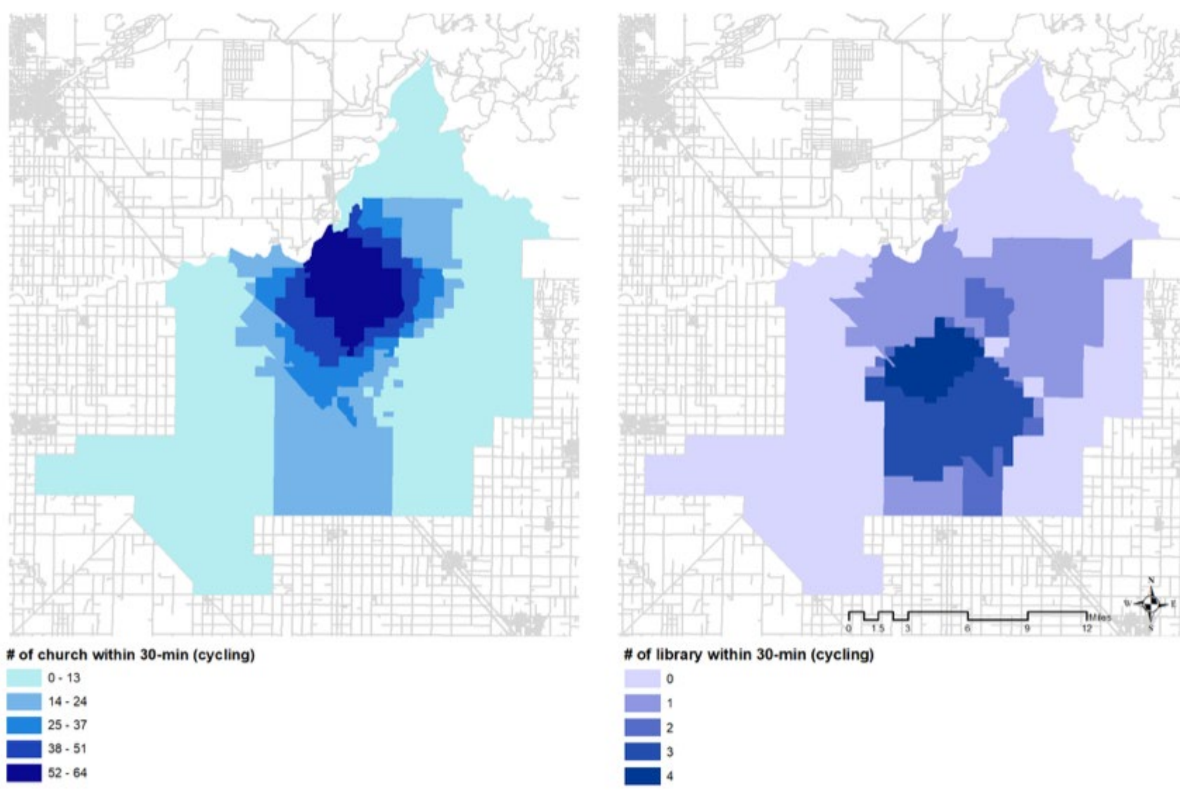

Figure 18. Accessibility to Jobs (30 minutes by Cycling)

Accessibility to Education

The accessibility to education is measured as the ability to reach the number of schools in the city. The results for both transportation modes within the 30-minute threshold show a clear core of accessibility in the central area of the city in Figure 19.

