Neighborhood Characteristics that Support Bicycle Commuting: Analysis of the Top 100 United States Census Tracts

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ABSTRACT

This study examines American Community Survey (ACS) journey-to-work data from 2008 to 2012 to identify characteristics of neighborhoods with the highest levels of bicycle commuting in the United States. The 100 census tracts with the highest bicycle commute mode shares (Top 100 census tracts) are identified and paired with 100 other randomly-selected census tracts from the same county (100 Comparison census tracts). As a whole, the Top 100 tracts have a bicycle commute mode share of 21%. Seventy of the Top 100 tracts are in locations that have fewer than 10 days per year with high temperatures below 32°F (0°C) and 68 are within two miles (3.2 km) of a college or university campus. Seventeen have relatively low college populations and are in high-density neighborhoods close to large city central business districts. Conditional logistic regression is used to estimate the likelihood of a paired tract being the Top 100 rather than the Comparison tract. After controlling for climate and topography, being a Top 100 tract is associated with several socioeconomic and local environment characteristics, including being located closer to a university and having more households without automobiles, more people born in other states and countries, higher population density, more housing constructed before 1940, and greater bicycle facility density. The results suggest that policies to model employment centers after university campuses; design neighborhoods that support routine, multimodal travel; and reduce barriers to bicycling in bad weather may help create more local areas with high rates of bicycle commuting.

INTRODUCTION

According to the American Community Survey (ACS) five-year estimates from 2008 to 2012, 0.56% of United States workers (1 in 178) used a bicycle as their primary commute mode during the previous week (*1*). This represents approximately 785,000 workers nationwide, an increase of approximately 98,000 workers since the 2005 to 2009 ACS period (*1*). However, rates of bicycling in the United States are small compared to countries such as the Netherlands, Germany, and Denmark (*2*). While the United States currently has a low share of bicycle commuters, 35 states and 47 of the 52 largest cities in the country have established goals to increase overall levels of bicycling (*3*).

Cities and states that seek to increase bicycling often look to other communities for examples of bicycle-friendly policies, projects, and programs. These examples are often summarized at the city and state level. For example, the League of American Bicyclists recognizes the cities of Portland, OR, Minneapolis, MN, Davis, CA, and Boulder, CO as platinum-level Bicycle-Friendly Communities (*4*). The Alliance for Bicycling and Walking ranks the most populous 52 cities and all states by their American Community Survey journey-to-work mode shares (*3*). However, there are notable differences in bicycle commute mode shares among neighborhoods, even within top-ranked cities and states. For example, both Portland, OR and Minneapolis MN contain neighborhoods with bicycle commute mode shares greater than 15% and less than one percent (*5*). Therefore, it is also valuable to explore the characteristics of neighborhoods that are associated with high levels of bicycling. As a whole, the Top 100 neighborhoods in the United States have a bicycle commute mode share of 21% (*1*). These data show that high bicycle mode shares already exist in localized areas.

The purpose of this study is to identify common socioeconomic and local environment characteristics found in the neighborhoods with the highest bicycle commuting rates in the United States. The neighborhoods analyzed in this study can provide insights into policies that may be able to increase local bicycle commuting significantly.

LITERATURE REVIEW

There is a substantial body of research on factors that influence bicycle mode choice and overall levels of bicycling. Some of the most commonly-cited characteristics associated with bicycling in recent literature reviews are short distances between activity locations, the presence and connectivity of bicycle facilities (e.g., bicycle lanes, multi-use trails, and cycle tracks), bicycle parking, limited automobile parking supply and high parking cost, low automobile ownership, flat terrain, and mild weather (*6*,*7*,*8*). Bicycle volume models have shown that bicycle counts are positively associated with employment density, land use mix, proximity to a university, proximity to bicycle facilities, connected roadway networks, and flat terrain (*9*,*10*,*11*,*12*).

Several recent studies have focused specifically on bicycle commuting to and from work. Bicycle commuting is associated with short distance to work (*13*,*14*), more on- and off-road bicycle facilities (*8*,*15*,*16*), bicycle parking and showers at work (*14*), nice weather (*3*,*13*,*17*), not carrying packages (*13*), not wearing business attire (*13*), paying for automobile parking at work (*14*), and high gas prices (*16*). Socioeconomic factors associated with bicycle commuting include owning fewer automobiles (*3*,*16*,*18*), being male (*14*,*19*), being younger (*18*), being a student (*6*,*16*), and identifying as White (*14*,*19*), although bicycling is increasing among other ethnic groups (*19*). In addition, recent immigrants are more likely to bicycle than native-born residents of the United States (*20*).

Few studies have analyzed bicycling to work in multiple communities across the country at the neighborhood level. An analysis of nine large North American metropolitan areas mapped bicycle commute data for sub-city areas (*19*). These maps showed notable variation across each region, and the highest levels of bicycling were generally found in neighborhoods close to the regional central business district and close to university campuses (*19*).

In addition, few studies have focused specifically on neighborhoods with very high rates of bicycling to work. This study helps address this gap in the literature.

METHOD

This section describes the research approach used to identify local environment and socioeconomic characteristics of neighborhoods with the highest bicycle commute mode shares in the United States.

