TRR
JOURNAL OF THE TRANSPORTATION RESEARCH BOARD

Research Article

Transportation Research Record
2020, Vol. 2674(4) 101–113

DOI: 10.1177/0361198120912241
journals.sagepub.com/home/trr
SAGE

Statewide Analysis of Individuals' Exposure to Business Establishments and Active Travel Behavior

Yicong Yang[1] and Carolyn McAndrews[1]

Abstract

This study analyzes the association between exposure to various economic establishments, such as retail stores and schools, and walking and cycling at the individual level. Instead of using a land use mix indicator applied in many previous studies, 17 types of establishments were investigated, based on the North American Industrial Classification System, located within individuals' activity spaces. The 2017 Wisconsin Add-On to the National Household Travel Survey was used to compute the density of establishments for two different activity space measurements: (1) time-weighted one standard deviational ellipses, and (2) convex hulls. Among the significant results agreed on by both activity space measurements, walking and cycling are positively associated with exposure to educational services and public administration establishments, and negatively associated with exposure to finance and insurance establishments. The results indicate a possible strategy: active travel promotion could leverage the potential for schools and local government offices to serve as anchor institutions for health-promoting travel behavior. In addition to strategies for the built environment, the research also suggests that physical activity encouragement could target individuals, such as workers, who probably have exposure to establishments with a negative association with active travel, such as in the finance and insurance sector.

National public health policies throughout the world emphasize the importance of adequate physical activity, which decreases the risks of mortality, being overweight, obesity, and chronic diseases (*1–3*). People can meet these national guidelines by walking, cycling, and riding transit for everyday needs, not only through leisure and exercise (*4*, *5*). In addition, experts in health behavior have found that people with lower levels of fitness can more easily participate in walking and cycling, which makes these modes especially important for health promotion. Compared to vigorous exercise, adopting moderate physical activity is easier to achieve and maintain, and it generates the greatest relative health improvement for sedentary people (*6–8*). Therefore, promoting physically active travel, especially walking and cycling, has become a key public health strategy.

One policy approach has focused on removing environmental barriers to physical activity by investing in built environments that encourage people to incorporate active travel into their daily routine (*9*). Plenty of interventions from transportation, planning, and urban design are relevant to this approach, such as complete streets policies, safe routes to school polices, and methods for metropolitan planning organizations and other agencies to prioritize health in their transportation improvement programs.

This study contributes to understanding policies that support active travel through built environments, with a specific focus on business environments such as retail, educational, recreational, and industrial places. Previous research has shown that an area's land use mix, presence of retail, and the density of activities—in combination with infrastructure and transportation system design—influence walking and cycling (*10–12*). For instance, auto repair shops and auto dealerships deter walking, and parks generate walk trips (*13*, *14*).

Although these built environment conditions describe urban or metropolitan walkability, they may not be key factors for rural or exurban locations or populations (*15*). Therefore, in this study the scale of analysis is changed to include urban and rural places and examine how exposure to the business establishments influences

[1]Department of Planning and Landscape Architecture, University of Wisconsin–Madison, Madison, WI

Corresponding Author:
Yicong Yang, yicong.yang@wisc.edu

walking and cycling for a representative sample for the state of Wisconsin in the United States. Moreover, the analysis aligns individual-level exposures and individual-level outcomes instead of relying on aggregated measurements. The results can be useful to communities developing land use, transportation, and health policies to increase active transportation.

Literature and Background

Representing Specific Establishments in the Built Environment

The broader question guiding this research asks which features of built environments influence active travel behavior. Cervero and Kockelman distilled these features into indicators representing an area's activity density, land use diversity, and design (3Ds) (*16*). Recent studies have generally confirmed that places with higher residential and employment density, smaller block size, connected street patterns, pedestrian and bicycle infrastructure and amenities, and a higher degree of land use mix are associated with less driving and more walking and cycling (*17–21*). However, Frank and Engelke pointed out that built environment variables usually covary or correlate across space (*6*). It is difficult to determine precisely which features matter most.

Many studies find that land use mix is an important determinant of walkability, and entropy-based indices have been the most popular indicator of land use mix (*22–25*). These studies usually categorize land use as residential, commercial, recreational, office, and educational. Cao et al., using information from an online yellow pages, accounted for the location of institutional, maintenance, dining, and leisure destinations (*26*). Nonetheless, commercial establishments were aggregated into one accessibility variable for a causal model. By simply looking at the degree of mix or accessibility to amenities, it is still unclear which specific types of neighborhood amenities, specifically economic establishments, are most critical to active travel behavior, particularly across urban, suburban, and rural places with different land use patterns.