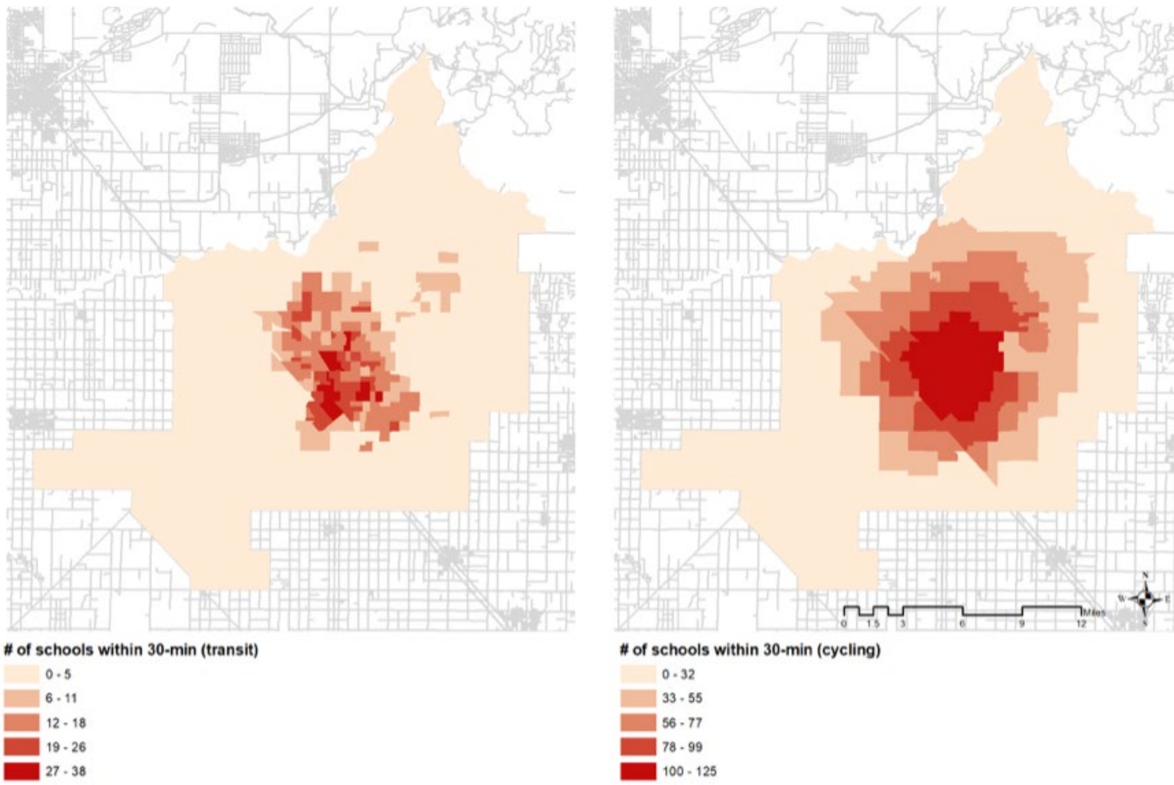

Figure 19. Accessibility to Education (30 minutes)

Accessibility to Physical Activities

This study uses the accessibility to parks and multi-use paths to capture the opportunity to conduct physical activities within a 30-minute ride. Figure 20 and Figure 21 show an interesting result that northwestern Fresno has better accessibility to parks, while northeastern Fresno has better accessibility to multi-use paths for conducting physical exercises. This implies that different types of green transportation infrastructure and facilities for physical exercises are allocated quite differently across this city. Higher accessibility to parks in the northwest is most likely due to the physical setting of the largest park, Woodward Park, in the city. Note that there are not many large parks found in the city because of low precipitation in the Central Valley. In addition, northeast Fresno contains high-income neighborhoods (e.g., Clovis) where new residential developments were designed and constructed to provide multi-use paths or complete streets.

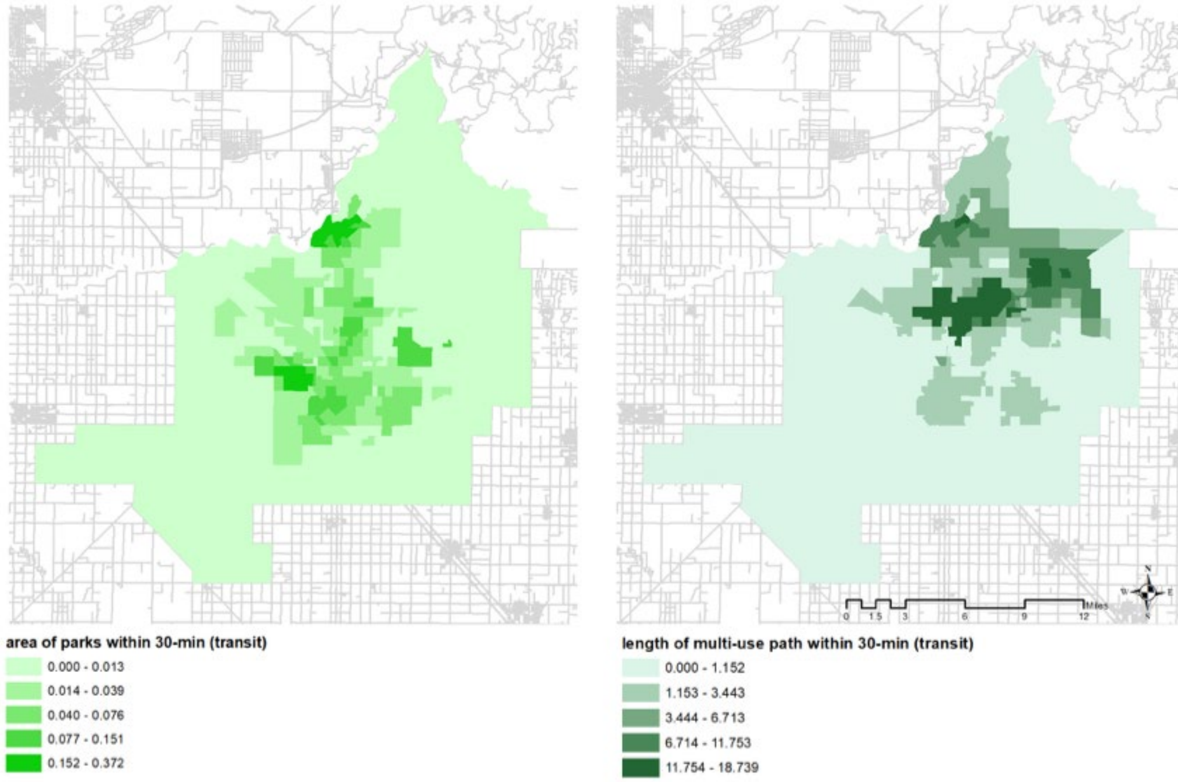

Figure 20. Accessibility to Physical Activities (30 minutes by Transit)