Study Data

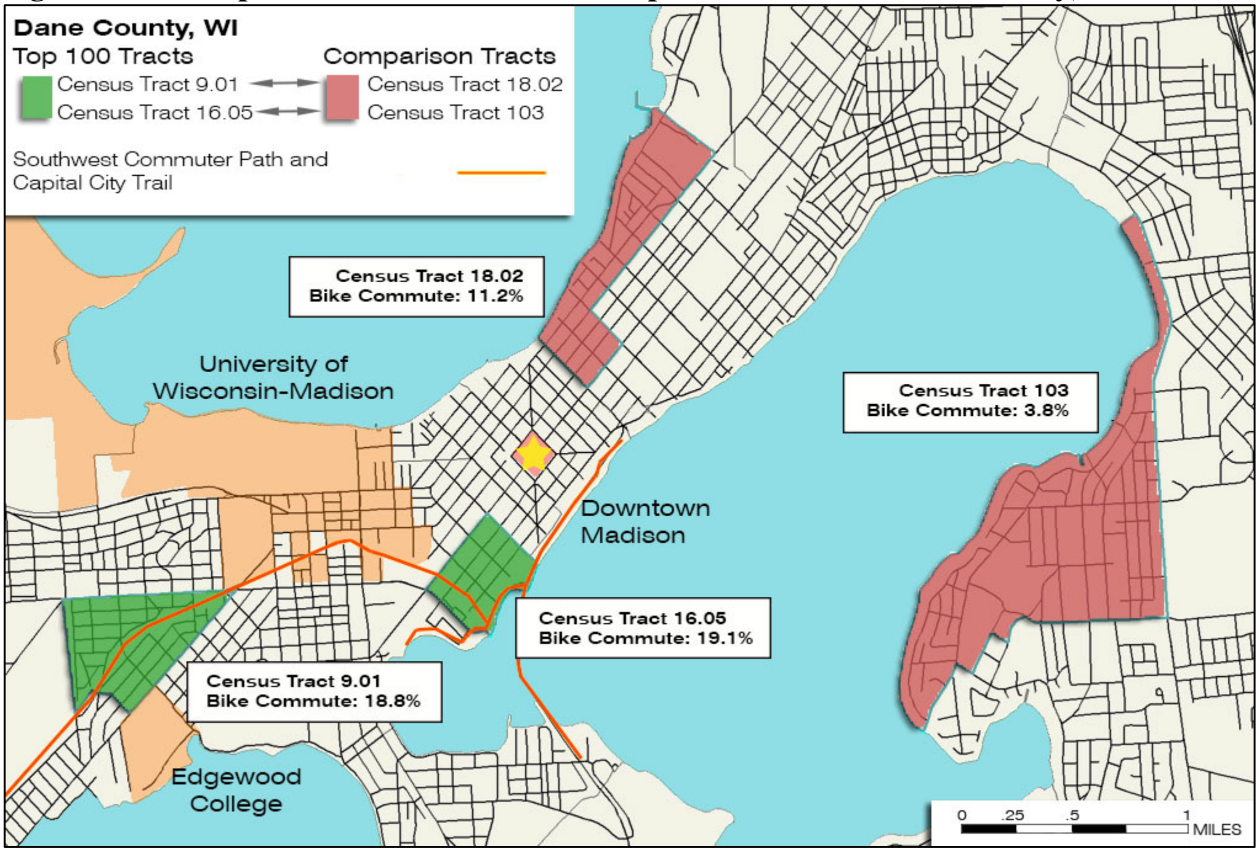
The ACS collects data from a sample of approximately 10 million addresses throughout the United States over a five-year period. The US Census Bureau has determined that this five-year sample is sufficient to provide estimates of journey-to-work mode and other detailed information at the census tract level (*21*). The first ACS five-year estimates were provided for 2005 to 2009, and this study uses the most recent data from 2008 to 2012.

This study analyzes ACS data describing the primary mode of transportation used by workers (paid for at least one hour in the last week) to travel to their job location. Primary mode is defined as the type of transportation used for the longest distance on the respondent's journey to work on the most days during the previous week (i.e., bicycling a short distance and taking the train for a longer distance is recorded as a train commute; bicycling on Friday after driving the rest of the week is recorded as an automobile commute) (*22*). The percentage of bicycle commuters is based on the total number of workers in each census tract, which includes people who work at home. Since the survey is conducted on a rolling basis throughout the year, it captures seasonal variations in commuting by bicycle.

Research Approach

The research approach included the following steps: 1) identify the 100 census tracts with the highest bicycle commute mode shares in the United States (i.e., Top 100 census tracts), 2) select one census tract randomly from the same county as each of the Top 100 tracts to create a set of 100 Comparison tracts, 3) gather data on socioeconomic and local environment characteristics of all 200 census tracts, and 4) compare the characteristics of the Top 100 tracts with the 100 Comparison tracts using descriptive statistics and regression models. Note that having each Top 100 tract and its corresponding Comparison tract in the same county reduces variation in bicycle commuting due to major differences in climate, culture, and bicycle policy (although there may still be some differences in bicycle project and program implementation between local municipalities in the same county). For example, Figure 1 shows the locations of two Top 100 census tracts in Madison, WI and the locations of their two corresponding Comparison census tracts that were selected randomly from all other census tracts in Dane County, WI.

Figure 1. Two Top 100 Census Tracts and Comparison Tracts in Dane County, WI



ANALYSIS

The analysis first explored the characteristics of the Top 100 census tracts and then evaluated the Top 100 tracts versus the 100 Comparison tracts.

Characteristics of the Top 100 Census Tracts

The 2008 to 2012 ACS dataset includes 73,056 census tracts throughout the United States. Some of these tracts are in remote areas with sparse populations, so the Top 100 bicycle commute census tracts and their 100 Comparison tracts were selected from the 60,090 tracts with 300 or more workers and 100 or more people per square mile. Military bases were also excluded. Table 1 lists the locations and bicycle commute mode shares of the Top 40 census tracts. All Top 100 are not listed due to space constraints, but the bottom rows of the table summarize the mode shares and other data for all Top 100 census tracts and the entire United States.

To make the Top 100, census tracts needed to have at least 15.7% of their workers commute by bicycle. The highest census tract bicycle commute mode share (52.0%) was in Santa Clara County, CA, at the heart of the Stanford University Campus. Seventy-two of the Top 100 tracts were in just four states: Oregon (24), California (23), Florida (15), and Colorado (10). Twelve of the Top 100 tracts were in Portland, OR, nine were in Davis, CA, and nine were in Eugene, OR.

A cursory examination of the Top 100 tracts showed the importance of a moderate climate and proximity to a university campus. Seventy of the Top 100 tracts were in locations that have fewer than 10 days per year with high temperatures below 32°F (0°C). This mild climate generally includes the southern half of the continental United States, western Oregon, western Washington, and Hawaii (*23*). The cold climate of Minneapolis, MN is probably a main reason why this city had no census tracts in the Top 100 (its top census tract had a 15.6% bicycle mode share and ranked 102nd), despite being recognized as a Platinum Bicycle Friendly Community (*1*,*4*). Sixty-eight of the Top 100 were within two miles (3.2 km) of a college or university with more than 2,000 students.

While proximity to a university was important, and 76 of the Top 100 tracts had college enrollment levels higher than the national average, only a portion of the Top 100 tracts were dominated by college student populations. Eighty-one of the Top 100 tracts had fewer than half of their residents enrolled in college, suggesting that there are many non-student workers in Top 100 census tracts who commute by bicycle. Further, six of these tracts were in cities with major universities (Eugene, OR; Madison, WI; Boulder, CO; Palo Alto and Menlo Park, CA) but had fewer than 15% of their residents enrolled in college. This suggests that university campus environments support bicycling among many segments of the population.