The relevance of specific establishments is an important concern in research about the association between built environment and public health. Kestens et al. accounted for exposure to different types of food stores in research about the risk of being overweight (*27*). They found that the risk of being overweight increases with exposure to fast food restaurants. However, there is more to understand about the interrelationships between specific land use types and active travel behavior.

Representing Exposure to Built Environments

Most studies of active travel and built environments rely on two types of aggregated data: 1) representing places by their neighborhood boundaries, census tracts, block groups, ZIP codes, or traffic analysis zones; and 2) representing populations by their aggregate travel outcomes (*17*, *21*, *28*, *29*). In this analysis, the concept of the activity space is used as the unit of analysis, which allows us to link individual-level travel outcomes with individual-level exposures, thereby making a closer connection between the exposure and the outcome.

Activity spaces are the geographical areas that people visit during the course of their daily activities (*30*, *31*). Activity spaces have been used to represent exposure, usually as an alternative to residential neighborhood. With respect to transportation systems, activity spaces include areas near the home and place of work, as well as journeys to school, church, medical appointments, shopping, social occasions, and other activities through which people have direct contact with their environments. Activity spaces have both spatial and temporal components. Several socioeconomic and demographic factors influence the size and nature of individuals' activity spaces, such as age, gender, labor force participation, access to a private automobile, household size, household income, and education (*32*, *33*).

Activity spaces help overcome prior methodological limitations of similar analyses. For example, Howell et al. (*34*) used a survey of Canadian college students to show that the built environment and transportation-related physical activity relationship cannot be adequately assessed by using only individuals' residential environments, as people may spend much of their time outside home-based activity spaces. Instead of analyzing the home-based activity spaces, Gunn et al. examined metrics for built environment features surrounding local shopping centers anchored by supermarkets, and derived policy implications for supermarket provision (*20*). However, no previous studies have examined how built environment features within personal activity space influence active travel among populations in general.

Data and Methods

Travel Data

This study uses the Wisconsin Add-On to the 2017 National Household Travel Survey (NHTS) to construct activity spaces for individuals, represent individual and household characteristics, and indicate levels of physical activity (*35*). In the travel survey, Wisconsin households were selected from 16 substrata representing the entire state. The daily travel data include an inventory of all trips taken within a 24-h period by all household members aged 5 or older. This data set includes 84,544 trips for 19,941 persons in 10,723 households. The confidential data also include geocoded location information for 57,040 homes, workplaces, schools, and other travel destinations. The activity space construction for this study was based on these geocoded locations.

Activity Spaces Measures

Several different activity space measurements have been applied to study health and travel behavior, including perceived or officially defined neighborhoods, convex hulls (CHs), route buffers, kernel density surfaces, and standard deviational ellipses (SDEs). The measures have unique advantages and drawbacks with respect to data availability and measurement accuracy. They have been constructed using travel diaries, global positioning system tracking, social media data mining, or web-based questionnaires (*36–41*).

Two measures were used to represent activity spaces: time-weighted one SDEs and CHs. These two representations accommodate the NHTS data, which provide a finite set of point locations but no line features to represent route choice. Because of this data limitation, as well as the large scope of the study area, questions that required detailed route trajectories were not pursued. The time-weighted SDE and CH measures generally result in an activity space larger than observed route-based activity spaces (*42*). Nevertheless, these larger areas capture places that an individual might not have interacted with but would potentially encounter when carrying out everyday activities.

The duration of activity space data collection also affects the measurement's reliability. Studies of this issue show that at least 14 days of travel activity observation are desirable for identifying activity space accurately (*39*, *43*). However, obtaining 14 days of GPS data is not always feasible. Using only 1 day of travel activity for each person is also considered valid when the travel survey data set is sufficiently large, such as for the Wisconsin Add-On to the NHTS (*27*).