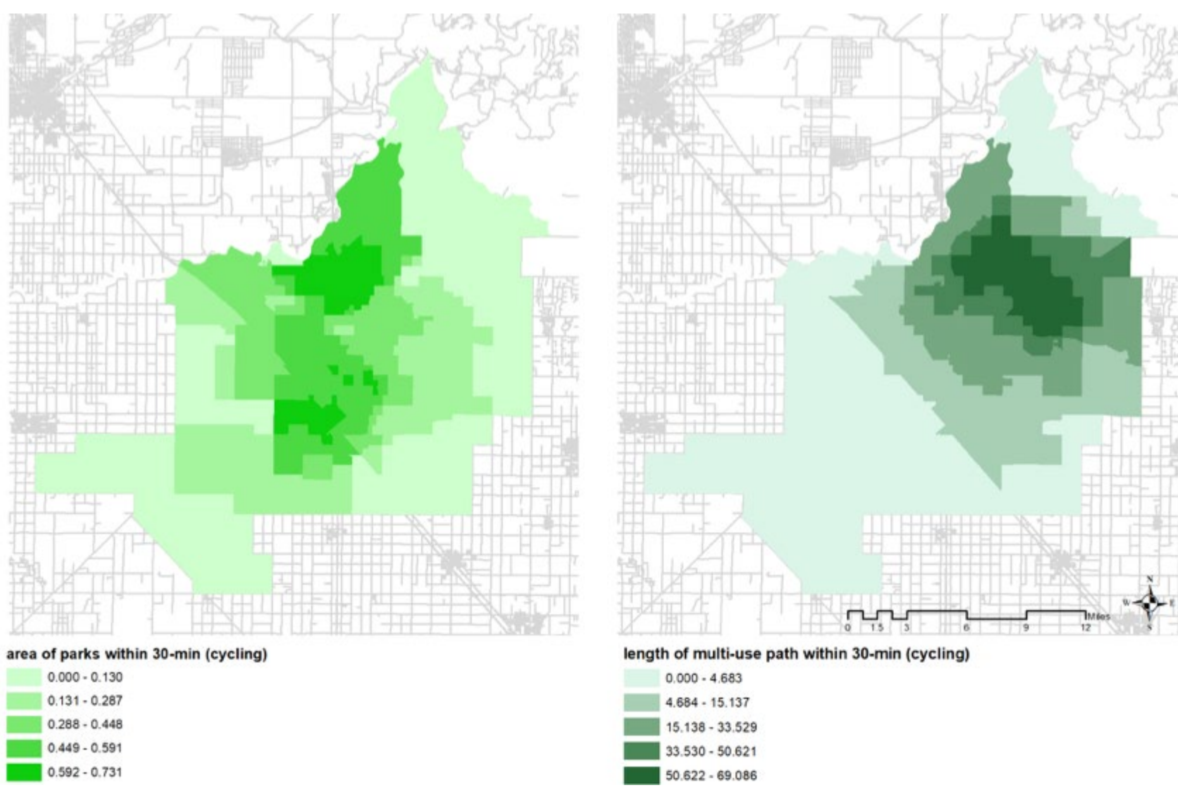

Figure 21. Accessibility to Physical Activities (30 minutes by Cycling)

ACCESSIBILITY COMPARISON

The accessibility to urban opportunities in the five categories (jobs, dining, physical activities, social activities, and education) presented above only shows how capable a resident can reach out by using public transit or cycling within 30 minutes. It is also important to better understand if transport inequity exists between better-off and worse-off neighborhoods. To serve this purpose, the calculated accessibility was statistically compared between higher-share and lower-share groups for the six socio-economic factors (income, property value, school non-enrollment, vehicle ownership, race, and age). For each of the six socioeconomic factors, each of the three percentiles (25%, 50%, and 75%) was used as the threshold to separate the population (block groups) into two groups for comparison. For instance, we conducted a t-test to see whether there is any significant difference in accessibility between the foot 25% income neighborhoods and the top 75%, the foot 50% and the top 50%, and the foot 75% and the top 25%. The purpose is to see whether the comparison results would be sensitive to the grouping threshold. Furthermore, this would help identify who should be targeted for corresponding policies where the difference exists. The comparison results for the six socioeconomic factors are presented in Tables 3 to 8, using two sample t-tests for equal means. The bold t-values represent the results at the significance level of 0.05.