The Top 100 tracts had low rates of automobile ownership (79% of occupied housing units had a vehicle available) relative to the national average (91% had a vehicle available). However, 25 of the Top 100 tracts had higher automobile ownership than the national average, indicating that some top bicycle commuting neighborhoods have many people who could drive but choose to bicycle instead. Most of these 25 tracts were close to universities, so many of their residents may work on campus where automobile parking is limited and expensive. Some may commute to work by bicycle but use an automobile for other trips.

Table 1. Top 40 Census Tracts for Bicycle Commuting in the United States, 2008-2012

				% of Workers who Bicycled				
Rank	**Local Jurisdiction**	**Description**	**Workers**	**Estimate**	**90% MOE[1]**	**Distance to Closest Campus (mi.)[2]**	**% of Residents in College[3]**	**Days Per Year with High Temp. Below Freezing[4]**
1	Santa Clara County, CA	Stanford University Campus (Central)	3207	**52.0%**	+/- 7.6%	0.0	82.6%	0.0
2	Davis, CA	UC Davis Campus & Neighborhoods to W	1849	**46.6%**	+/- 9.3%	1.2	85.1%	0.0
3	Santa Clara County, CA	Stanford University Campus (NW)	926	**43.4%**	+/- 13.9%	0.5	96.7%	0.0
4	Davis, CA	W side of Downtown Davis & NE of UC Davis	2313	**38.6%**	+/- 8.9%	1.3	46.3%	0.0
5	Davis, CA	NW of UC Davis	1886	**31.8%**	+/- 18.1%	1.5	36.1%	0.0
6	Isla Vista, CA	SW side of Isla Vista & W of UC Santa Barbara	2147	**31.6%**	+/- 9.5%	1.2	75.6%	0.0
7	Eugene, OR	Downtown Eugene & NW of U. of Oregon	1048	**31.2%**	+/- 11.4%	1.3	18.6%	2.0
8	Gainesville, FL	E and NE of University of Florida	2709	**30.9%**	+/- 12.9%	1.0	80.0%	0.1
9	Isla Vista, CA	S side of Isla Vista & W of UC Santa Barbara	2646	**30.5%**	+/- 9.2%	0.8	83.7%	0.0
10	Davis, CA	N of UC Davis & SW of Davis High School	1173	**28.3%**	+/- 11.3%	1.0	40.5%	0.0
11	Key West, FL	W of Key West Airport	1508	**28.2%**	+/- 10.6%	123.7	3.4%	0.0
12	Davis, CA	N of UC Davis & E of CA 113	1795	**28.1%**	+/- 8.1%	1.1	64.5%	0.0
13	Isla Vista, CA	UCSB Campus & Neighborhoods to NW	3182	**26.3%**	+/- 6.8%	0.7	80.2%	0.0
14	Portland, OR	W side of Ladd's Edition & E of Grand Ave.	919	**25.9%**	+/- 12.3%	1.2	13.5%	2.0
15	Key West, FL	Key West, around W end of Truman Ave.	1808	**25.5%**	+/- 14.0%	124.7	1.7%	0.0
16	Davis, CA	E side of Downtown Davis	2763	**24.2%**	+/- 8.5%	1.4	50.0%	0.0
17	Santa Clara County, CA	SE of Stanford University	4095	**24.1%**	+/- 6.0%	1.1	17.4%	0.0
18	East Lansing, MI	Michigan State U. (NE) Residence Halls	354	**24.0%**	+/- 21.8%	0.0	100.0%	48.5
19	Miami Beach, FL	S of Flamingo Park	2447	**23.7%**	+/- 14.3%	3.3	8.5%	0.0
20	Key West, FL	Key West, around E end of Truman Ave.	1664	**23.3%**	+/- 7.5%	124.3	5.1%	0.0
21	Tampa, FL	E of Tampa Airport & Near Hillsborough Com. Col.	698	**22.6%**	+/- 12.2%	4.2	10.6%	0.0
22	Boulder, CO	University of Colorado Research park	672	**22.6%**	+/- 9.8%	1.0	53.2%	13.0
23	Iona, FL	S of McGregor Blvd. & E of San Carlos Blvd.	521	**22.5%**	+/- 4.2%	11.1	0.7%	0.0
24	Gainesville, FL	W of Main St. & N of 8th Ave. Gainesville	1390	**22.4%**	+/- 12.4%	2.0	29.8%	0.1
25	Portland, OR	Boise Neighborhood Area	2074	**22.2%**	+/- 9.1%	2.8	14.3%	2.0
26	Philadelphia, PA	Spruce Hill Neighborhood Area	2655	**21.9%**	+/- 13.0%	0.8	37.8%	12.5
27	Isla Vista, CA	SE side of Isla Vista & W of UC Santa Barbara	2763	**21.8%**	+/- 6.9%	0.7	87.4%	0.0
28	Eugene, OR	W of Downtown Eugene	1637	**21.8%**	+/- 7.2%	1.6	17.2%	2.0
29	Davis, CA	N of Davis High School	1651	**21.7%**	+/- 8.4%	2.0	27.9%	0.0
30	Gainesville, FL	Downtown & NE of Downtown Gainesville	2799	**21.7%**	+/- 10.6%	2.3	22.8%	0.1
31	Eugene, OR	W of University of Oregon	2105	**21.0%**	+/- 9.2%	0.9	61.6%	2.0
32	Fort Collins, CO	S of Colorado State University	926	**20.8%**	+/- 10.2%	1.0	26.4%	21.4
33	Urbana, IL	NE of University of Illinois	2257	**20.7%**	+/- 6.9%	1.0	49.9%	36.6
34	North Port, FL	SW end of North Port near Myakka River	455	**20.4%**	+/- 7.3%	49.7	1.9%	0.0
35	Fort Collins, CO	W of Colorado State University	1466	**20.4%**	+/- 10.4%	0.9	51.7%	16.2
36	Fort Collins, CO	E of Colorado State University	1628	**20.3%**	+/- 6.5%	0.6	28.6%	21.4
37	Portland, OR	E of Willamette River & S of I-84	1450	**20.2%**	+/- 8.5%	1.5	17.7%	2.0
38	Philadelphia, PA	SE East Passyunk Crossing & NW Whitman Nbhds.	2178	**20.2%**	+/- 9.0%	2.8	3.9%	12.5
39	Boulder, CO	SE of University of Colorado	2685	**20.0%**	+/- 8.2%	1.5	40.0%	13.0
40	Portland, OR	Humboldt Neighborhood Area	1384	**19.9%**	+/- 6.2%	0.4	13.8%	2.0
		All Top 100 Census Tracts[5,6]	**183618**	**21.0%**	**N/A**	**8.8**	**32.7%**	**9.7**
		United States[5]	**~140M**	**0.56%**	**+/- 0.08%**	**N/A**	**7.5%**	**N/A**

1) 90% MOE is the 90% margin of error of the estimate provided by the American Community Survey. Using the top-ranked tract as an example, if the ACS sample was taken independently 100 different times, we would expect 90 of those surveys to produce bicycle mode share estimates for the central part of the Stanford University Campus between 44.4% and 59.6%. This is 52.0% +/- 7.6%.