Based on the geocoded locations in the travel survey, 10,362 valid SDEs and 19,941 CHs for individuals who traveled on the day of the travel survey were constructed. For SDEs, a one SDE was generated for each individual and weighted based on the individual's duration at each location, which is information available from the travel diary (see Figure 1). Because creating an ellipse requires at least three distinct point features with variation in both the X and Y axes, 9,579 out of 19,941 cases had too few features or too few vertices to create a valid geometry and were excluded from this step. Among these 9,579 excluded cases, 7,819 contained only two points, which indicates that the person had only been at two places on

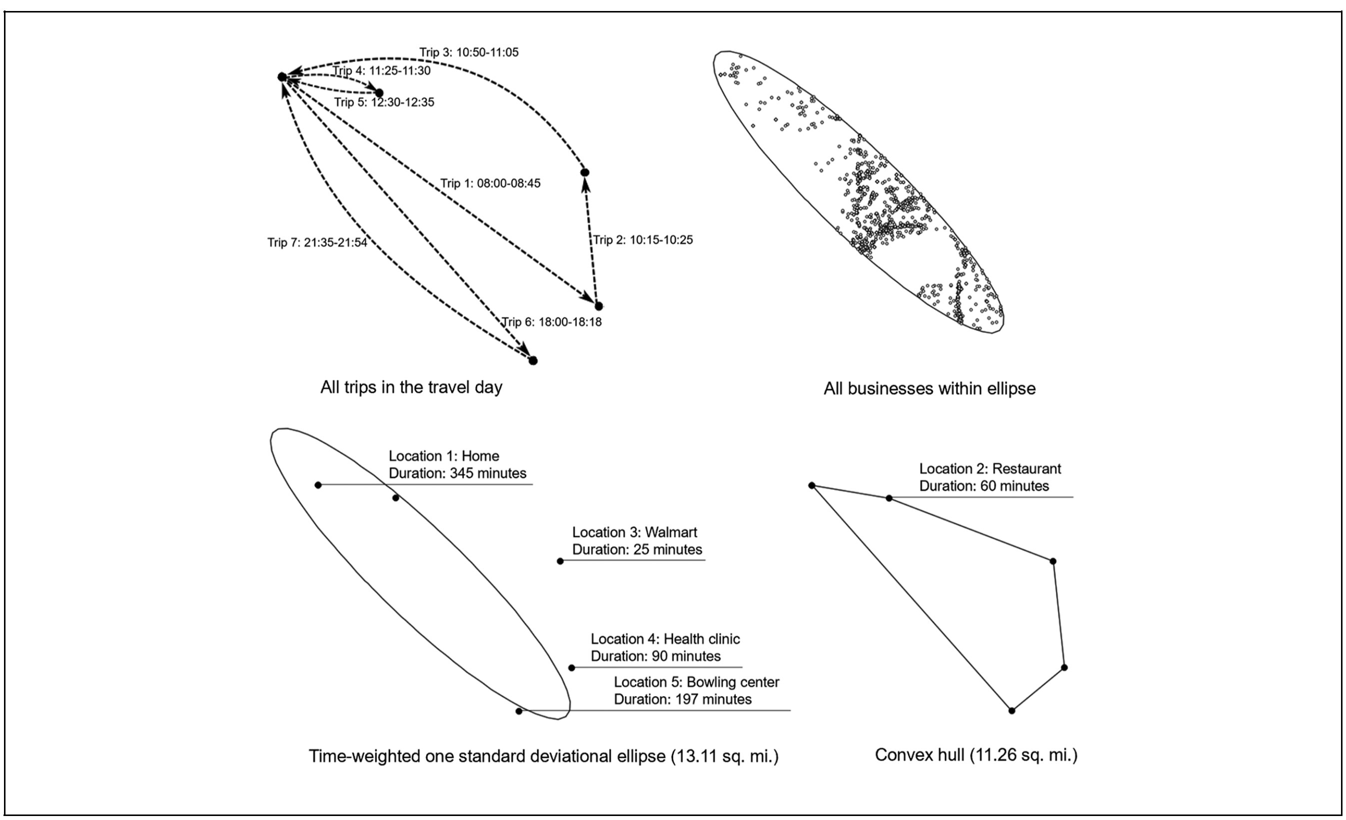

Figure 1. Illustration of activity space measurements for an individual's travel survey day.

the travel day. The other 1,760 cases contained missing values for duration, which were time-weighted as zeros, resulting in missing vertices.

A CH is the minimum convex polygon enclosing the set of destinations of an individual on a Euclidean space. All 19,941 people generated a valid CH based on the ArcGIS minimum bounding geometry tool. If only two points were available, a line feature was generated.

The data set was further refined by selecting cases in which the activity space was located completely within Wisconsin, which resulted in 7,539 SDEs and 15,640 CHs.

Business Types and Economic Exposure

In this study, "economic exposure" is defined as an individual's exposure to different types of businesses in the built environment. The North American Industry Classification System (NAICS) codes were used, available from the 2015 Environmental Systems Research Institute (Esri) Business Analyst, to identify and classify geocoded business locations (*44*).