Table 3. Comparison by Income

Accessibility to		Median household income								
		25% ($27974)			50% ($41185)			75% ($67500)		
		Below	Above	t	Below	Above	t	Below	Above	t
	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
By transit	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
	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
By cycling	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

Table 4. Comparison by Property Value

	Accessibility to	Median property value								
		25% ($119000)			50% ($160050)			75% ($237400)		
		Below	Above	t	Below	Above	t	Below	Above	t
By transit	Jobs									
	Low-wage	3569.61	2358.90	4.10	3228.66	2091.25	4.48	3067.63	1445.61	5.62
	Medium-wage	5306.60	2876.38	5.03	4408.44	2552.94	4.41	4054.95	1770.12	4.73
	High-wage	5319.09	2461.49	5.26	4218.05	2126.09	4.41	3779.75	1361.96	4.42
	Dining									
	Fast food	0.46	0.32	2.03	0.43	0.28	2.42	0.42	0.15	3.86
	Family restaurant	2.33	1.20	4.00	1.74	1.22	2.09	1.70	0.84	3.03
	Physical activities									
	Park	0.05	0.02	5.34	0.04	0.02	4.59	0.03	0.02	2.58
	Multi-use path	1.66	3.24	-3.30	2.24	3.45	-2.90	2.61	3.53	-1.91
	Social activities									
	Church	2.84	2.57	0.56	2.48	2.79	-0.75	2.76	2.28	1.01
	Library	0.57	0.19	4.31	0.39	0.18	2.76	0.34	0.12	2.48
	Education									
	School	13.67	6.82	7.98	11.72	5.32	8.75	10.22	3.47	7.88
By cycling	Jobs									
	Low-wage	22700.14	19549.86	3.05	22631.50	18034.94	5.28	21783.46	16013.36	5.79
	Medium-wage	33633.40	25417.56	6.52	32020.90	22900.18	8.70	30004.30	19883.36	8.31
	High-wage	32892.71	22523.07	8.46	30415.46	19787.77	10.45	27866.80	16864.89	9.13
	Dining									
	Fast food	4.69	3.67	4.77	4.51	3.34	6.55	4.30	2.80	7.37
	Family restaurant	18.49	11.85	9.56	16.39	10.62	9.60	15.00	9.03	8.43
	Physical activities									
	Park	0.48	0.36	5.26	0.42	0.35	3.78	0.41	0.32	4.09
	Multi-use path	13.01	25.84	-5.40	15.91	29.39	-6.69	19.23	32.84	-5.78
	Social activities									
	Church	25.03	27.08	-0.98	25.23	27.91	-1.48	26.28	27.45	-0.56
	Library	2.90	1.43	10.16	2.47	1.13	10.92	2.14	0.80	9.08
	Education									
	School	91.31	62.08	8.60	86.41	52.29	12.69	78.70	41.49	11.75

Table 5. Comparison by Non-Enrollment in School

	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

Table 6. Comparison by Vehicle Ownership

	Accessibility to	Zero-vehicle ownership								
		25% (1.98%)			50% (7.48%)			75% (16.0%)		
		Below	Above	t	Below	Above	t	Below	Above	t
By transit	Jobs									
	Low-wage	1597.88	3231.23	-5.60	2070.18	3579.60	-6.02	2392.35	4130.98	-6.00
	Medium-wage	1944.28	4410.29	-4.88	2501.21	5092.39	-6.02	2906.23	6485.96	-7.33
	High-wage	1627.91	4149.21	-4.36	2122.58	4921.33	-5.69	2494.25	6625.22	-7.45
	Dining									
	Fast food	0.25	0.42	-2.35	0.32	0.44	-2.06	0.34	0.50	-2.23
	Family restaurant	0.91	1.87	-3.27	1.21	2.04	-3.28	1.29	2.66	-4.74
	Physical activities									
	Park	0.02	0.04	-2.71	0.02	0.04	-3.18	0.03	0.05	-3.77
	Multi-use path	3.20	2.87	0.69	3.10	2.81	0.71	3.15	2.36	1.67
	Social activities									
	Church	2.09	2.87	-1.71	2.58	2.77	-0.47	2.64	2.76	-0.27
	Library	0.15	0.40	-2.71	0.17	0.51	-4.17	0.20	0.75	-6.07
	Education									
	School	4.36	10.39	-6.80	5.89	11.89	-7.97	6.95	14.75	-9.16
By cycling	Jobs									
	Low-wage	15502.65	22249.21	-7.29	18258.36	22883.23	-5.65	19701.33	23196.25	-3.61
	Medium-wage	19745.60	30496.85	-9.52	23462.29	32182.00	-8.81	25859.80	33747.68	-6.65
	High-wage	17022.64	28289.63	-9.98	20623.03	30350.21	-9.96	23142.80	32564.05	-8.05
	Dining									
	Fast food	3.36	4.12	-3.74	3.50	4.37	-4.97	3.71	4.62	-4.51
	Family restaurant	9.75	15.11	-7.79	11.17	16.39	-8.95	12.39	17.97	-8.17
	Physical activities									
	Park	0.30	0.42	-5.65	0.35	0.43	-4.30	0.37	0.46	-4.55
	Multi-use path	27.88	21.00	2.91	27.15	18.27	4.40	25.12	15.44	4.14
	Social activities									
	Church	22.55	28.11	-2.81	26.13	27.32	-0.69	27.14	25.48	0.83
	Library	0.94	2.15	-8.51	1.29	2.41	-9.29	1.56	2.75	-8.33
	Education									
	School	46.94	78.44	-9.91	55.72	85.49	-11.1	63.66	91.58	-8.57