2) Straight-line distance between the center of the census tract and the center of the closest university campus. To be considered, campuses had >= 2,000 students.

3) Percentage of residents enrolled in college includes college and graduate school.

4) Uses nearest weather station available from the U.S. NOAA, National Climatic Data Center. Data are from the 1981-2010 U.S. Climate Normals.

5) All data in these rows are averages except the first column, which lists the total number of workers.

6) The average values of % commuting by bicycle and % in college in this table are weighted to account for different sizes of the Top 100 Census Tracts. This is done so that they could be compared directly with the characteristics of the United States as a whole. The means and standard deviations in Tables 2 and 3 are not weighted.

While many of the Top 100 census tracts were associated with universities, several tracts did not follow this pattern. For example, the list included the following types of census tracts that had less than 15% of the tract population enrolled in college:

- 19 tracts within four miles (6.4 km) of a large city central business district (city population over 300,000). These tracts were in Portland, OR (10), Philadelphia, PA (3), Miami Beach, FL (3), Chicago, IL (1), Las Vegas, NV (1), and New Orleans, LA (1). These tracts tended to be in dense neighborhoods: all but two had more than 7,000 residents/sq. mi. (18,000 residents/sq. km). Nine other tracts were close to large city central business districts but had more than 15% of their residents in college.
- Four tracts in rural areas of Ohio and Indiana with significant Amish populations.
- Three tracts in Key West, FL (population 24,000), a compact community located more than a 100-mile drive from other mainland Florida cities.

Therefore, high levels of bicycle commuting may be associated with high-density neighborhoods close to major job centers, compact villages that contain a majority of residences and workplaces (e.g., have little intercity commuting), as well as social and religious customs. Follow-up case studies could be used to explore the socioeconomic, local environment, and cultural characteristics that make these specific neighborhoods support bicycling to work.

Since the bicycle commute mode share data come from a survey sample, the estimates have a margin of error. The ACS provides 90% confidence intervals for each census tract estimate. This is particularly important for neighborhood-level studies of bicycle commuting since the number of bicycle commuters in a particular census tract may be relatively small. The Top 100 census tracts have confidence intervals ranging from +/- 4.2% to +/- 30.2%. This suggests the true order of the Top 100 tracts may be somewhat different than the estimates made from the ACS and that some other tracts that did not make the Top 100 should actually be on the list (for comparison, 28 of the Top 100 tracts from 2007 to 2011 did not make the Top 100 for 2008 to 2012, though most of these were still in the Top 200). Despite some uncertainty, the estimates provided by the ACS are mean values and remain the best data available for this analysis.

Descriptive Analysis of Top 100 versus 100 Comparison Tracts

Socioeconomic and local environment characteristics of each of the Top 100 tracts and the 100 Comparison tracts were gathered from the ACS and online aerial imagery (Table 2 and Table 3). The difference in the mean value of each variable for the Top 100 census tracts and 100 Comparison tracts was evaluated using a t-test. As expected, the average bicycle commute mode share for the Top 100 census tracts (21%) was significantly higher than for the Comparison tracts (3%). The Top 100 tracts also had significantly higher average values for the percentage of residents who:

- Are male
- Are young adults
- Are in college
- Have college degrees
- Do not have disabilities
- Were born in a different state or country than their current residence
- Work in “educational services” and “health care and social assistance”
- Work in “arts, entertainment, and recreation” and “accommodation and food services”

- Have a low household income
- Are renters
- Have no vehicles available in their household

ACS data also showed that Top 100 census tracts had a significantly higher percentage of houses built before 1940 and lower percentage of houses built after 1959 than the Comparison tracts. Not surprisingly, many of the local environment variables that had significantly higher values for the Top 100 census tracts are features often found in older neighborhoods, such as:

- More complete sidewalk coverage
- More transit stops
- Closer proximity to a rail station
- Closer proximity to the historic city center
- Higher population and job density
- A mix of land uses

Importantly, the Top 100 census tracts had significantly more multi-use trails and total bicycle facilities per square mile and were more likely to have a major trail connecting the census tract to the closest university than the 100 Comparison tracts. In addition, the Top 100 tracts had significantly flatter terrain.

While the mean distance to the closest university was not significantly different for the Top 100 and 100 Comparison tracts, the mean distance was significantly shorter for the Top 97 census tracts than their 97 Comparison tracts after three outlier pairs from Monroe County, FL were removed (see footnote 7 in Table 3).

Note that additional socioeconomic variables were compared between the two sets of census tracts, including the percentage of residents who were unemployed, worked in other major industries, and identified with particular ethnicities. Other local environment characteristics were also compared, such as the proportion of roadways with different numbers of lanes, proportion of multilane roadway crossings with medians and traffic signals, and proportion of developed land used for off-street parking. However, the mean values of these variables were not statistically different between the Top 100 and 100 Comparison tracts.

Table 2. Top 100 Census Tracts vs. 100 Comparison Tracts: Socioeconomic Variables

	Top 100 Tracts		100 Comparison Tracts		Difference between Means[1]		
Census Tract Socioeconomic Variables	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**p-value**	**Significance**	**Data Source (Year)**
% of workers commuting by bicycle	**20.88**	6.44	**2.85**	3.53	0.00	+++	ACS (2008-2012)
% of residents who are male	**52.00**	5.41	**49.22**	3.59	0.00	+++	ACS (2008-2012)
Average age of all residents	**31.02**	9.12	**37.67**	8.00	0.00	---	ACS (2008-2012)
% of residents under 18 years old	**14.12**	8.62	**20.86**	7.38	0.00	---	ACS (2008-2012)
% of residents above 64 years old	**9.68**	9.33	**13.36**	7.36	0.00	---	ACS (2008-2012)
% of residents in college or graduate school	**28.11**	26.62	**10.69**	12.62	0.00	+++	ACS (2008-2012)
% of residents with bachelor's degree or higher	**45.40**	23.90	**35.68**	20.98	0.00	+++	ACS (2008-2012)
% of residents with a disability	**9.49**	5.72	**11.21**	5.18	0.03	--	ACS (2008-2012)
% of residents born in the same state as the census tract	**42.24**	18.25	**48.64**	16.77	0.01	--	ACS (2008-2012)
% of workers in “construction”	**3.94**	4.43	**5.52**	3.77	0.01	--	ACS (2008-2012)
% of workers in “finance and insurance” and “real estate and rental and leasing”	**4.28**	3.01	**6.85**	3.65	0.00	---	ACS (2008-2012)
% of workers in “educational services” and “health care and social assistance”	**31.09**	16.14	**24.17**	8.85	0.00	+++	ACS (2008-2012)
% of workers in “arts, entertainment, and rec.” and “accommodation and food services”	**17.00**	10.58	**10.49**	6.10	0.00	+++	ACS (2008-2012)
Median household income (thousands of $)[2]	**41.02**	21.75	**54.69**	19.96	0.00	---	ACS (2008-2012)
% of individuals whose income is below the poverty level[2]	**28.95**	16.80	**16.10**	11.24	0.00	+++	ACS (2008-2012)
% of housing units that are renter-occupied[2]	**64.13**	22.39	**40.86**	21.25	0.00	+++	ACS (2008-2012)
% of households with no vehicles available[2]	**21.31**	14.32	**10.57**	11.73	0.00	+++	ACS (2008-2012)

1) Statistical significance is for a t-test of the difference between two sample means (Top 100 census tracts vs. 100 comparison tracts) with unequal variance using Welch's method. For variable values where the mean of the Top 100 tracts > 100 comparison tracts, +++ indicates highly significant difference ($p < 0.01$), ++ indicates significant difference ($p < 0.05$), and + indicates moderately significant difference ($p < 0.10$). For variable values where 100 comparison tracts > Top 100 tracts, --- indicates highly significant difference ($p < 0.01$), -- indicates significant difference ($p < 0.05$), - indicates moderately significant difference ($p < 0.10$).
2) The descriptive statistics related to income and housing for the set of Top 100 census tracts are based on 99 census tracts. One census tract containing Michigan State University student housing did not have these variables.

Table 3. Top 100 Census Tracts vs. 100 Comparison Tracts: Local Environment Variables

	Top 100 Tracts		100 Comparison Tracts		Difference between Means[1]		
Census Tract Local Environment Variables	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**p-value**	**Significance**	**Data Source (Year)**
Census tract area (sq. mi.)[2]	**2.31**	8.24	**4.34**	10.38	0.13		US Census (2008-2012)
Sidewalk coverage[3]	**0.79**	0.30	**0.71**	0.31	0.05	+	Google Earth (2011 to 2014)[12]
Bike facility density (mi./sq. mi.)[2,4]	**6.96**	6.04	**3.85**	3.62	0.00	+++	Google Earth (2011 to 2014)[12]
Multi-use trail density (mi./sq. mi.)[2,5]	**1.21**	2.15	**0.61**	1.37	0.02	++	Google Earth (2011 to 2014)[12]
Transit stop density (stops/sq. mi.)[2]	**44.06**	35.52	**22.72**	23.88	0.00	+++	Google Maps (2011)
Rail station within tract or within 0.5 mi. of tract boundary (1 = yes, 0 = no)[2]	**0.25**	0.44	**0.12**	0.33	0.02	++	Google Maps (2011)
Straight-line distance from center of tract to local central business district (mi.)[2,6]	**2.19**	2.11	**4.10**	3.89	0.00	---	Google Earth (2011 to 2014)[12]
Straight-line distance from center of tract to closest university campus (mi.)[2,7]	**8.82**	24.00	**11.63**	17.48	0.35		Google Earth (2011 to 2014)[12]
Major trail between the census tract and the closest university (1 = yes, 0 = no)[8]	**0.12**	0.33	**0.06**	0.24	0.14		Google Earth (2011 to 2014)[12]
Straight-line distance from center of tract to closest shopping center (mi.)[2]	**1.13**	2.22	**1.79**	2.99	0.08	-	Google Earth (2011 to 2014)[12]
Population density (in thousands) (pop./sq. mi.)[2]	**10.61**	11.56	**5.62**	6.21	0.00	+++	ACS (2008-2012)
Jobs within 0.5 mi. of the center of the census tract (in thousands)[2]	**3.10**	3.51	**1.41**	2.63	0.00	+++	US Census (2010)
Census tract has a mix of land uses (1 = yes, 0 = no)[9]	**0.69**	0.46	**0.47**	0.50	0.00	+++	Google Earth (2011 to 2014)[12]
% of housing units built after 1959[10]	**52.04**	28.17	**69.11**	27.54	0.00	---	ACS (2008-2012)
% of housing units built before 1940[10]	**29.53**	26.95	**13.80**	18.89	0.00	+++	ACS (2008-2012)
Range of elevations at 5 specific points in the census tract (feet)[11]	**43.80**	50.49	**82.49**	124.31	0.00	---	Google Earth (2011 to 2014)[12]

1) Statistical significance is for a t-test of the difference between two sample means (Top 100 census tracts vs. 100 comparison tracts) with unequal variance using Welch's method. For variable values where the mean of the Top 100 tracts > 100 comparison tracts, +++ indicates highly significant difference ($p < 0.01$), ++ indicates significant difference ($p < 0.05$), and + indicates moderately significant difference ($p < 0.10$). For variable values where 100 comparison tracts > Top 100 tracts, --- indicates highly significant difference ($p < 0.01$), -- indicates significant difference ($p < 0.05$), - indicates moderately significant difference ($p < 0.10$).

2) 1.00 mi. = 1.61 km.

3) Overall sidewalk coverage is the proportion of roadways that have sidewalks on both sides. If a street has sidewalks on both sides, it has 100% (1.00) sidewalk coverage. If a street has a complete sidewalk on one side, but no sidewalk on the other, it has 50% (0.50) coverage. The variable is calculated as the distance-weighted average of sidewalk coverage for all roadway segments.

4) Bicycle facility density is the total length of bicycle facilities divided by the census tract area. Bicycle facilities include cycle tracks, bicycle lanes, shared lane markings, bicycle boulevards, and multi-use trails. If bicycle lanes or shared lane markings are on both sides of a 1-km-long street segment, this represents 2 km of bicycle facilities. Bicycle boulevards and multi-use trails are two-way facilities, so 1 km of centerline counts as 2 km of bicycle facilities.

5) Multi-use trail density is the total length of multi-use trail facilities divided by the census tract area. Multi-use trails are defined as being in their own transportation corridor (e.g., a rail-trail) or sharing a roadway corridor but being separated from the roadway by five feet or more (e.g., a sidepath). Wide sidewalks and cycle tracks are not considered to be multi-use trails. Multi-use trails within parks, campuses, or developments that do not connect to other parts of the community are not included. Multi-use trails are two-way facilities, so one-km of centerline counts as two km of multi-use trail facilities.