Table 7. Comparison by Race

	Accessibility to	Non-white								
		25% (20.9%)			50% (35.0%)			75% (50.1%)		
		Below	Above	t	Below	Above	t	Below	Above	t
	Jobs									
	Low-wage	2338.11	2988.21	-2.17	2355.67	3294.11	-3.65	2683.27	3252.53	-1.89
	Medium-wage	2807.03	4128.87	-2.57	2743.48	4850.11	-4.82	3493.79	4711.76	-2.36
	High-wage	2357.34	3912.69	-2.66	2266.97	4776.94	-5.06	3160.47	4613.49	-2.48
	Dining									
	Fast food	0.22	0.43	-2.97	0.25	0.51	-4.35	0.35	0.48	-1.86
	Family restaurant	1.14	1.79	-2.25	1.20	2.06	-3.40	1.56	1.85	-1.01
By transit	Physical activities									
	Park	0.02	0.03	-2.31	0.03	0.04	-2.79	0.03	0.04	-1.91
	Multi-use path	3.22	2.87	0.73	3.72	2.19	3.77	3.32	1.87	3.05
	Social activities									
	Church	2.94	2.58	0.79	3.04	2.30	1.88	2.90	2.00	1.97
	Library	0.16	0.40	-2.60	0.15	0.53	-4.68	0.29	0.50	-2.26
	Education									
	School	5.49	10.03	-5.02	5.84	11.94	-8.12	7.58	12.84	-5.86
	Jobs									
	Low-wage	20218.48	20689.00	-0.48	19889.67	21251.92	-1.61	20525.04	20708.97	-0.19
	Medium-wage	25378.03	28642.16	-2.64	25131.70	30512.60	-5.14	26763.59	31018.56	-3.46
	High-wage	21998.14	26657.02	-3.78	21921.20	29052.03	-6.92	23953.57	30115.82	-5.04
	Dining									
	Fast food	3.26	4.16	-4.46	3.28	4.59	-7.81	3.65	4.79	-5.76
	Family restaurant	11.15	14.66	-4.93	11.74	15.81	-6.74	12.94	16.30	-4.68
By cycling	Physical activities									
	Park	0.37	0.40	-1.14	0.37	0.41	-1.91	0.39	0.41	-0.93
	Multi-use path	31.36	19.81	5.00	31.11	14.31	8.88	26.28	11.93	6.29
	Social activities									
	Church	30.98	25.30	2.89	29.97	23.48	3.83	28.56	21.17	3.77
	Library	1.32	2.03	-4.73	1.35	2.35	-8.06	1.64	2.48	-5.63
	Education									
	School	30.98	25.30	2.89	29.97	23.48	3.83	28.56	21.17	3.77

Table 8. Comparison by Age

	Accessibility to	Adolescent (under 19 years)								
		25% (23.38%)			50% (30.63%)			75% 36.98%)		
		Below	Above	t	Below	Above	t	Below	Above	t
By transit	Jobs									
	Low-wage	3197.40	2701.52	1.64	2815.63	2834.15	-0.07	2641.57	3371.28	-2.44
	Medium-wage	4021.17	3722.49	0.57	3625.05	3968.55	-0.77	3417.55	4927.17	-2.95
	High-wage	3442.26	3548.35	-0.18	3223.88	3820.03	-1.17	3077.94	4845.38	-3.03
	Dining									
	Fast food	0.28	0.41	-1.79	0.33	0.43	-1.58	0.34	0.50	-2.16
	Family restaurant	1.68	1.61	0.21	1.61	1.64	-0.11	1.56	1.84	-0.98
	Physical activities									
	Park	0.03	0.03	0.62	0.03	0.04	-1.97	0.03	0.04	-3.02
	Multi-use path	3.72	2.70	2.14	3.33	2.58	1.82	3.15	2.38	1.61
	Social activities									
	Church	4.11	2.20	4.27	3.13	2.21	2.34	2.69	2.63	0.12
	Library	0.31	0.35	-0.35	0.29	0.39	-1.13	0.28	0.50	-2.35
	Education									
	School	7.93	9.21	-1.37	7.61	10.17	-3.19	7.61	12.70	-5.66
By cycling	Jobs									
	Low-wage	22716.24	19860.29	2.94	21246.61	19894.98	1.59	20322.43	21311.06	-1.01
	Medium-wage	28979.57	27438.84	1.24	27481.67	28162.62	-0.63	26675.00	31241.31	-3.73
	High-wage	25430.19	25505.31	-0.06	24409.65	26563.59	-1.99	23923.10	30146.82	-5.11
	Dining									
	Fast food	3.40	4.11	-3.48	3.60	4.27	-3.86	3.69	4.67	-4.91
	Family restaurant	12.36	14.25	-2.58	12.64	14.91	-3.62	12.80	16.70	-5.51
	Physical activities									
	Park	0.44	0.38	2.74	0.40	0.38	0.98	0.38	0.41	-1.15
	Multi-use path	28.97	20.64	3.54	27.53	17.90	4.79	25.43	14.62	4.66
	Social activities									
	Church	36.55	23.47	6.93	30.68	22.77	4.71	28.00	22.93	2.57
	Library	1.55	1.95	-2.63	1.61	2.09	-3.68	1.61	2.57	-6.58
	Education									
	School	65.46	72.31	-1.94	65.92	75.29	-3.10	66.10	84.04	-5.25