6) Distance to the central business district (CBD) of the local jurisdiction containing the census tract. For suburban census tracts, the "central business district" is the historic center of the suburb (not the distance to the major city CBD at the center of the region).

7) To be considered, campuses had >= 2,000 students. This analysis included several outlier values. For example, three census tracts on the island of Key West, FL were located more than 120 mi. (193 km) from a university campus. Their three comparison tracts were on the mainland portion of Monroe County, FL, located between 40 and 80 mi. (64 and 129 km) closer to universities than the Key West tracts. Comparing the pairs of census tracts without these outliers showed a mean value of 5.25 mi. for the Top 97 Tracts and 9.77 mi. for the 97 Comparison Tracts (significant at $p = 0.02$).

8) The major trail must meet the criteria of a multi-use trail and not require a person using the trail to travel more than 150% of the shortest-path distance to the campus, and be available for more than 50% of the distance between the center of the census tract and the campus.

9) Mixed land use = at least 20% of the non-park developed land area in the census tract contains non-residential uses.

10) The descriptive statistics related to income and housing for the set of Top 100 census tracts are based on 99 census tracts. One census tract containing Michigan State University student housing did not have these variables.

11) Elevation was measured at the center of the tract and at points 0.5 mi (804m) due north, east, south, and west of the center. 1.00 ft. = 0.305 m.

12) Google Earth images range from 2011 to 2014. Variables from Google Earth and Google Maps were hand-coded by the co-author and checked for reasonableness by the lead author.

Conditional Logistic Regression

The comparisons of individual variables showed expected results, but they did not account for interdependence between variables. Therefore, multivariate conditional logistic regression models were estimated to identify variables associated with observing a particular outcome in matched pairs of subjects. One subject in the pair exhibits the outcome (the Top 100 census tract), and the other does not (the Comparison tract). This type of regression has been used previously in pedestrian and bicycle safety studies to compare locations where crashes occurred with control locations where they did not occur (*24*,*25*), but this is one of the first applications of this method to analyze bicycle commuting. The statistical model derivation and additional examples can be found in other sources (*26*).

The modeling process involved estimating a series of conditional logistic regression models using different combinations of explanatory variables. The first models included socioeconomic and local environment variables that had a theoretical connection with bicycle commuting. Most socioeconomic and local environment variables that had significantly different mean values for the Top 100 and 100 Comparison tracts were tested; exceptions included moderately correlated variables ($|\rho| > 0.5$), such as average age and percent of residents who are in college. Correlated variables were substituted for each other during model testing, and the ones with the greatest statistical significance were kept in subsequent model runs. As the modeling process continued, the variables with the least precise parameter estimates in previous models were eliminated from consideration.

Table 4 presents two models. The Initial Model was estimated early in the analysis process and included many theoretically-important variables. However, several of the parameter estimates were imprecise. The final, Top 100 Model, included a combination of variables with highly to moderately significant parameter estimates ($p < 0.10$) and positive and negative signs consistent with previous research. This Top 100 Model is discussed in the results section.

Note that two models were also created using a subset of 55 tracts with more than 15% of residents in college and their 55 Comparison tracts. This was done to detect differences between variables that support high bicycle commute rates in neighborhoods with high proportions of college students and neighborhoods with a wider cross-section of residents.

Table 4. Models of Top Bicycle Commuting Tracts versus Comparison Tracts

	Initial Model[1]			Top 100 Model[1]		
Explanatory Variables	**Beta[2]**	**OR[3]**	**p-value**	**Beta[2]**	**OR[3]**	**p-value**
% of households with no vehicles available	0.365	**1.440**	0.042	0.200	**1.221**	0.005
% of residents born in the same state as the census tract	-0.261	**0.770**	0.026	-0.182	**0.834**	0.002
% of residents who are male	0.325	**1.384**	0.212			
% of residents in college or graduate school	0.048	**1.049**	0.250			
% of residents with a disability	-0.207	**0.813**	0.251			
Median household income (thousands of $)	0.036	**1.036**	0.547			
% of residents above 64 years old	0.061	**1.063**	0.567			
% of residents with bachelor's degree or higher	-0.013	**0.987**	0.803			
Straight-line distance from center of tract to closest university campus (mi.)[4,5]	-0.119	**0.887**	0.125	-0.063	**0.939**	0.090
Population density (in thousands) (pop./sq. mi.)[4]	0.291	**1.338**	0.061	0.196	**1.217**	0.003
% of housing units built before 1940	0.155	**1.168**	0.029	0.069	**1.072**	0.008
Bike facility density (mi./sq. mi.)[4,6]	0.246	**1.279**	0.106	0.246	**1.278**	0.013
Jobs within 0.5 mi. of the center of the census tract (in thousands)[4]	-0.775	**0.461**	0.038	-0.364	**0.695**	0.054
Range of elevations at 5 specific points in the census tract (feet)[7]	-0.026	**0.974**	0.096	-0.012	**0.988**	0.066
Straight-line distance from center of tract to local central business district (mi.)[2,8]	-0.209	**0.811**	0.461			
Model chi-square score (df) and p-value	**66.9 (15)**		**0.000**	**59.5 (8)**		**0.000**
Model sample size (pairs of tracts)	**99**			**99**		

1) The models predict the likelihood of being a Top 100 bicycle commute tract rather than a Comparison tract. Both models are based on all Top 100 tracts except one that only contains Michigan State University housing (the Top 100 Model is not called the Top 99 Model for simplicity). Note that the parameter estimates for the variables maintained in the Top 100 Model are substantially similar to the parameter estimates in Initial Model, suggesting that the Top 100 Model keeps most of the important characteristics related to bicycle commuting. The largest changes are for percentage of households with no vehicles available (which may be partially correlated with other socioeconomic variables dropped during the modeling process) and for percent of housing units built before 1940 and job density (which may be partially correlated with the distance to the local central business district, which was also dropped during the modeling process).
2) Beta is the parameter estimate for each variable.
3) OR is the odds ratio, or e to the beta power. It indicates the number of times more likely a tract with a particular characteristic is to be a Top 100 tract than a Comparison tract.
4) 1.00 mi. = 1.61 km.
5) To be considered, campuses had >= 2,000 students. This analysis included several outlier values. For example, three census tracts on the island of Key West, FL were located more than 120 mi. (193 km) from a university campus. Their three comparison tracts were on the mainland portion of Monroe County, FL, located between 40 and 80 mi. (64 and 129 km) closer to universities than the Key West tracts.
6) Bicycle facility density is the total length of bicycle facilities divided by the census tract area. Bicycle facilities include cycle tracks, bicycle lanes, shared lane markings, bicycle boulevards, and multi-use trails. If bicycle lanes or shared lane markings are on both sides of a 1-km-long street segment, this represents 2 km of bicycle facilities. Bicycle boulevards and multi-use trails are two-way facilities, so 1 km of centerline counts as 2 km of bicycle facilities.
7) Elevation was measured at the center of the tract and at points 0.5 mi (804m) due north, east, south, and west of the center. 1.00 ft. = 0.305 m.
8) Distance to the central business district (CBD) of the local jurisdiction containing the census tract. For suburban census tracts, the "central business district" is the historic center of the suburb (not the distance to the major city CBD at the center of the region).

MODEL RESULTS

The Top 100 Model shows that several socioeconomic variables have a statistically-significant association with high bicycle commute mode shares. These are:

- *Percent of housing units with no automobile*. As expected, lower automobile ownership was associated with bicycle commuting. Specifically, each percentage point increase in no-vehicle households was associated with a 22% higher likelihood of being a Top 100 tract rather than a Comparison tract (odds ratio of 1.22). This variable likely represents neighborhoods where many people do not have an opportunity to own a car, but it is also possible that residents of some neighborhoods choose to give up their car because they live in a place with good bicycle commuting options. Removing automobile ownership from the Top 100 model had only minor impacts on other parameter estimates, providing support for keeping it in the model, but future research should explore various chains of causality between automobile ownership and bicycle commuting.
- *Percent born in the state containing the census tract*. Each percentage point increase in the in-state population was associated with a 17% lower chance of being a Top 100 tract. One explanation for this could be that people who have moved from other states and countries may be more familiar with or have a more positive attitude toward bicycle commuting.

The Top 100 Model also includes several significant local environment characteristics:

- *Distance to closest university campus.* Each mile further from the closest university campus was associated with a 6% lower likelihood of being a Top 100 tract rather than a Comparison tract (odds ratio of 0.939). This supports the overarching finding that many neighborhoods with very high rates of bicycle commuting in the United States are located close to college campuses.
- *Population density*. Each additional 1000 residents per square mile (386 residents per square km) was associated with a 22% higher likelihood of being a Top 100 tract. Higher population density is often associated with having more activity destinations (e.g., shopping, restaurants, parks) within easy bicycling distance of residences. This provides opportunities for people to access other activity locations by bicycle while traveling to or from work. Higher population density also tends to be related to more automobile traffic congestion and more constrained and expensive automobile parking.
- *Percentage of housing built before 1940*. Each additional percentage point of housing built before 1940 was associated with a seven-percent higher chance of being a Top 100 tract. This variable is likely to capture other aspects of the built environment that support bicycling, such as connected street networks and mixed land uses.
- *Bicycle facility density*. For a one-square-mile (2.59-square-km) tract, each additional linear mile of bicycle facilities was associated with a 28% greater chance of being a Top 100 tract than a Comparison tract. This does not necessarily imply that installing bicycle facilities will increase bicycle commuting directly, since this relationship may also be found when facilities are added to provide more comfortable riding conditions in census tracts that already have high bicycle commute mode shares. However, it does show that many Top 100 tracts have bicycle-supportive infrastructure, such as bicycle lanes, cycle tracks, and multi-use trails.

Hilly terrain and the number of jobs within one-half mile (0.8 km) of the center of the tract were both associated with lower likelihoods of being a Top 100 tract. Hills increase the effort required to bicycle a given distance. High job density nearby may make walking to work more attractive than bicycling.

The models based on census tracts with high proportions of college students (not shown) had many similarities to the Top 100 Model. While the college models had less precise parameter estimates for all variables (as expected in models with a lower sample size), their parameters produced similar odds ratios as the Top 100 Model. Overall, the college models suggested that census tracts with large student populations have high shares of bicycle commuters for many of the same underlying reasons as other neighborhoods, such as high population densities, more bicycle facilities, and older housing (likely representing connected street networks and mixed land uses).

POLICY IMPLICATIONS

Analysis of the Top 100 census tracts and their 100 Comparison tracts showed that several socioeconomic and local environment characteristics were associated with high rates of bicycling to work. These results suggest several policy strategies that could potentially increase neighborhood bicycle commuting. The policy strategies also draw from other studies of travel behavior, such as the Theory of Routine Mode Choice Decisions (*27*). In particular, these strategies recognize that the initial choice of commute mode is a tradeoff between the safety, convenience and cost, and enjoyment of modes available to each worker and that day-to-day commute choices are often the product of established habits. The approaches described below are intended to increase the relative attractiveness of bicycling for one or more of these core considerations and may ultimately lead to more workers developing a habit of bicycle commuting.

Model Employment Centers after University Campuses

A majority of the Top 100 census tracts are close to a university campus. While there are a range of university campus designs and transportation policies, and the results do not identify which specific university characteristics are most important for bicycle commuting, many of the campuses close to the Top 100 census tracts are employment centers that include a dense concentration of jobs with a mix of activities nearby, limited and expensive automobile parking, dense concentrations of housing within bicycling distance, a network of high-quality bicycle facilities serving the campus and surrounding neighborhoods, and plentiful bicycle parking. Given these conditions, bicycling may be more convenient and less expensive than driving for workers living nearby. Results from the Top 100 tracts show that many other workers besides students commute by bicycle when the local environment has these characteristics. Strategies to create these sorts of employment centers include:

- Use zoning policies and economic development incentives to concentrate jobs near dense, mixed-use neighborhoods (e.g., build on surface parking lots, redevelop abandoned industrial properties).
- Charge market rates for on-street parking and encourage employers to offer transit passes and financial incentives for bicycle commuting instead of free on-site parking.
- Install bicycle lanes, cycle tracks, bicycle boulevards, and other bicycle facilities on roadways near job centers.
- Convert abandoned rail lines in redeveloping industrial areas into multi-use trails.

- Install bicycle parking near office and industrial building entrances.