Table 8. Comparison by Age (Cont.)

	Accessibility to	Elderly (at least 65 years old)								
		25% (23.38%)			50% (30.63%)			75% (36.98%)		
		Below	Above	t	Below	Above	t	Below	Above	t
	Jobs									
	Low-wage	3256.69	2680.02	1.92	3032.58	2617.20	1.59	2856.12	2731.80	0.41
	Medium-wage	4579.74	3534.12	2.03	4266.55	3327.05	2.10	3919.97	3429.67	0.95
	High-wage	4446.74	3211.69	2.11	4164.73	2879.18	2.54	3736.05	2883.85	1.45
	Dining									
	Fast food	0.51	0.34	2.53	0.44	0.32	2.06	0.41	0.29	1.67
	Family restaurant	1.95	1.52	1.46	1.78	1.48	1.14	1.72	1.37	1.18
By transit	Physical activities									
	Park	0.04	0.03	1.37	0.03	0.03	1.49	0.03	0.02	1.77
	Multi-use path	2.92	2.97	-0.11	2.78	3.14	-0.87	2.89	3.16	-0.56
	Social activities									
	Church	2.38	2.77	-0.86	2.34	3.01	-1.71	2.41	3.47	-2.34
	Library	0.43	0.31	1.24	0.41	0.27	1.72	0.36	0.27	0.95
	Education									
	School	10.63	8.31	2.51	10.45	7.33	3.94	9.59	6.82	3.00
	Jobs									
	Low-wage	20666.06	20538.83	0.13	20690.49	20451.10	0.28	20344.16	21246.29	-0.92
	Medium-wage	29457.20	27273.58	1.76	28901.14	26743.16	2.01	28154.49	26831.58	1.06
	High-wage	27832.66	24699.51	2.52	27044.89	23928.35	2.89	26205.82	23342.98	2.30
	Dining									
	Fast food	4.52	3.74	3.89	4.29	3.58	4.03	4.07	3.51	2.74
	Family restaurant	15.49	13.21	3.14	15.20	12.36	4.56	14.46	11.74	3.77
By cycling	Physical activities									
	Park	0.39	0.39	0.19	0.39	0.39	0.42	0.39	0.39	-0.10
	Multi-use path	16.18	24.90	-3.73	18.28	27.14	-4.39	21.03	27.71	-2.83
	Social activities									
	Church	23.19	27.91	-2.39	24.04	29.40	-3.15	24.57	33.15	-4.42
	Library	2.30	1.70	3.98	2.13	1.57	4.29	2.01	1.38	4.19
	Education									
	School	79.70	67.55	3.49	77.67	63.54	4.74	74.16	60.01	4.09

Accessibility Comparison by Income and Property Value

Table 3 shows the t-test results for the comparison of the accessibility to urban opportunities between the lower- and higher-income neighborhoods. As mentioned earlier, we used the 25th, 50th, and 75th percentile as the thresholds to separate the population (block groups) into two income groups for the comparison. We found that there is a significant difference in accessibility by both transit and cycling between the lower- and higher-income neighborhoods, except the accessibility to churches, in the uses of all the three percentile thresholds. The results suggest that residents from a lower-income neighborhood have better accessibility to urban opportunities (except to churches) by transit or cycling as compared to those from a higher-income neighborhood. This might be the best case of addressing social inequality issues, because it suggests that the current green transportation network (transit and cycling) in Fresno does promote an equal environment for economically disadvantaged groups. Nevertheless, the t-test results also show that a higher-income neighborhood has better accessibility to multi-use paths by transit, although the statistical results become insignificant when shifting the threshold from the 25th to the 50th percentile.

Similar results were also found in the comparisons of the accessibility between lower- and higher- property value groups (Table 4), because property value shows a very similar spatial pattern with income (Figure 3). The main transportation mode used by the residents living in these high-property-value neighborhoods is driving a private vehicle. These neighborhoods are mostly located in the outskirts of the city, since residents prefer better privacy and amenities and some of them would like to be away from bus stops. Overall, we find that neighborhoods in Fresno with relatively low household income and property value do not suffer from low accessibility to most urban opportunities (e.g., jobs and dining) by using public transit and cycling. These findings are consistent with the results reported by Foth et al. (2013), namely, that socially disadvantaged census tracts (defined based on income, labor force, immigration status, and housing expense) in Toronto have better accessibility with shorter transit travel time. It is worth noting that residents of Fresno living in a higher-income or higher-property-value neighborhood have better accessibility to multi-use paths by either transit or cycling. It might be explained that wealthy neighborhoods are better equipped with pedestrian-friendly infrastructure in the neighborhood construction.

Accessibility Comparison by School Enrollment

Overall, there is no significant difference in accessibility by transit between lower- and higher-school enrollment neighborhoods (Table 5). However, we do find that a neighborhood with a higher share of school-enrolled students tends to have worse accessibility to family restaurants by transit. Worse accessibility to low-wage jobs and parks was also found for the neighborhoods with a higher share of school non-enrollment, using the 75% threshold. Therefore, being unenrolled in school might not be necessarily seen as a socially or economically disadvantaged group in Fresno.

However, significant differences in accessibility, through cycling, to dining, physical activities, and social interactions exist. In general, a neighborhood with a higher share of school enrollment tends to have better accessibility to dining by cycling (see positive t-values in Table 5). When the threshold is set as the 25th percentile, the neighborhoods with a higher share of school non-enrollment, using the 25% threshold, have better accessibility to libraries. However, such a neighborhood would generally have lower accessibility to physical activities and churches (see negative t-values in Table 5).

In essence, transit and cycling perform very differently in accessibility to urban opportunities when considering school enrollment. Therefore, it would be interesting to further investigate enrolled students' travel behavior based on the green transportation investments to promote their accessibility. This is because students are the most potential and diverse group whose travel behavior and accessibility might be influenced easier through advocating sustainable transportation and also might influence other people through their social networking.

Accessibility Comparison by Vehicle Ownership and Race

Regarding the share of zero-vehicle ownership (Table 6), we found that there is a significant difference between neighborhoods with a higher share of zero-vehicle ownership and those with lower shares. It is worth noting that the results are exactly a mirror image of those by income and property value, meaning that overall a neighborhood with a higher share of zero-vehicle ownership (a transportation disadvantaged group) has better accessibility to a variety of urban opportunities by both transit and cycling.

Similar results can be found from the comparison between neighborhoods with a higher share of non-white groups and those with a lower one (Table 7). A neighborhood with a higher non-white share tends to have better accessibility. One exception is that a higher non-white share neighborhood has lower accessibility to multi-use paths through both transit and cycling and to schools through cycling. This might suggest a clear ethnical target when the city would like to improve physical health.

Accessibility Comparison by Age

Finally, a neighborhood with more elderly people (65 years old and above) tends to have lower accessibility, through transit and cycling, to jobs at all wage levels (Table 8), especially when the threshold is set as the 25th percentile. This is reasonable because most elderly people are already retired at this age. For a neighborhood with more adolescents (under 19 years old), the accessibility to jobs is better, especially those in the top 25% of neighborhoods with more adolescents (Table 7).

In terms of dining accessibility by green transportation modes, a neighborhood with more elders is generally lower than that with more adolescents. This result is also understandable because most elderly people would likely drive a private vehicle to a restaurant if necessary. A resident in a neighborhood with more elders would more easily access, by cycling, to a multi-use path for physical or recreational activities. This suggests beneficial signals for an aging population who need to and also generally have time to walk or cycle.

It is relatively complicated in the case of adolescents. A neighborhood with more adolescents has lower accessibility to multi-use paths by transit and cycling. However, such a neighborhood tends to have better accessibility to parks by transit, but lower one by cycling. This might suggest that there is a need to provide more multi-use paths for a neighborhood with a higher share of adolescents to satisfy the need of physical exercises. Furthermore, a neighborhood with more elders has better accessibility to churches but lower one to libraries and schools. For social activities and education, the neighborhoods with more adolescents have totally opposite results in terms of accessibility.

V. CONCLUSION

THE MAPPING OF ACCESSIBILITY

This research develops and applies a GIS-based analytical framework to calculate the accessibility to a variety of urban opportunities by two green transportation modes (public transit and cycling) for Fresno, California. The calculated accessibility results represent cumulative urban opportunities (jobs, restaurants, parks, multi-use paths, schools, churches, and libraries) that can be reached within a time threshold (e.g., a 30-minute bus ride or cycling). The spatial distributions of the computed results by public transit and cycling have been presented and analyzed respectively, using the network analysis operations in ArcGIS.

The mapping results point to a need to improve the frequency or efficiency of the current bus service in Fresno. For instance, a 30-minute bus ride cannot generate a large enough service area to reach more opportunities with the service area by cycling as reference. It is generally difficult, except for residents in the downtown area, to access high-wage jobs, restaurants, or libraries by taking a 30-minute bus ride. Overall, a 30-minute cycling generates a much larger service area as compared to that by a 30-minute bus ride, due to the time flexibility and route availability. The mapping of all accessibility results also points out that the outskirt areas might be a ‘food desert’ of the city where one cannot easily access to many restaurants by transit or cycling. Finally, the mapping results show that Western Fresno has better accessibility to parks, while Northeastern Fresno has better accessibility to multi-use paths for physical exercises.