Design Neighborhoods that Support Routine, Multimodal Travel

Regression showed that tracts with higher population densities and a greater proportion of housing constructed before 1940 were more likely to have high rates of bicycle commuting. In addition to having higher population densities, pre-1940 neighborhoods tended to be closer to central business districts, have more connected streets, and have a greater mix of land uses than newer neighborhoods. These types of neighborhoods also tended to have frequent transit service. Since locations for most daily activities are located within walking or bicycling distance of the neighborhood and other destinations can be reached by transit, these types of neighborhoods may allow people to live without an automobile or with one automobile instead of two. Given neighborhood convenience for walking, bicycling, and taking transit to routine activities, it may be easier for residents to develop the habit of bicycle commuting. Strategies to create these types of neighborhoods include:

- Change zoning policies to increase the density of housing, allow multi-use buildings, and many different types of activities close to each other.
- Increase transit service frequency and improve pedestrian and bicycle access to transit stops and stations.
- Construct bicycle lanes, cycle tracks, bicycle boulevards, and other bicycle facilities to create a bicycling network within the neighborhood and connections to nearby job centers.
- Provide paths between cul-de-sacs and allow bicyclists to pass through dead-ends for automobiles in order to provide connected network of bicycle facilities.

Reduce Barriers to Bicycling in Bad Weather

Many neighborhoods with high bicycle commute rates have nice weather for most of the year. Mild, dry climates may be more comfortable for bicycling (bicyclists are less exposed to rain, snow, and cold), and they also may be convenient for bicycling because bicyclists need less time on both ends of a trip to deal with extra jackets, pants, and special gear that make it tolerable to ride in bad weather. Therefore, specific strategies are needed to increase bicycle commuting in cold and wet climates. These strategies may include providing covered outdoor bicycle parking, indoor bicycle parking, places within or next to building entrances where bicyclists can remove gear, and workplace shower facilities. They also include removing snow and ice from bicycle facilities quickly after a storm so that it is more pleasant and safer to ride to work. In addition, it is important for communities in cold and wet climates to have frequent, reliable transit service to employment centers so that people can have an inexpensive alternative commuting option (i.e., so they do not need to invest in an automobile to commute when weather conditions prevent them from bicycling).

While the data in this study did not highlight hot and humid climates as a barrier to bicycle commuting, warm, muggy conditions can also prevent people from bicycling to work. These conditions are less pleasant for riding and make bicyclists sweaty when they arrive at work, especially when commuting long distances. Some strategies listed above, such as providing shower facilities, may also make bicycling more attractive in these conditions.

CONSIDERATIONS AND FUTURE RESEARCH

This study provides important insights into the characteristics of neighborhoods with the highest rates of bicycle commuting in the United States. However, there are limitations to the ACS data source and the breadth of variables included in the analysis.

The variables analyzed in the study represented the local environment in and around census tracts where workers live. While many bicycle commuters may work at the types of employment centers considered in this study (e.g., university campuses, central business districts), their actual work locations were not analyzed. Some workers may live close to a university campus but may choose not to bicycle because their actual workplace is a long distance from home. Future research should examine where residents are actually commuting, including the routes chosen by bicyclists, to increase understanding of specific aspects of the built and social environment between homes and workplaces that support bicycle commuting.

Since this analysis used aggregated census tract data and neighborhood-level characteristics, it does not apply to individual bicycle commuters. Individual-level travel surveys could ask about characteristics such as bicycling experience and parking availability at work to provide a more direct understanding of why particular people choose to bicycle commute, given socioeconomic and local environment attributes.

Several additional variables should be considered in future research. These include:

- *Attractiveness of automobile, transit, and pedestrian commuting.* Characteristics such as parking prices, traffic congestion, transit service frequency, and transportation demand management programs are related to the convenience and cost of commuting by bicycle versus other modes, so they are likely to influence commute mode choices (*27*). For example, a transit-rich environment may support owning fewer automobiles (complementing bicycle commuting), but good transit service may also substitute for bicycle commuting. While these variables were considered by proxy through other variables (e.g., tracts with high population densities, surrounded by many jobs, and close to university campuses often have high parking prices, congested traffic, and transportation demand management programs), they should be measured directly in future studies.
- *Specific types of bicycle facilities*. This study measured the density of several types of bicycle facilities in a single variable. However, future models could include different variables for bicycle lanes, cycle tracks, bicycle boulevards, and other common facilities. This may show which particular types of facilities are associated with a higher likelihood of census tracts having high rates of bicycling to work.
- *Bicycle encouragement programs*. A variety of programs have been designed to encourage bicycle travel, including bike to work days, individualized marketing efforts, and bike sharing systems. These efforts may increase bicycle commuting in some neighborhoods, so they should be considered in the future.
- *Personal preferences for living in pedestrian- or bicycle-friendly neighborhoods and local social norms*. Personal enjoyment of particular modes (e.g., "I like to bicycle for exercise") and social norms (e.g., "riding a bicycle is a sign of being environmentally-friendly" or "driving a car instead of riding a bicycle indicates a higher social status") are likely to influence travel behavior (*27*,*28*). As a result, some people who are already bicycle commuters may move to particular Top 100 tracts because they are bicycle-friendly. Not accounting for this type of self-selection may lead to overestimating the impacts of certain policy strategies to increase bicycle commuting.

These additional variables could be collected through in-depth surveys or interviews with local planners who are familiar with neighborhoods represented by the Top 100 tracts.

Some variables evaluated in this study, including urban design characteristics such as the prevalence of multilane roadways and off-street parking lots, did not show a statistically significant relationship with high levels of neighborhood bicycle commuting. However, this does not mean that they do not impact bicycle commute rates. People may choose not to bicycle to work because they do not feel comfortable riding on busy roadways with no bicycle lanes or many driveway crossings. Future studies with larger sample sizes or more specific analyses of commuting routes may be able to identify significant associations between these variables and bicycle commuting.

Future research should also track changes in bicycle commuting over time. This study examines cross-sectional data from one five-year time period, so it only identifies variables that are associated with bicycle commuting. Analyzing how bicycle commute rates increase or decrease after changes to roadway designs, bicycle facilities, land use patterns, and roadway and parking prices can illustrate causal relationships between policy strategies and bicycle commuting. While this study used statistical analysis to identify neighborhood-level variables that are associated with high rates of bicycle commuting, follow-up research could take advantage of a case-study approach. Gathering detailed data and stories from local experts and neighborhood field visits may provide a rich understanding of the local socioeconomic, environmental, and cultural characteristics that support bicycling in the Top 100 census tracts.

CONCLUSION

Analysis of the Top 100 census tracts in the United States showed that neighborhoods with the highest levels of bicycle commuting were associated with moderate climates, level terrain, and several socioeconomic and local environment characteristics. These included being located closer to a university and having more households without automobiles, more people born in other states and countries, higher population density, more housing constructed before 1940, and greater bicycle facility density. These results suggest that policies to model employment centers after university campuses; design neighborhoods that support routine, multimodal travel; and reduce barriers to bicycling in bad weather may help create more local areas with high rates of bicycle commuting.

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