THE QUANTITATIVE ANALYSIS OF ACCESSIBILITY

The analysis of the service areas by public transit and cycling were conducted based on a widely used 30-minute commuting time. Theoretically, the more block groups (BG) that a neighborhood can access, the more accessible it becomes to urban opportunities. The results show that one can access more block groups by cycling than by transit, which is consistent with the above mapping results. Nevertheless, the 30-minute service area by transit might not be large enough for residents to reach services or activities that people normally need in daily life. This finding implies the significance of increasing the frequency of bus service while promoting public transit.

Overall, a resident can access to a low-wage job much easier than a high-wage one across the core area of the city by both transit and cycling. In particular, those BGs along Highway 41 have better accessibility to jobs. It is interesting to note that only those BGs in the downtown area have better high-wage job accessibility by transit as compared to the other BGs. This implies that either the 30-minute service area by transit is limited to reach more high-wage jobs or most high-wage jobs essentially cluster in the downtown area. The variances of accessibility to jobs also reflect the uneven distribution of jobs at the three wage levels.

Similarly, residents’ accessibility to fast-food or family restaurants by transit is limited due to an insufficient service area by a 30-minute bus ride. Comparatively, cycling might be a better green transportation mode to serve for this trip purpose. It is worth noting that the outskirt areas might be defined as a ‘food desert’ of the city where we do not see many restaurants around the neighborhoods. However, this might not cause problems because residents in those high-income/high-property-value neighborhoods mainly drive to their daily-routing destinations. This study focuses on the accessibility to urban opportunities for those BGs with a lower vehicle ownership in the urban core rather than those with a higher vehicle ownership in the outskirt/suburban areas.

Regarding social activities, a few neighborhoods in the north have better accessibility to churches either by transit or cycling. It is also quite difficult for a resident to access to a library by transit except for those living in the downtown area. This might be explained by the fact that there are not enough libraries provided across the city of Fresno. The accessibility to a library is increased a little by cycling. However, the accessibility to schools is generally good across the central area of the city by both green transportation modes.

Finally, the accessibility to parks shows a very different spatial pattern as compared to that to multi-use paths. Overall, Northwestern Fresno has better park accessibility, while Northeastern Fresno has better multi-use-path accessibility. This might cause spatial mismatch problems between physical health and social status, because residents from the south, who are mostly low-income, have high zero-vehicle ownership, and are non-white, lack the access to these facilities for exercises to maintain their physical and mental health.

THE COMPARISON OF ACCESSIBILITY BETWEEN DIFFERENT SOCIOECONOMIC GROUPS

The two sample t-test for equal means was used to compare the accessibility results between two neighborhood groups for the selected six socioeconomic factors (income, property value, school enrolment, zero vehicle share, race, and age), using three percentiles (25%, 50%, and 75%) as the group thresholds. This method design provides an appropriate way to build a framework to compare accessibility to urban opportunities among a variety of socioeconomic factors. Another advantage of this approach is to see whether the calculated accessibility is sensitive to the threshold set for grouping.

The t-tests show some interesting results. First, the current green transportation investments (public transit and cycling network) seem to well take care of the social inequity concern that economically disadvantaged groups (low income and property-value neighborhoods toward Southern Fresno) tend to have better accessibility to a certain number of urban opportunities by public transit and cycling. Second, similar results were found for transport disadvantaged groups (neighborhoods with a high zero-vehicle share) and non-white neighborhoods.

A neighborhood with a higher share of enrolled students has a lower accessibility, through cycling, to physical activities (parks and multi-use paths), but higher accessibility to dining, schools and libraries. This type of neighborhood’s accessibility to most urban opportunities by public transit makes no significant difference, except to family restaurants. In a word, the results do not suggest that a neighborhood with more enrolled students necessarily has better accessibility under the current green transportation network. Therefore, this study suggests conducting further research to better understand students’ green transportation behavior. The results would be very helpful to promote the use of green transportation modes, because students have been regarded as the group with the most potential to be influenced through the advocacy of sustainable transportation.

Regarding the factor of age, a neighborhood with a higher share of elders generally has lower accessibility, through both transit and cycling, to most urban opportunities, except to churches. Those neighborhoods with a higher share of elders are mostly located in the outskirts, where driving is the main transportation mode for daily activities. This might not cause problems for elders in these neighborhoods to access to urban opportunities. However, a possible concern might be that they eventually need to use non-auto transportation modes in the future, especially when they become too old to drive safely.

By transit and cycling, the top 25% of neighborhood with a higher share of adolescents tend to have good accessibility to jobs, fast-food restaurants, parks, libraries, and schools. However, it is worth noting that a neighborhood with a higher share of adolescents (and non-white) seems to have lower accessibility to multi-use paths by cycling. This might help planners target a specific group for promoting corresponding policies to improve public health through providing more opportunities for physical activities.

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