NAICS is an industry classification system that groups establishments into industries based on the similarity of their production processes. The system includes 20 sectors represented by two-digit NAICS codes covering all economic activities (*45*). For 2015, there were 252,253 economic activities located within the state of Wisconsin; 91.7% of these were located within the sampled personal activity spaces measured by time-weighted SDEs, and 91.5% were located within the sampled personal activity space measured by CHs.

For this analysis, the top 17 categories that are most frequent and relevant to individuals' daily activities were selected and the remaining three that were not informative for the research objective were excluded. The number of establishments for the three excluded categories account for only 0.4% of the total establishments in both activity space measurements.

For each traveler in the Wisconsin Add-On to the 2017 NHTS, the density of economic exposure was computed as the count of economic locations within the individual's activity space divided by the size of the individual's activity space in square miles. In general, the density of economic exposure in activity spaces measured by CHs has a larger variance than that measured by time-weighted SDEs.

Active Travel Behavior and Person Characteristics

All travel behavior and sociodemographic variables were derived from the NHTS data set. The outcome variable—active travel behavior—is defined as the self-reported number of walking plus cycling trips for all purposes in the past 7 days for an individual, ranging from 0 to 149 with a mean of 6.0 and standard deviation of 8.7. These walk or bike trips include all purposes of walking or bicycling outside, including walking or bicycling to exercise, to a friend's house, around the neighborhood, to the store, and walking the dog; 44% of the unweighted self-reported walk or bike trips were strictly to exercise, according to the raw data.

Self-selection has been a key consideration in previous research (*26*, *34*, *46*). For example, a physically active person may choose to be exposed to certain economic establishments and a walkable built environment to satisfy their preferences for physical activity. Therefore, an individual's personal characteristics are assumed to affect both their exposure to economic locations and the active travel behavior. To control for the self-selection effect, age, sex, self-reported baseline level of physical activity, and household income were included as confounders.

In addition, two urban form characteristics were controlled for, beyond the business counts: intersection density and proximity to transit stops, measured at the activity space level for each individual. These two variables may affect both the location of different establishments and individuals' active travel behavior. Spatial data were extracted from the National Walkability Index (*47*).

Among the 7,539 SDE observations, eight had missing physical activity level data, 16 had missing self-reported walking in the past week, one had missing self-reported cycling in the past week, and 189 had missing household income information. Excluding these 214 missing values resulted in 7,325 observations for the SDE measurement. To make the two activity space measurements more comparable, the cases of CHs to SDEs were further matched, which resulted in 6,286 observations for both measurements. Therefore, the final data analysis was based on these 6,286 individuals. The average activity space size was 28.1 mi^2 measured by SDEs, and 36.6 mi^2 measured by CHs. Table 1 presents the definitions of all variables and descriptive statistics.

Model Specification

Table 1 shows that the outcome variable—the count of the self-reported walking and cycling trips in the past week—has a larger variance than mean, which indicates an overdispersion of the outcome variable. An overdispersion value of 11.06 for SDEs and 11.02 for CHs from an overdispersion test indicates that a negative binomial regression is preferred (*48*). The model specification is the following:

For each individual i,

$$\mu_i = \exp(\boldsymbol{\beta} X_i + \varepsilon_i) \quad (1)$$

Table 1. Variable Definitions and Descriptive Statistics by Time-Weighted SDEs and CHs ($N = 6{,}286$)

Variable	Definition	Mean		Standard deviation		Minimum	Maximum	
		SDEs	CHs	SDEs	CHs		SDEs	CHs
Dependent variable								
Active travel behavior	Count of walk trips plus bike trips in the past week	6.0	6.0	8.7	8.7	0	149	149
Exposure variables								
NAICS 44–45 Retail trade	Density of retail trade establishments in the individual's activity space (count/mi^2)	18.7	16.9	39.9	26.4	0.0	905.4	658.1
NAICS 81 Other personal services	Density of other personal services (e.g., repairs, religious activities, laundry, personal care …)	14.8	14.0	33.0	20.7	0.0	1,172.4	579.9
NAICS 62 Health care and social assistance	Density of health care and social assistance establishments	12.1	11.1	26.7	17.5	0.0	895.2	562.8
NAICS 52 Finance and insurance	Density of finance and insurance establishments	11.7	11.3	25.5	18.8	0.0	905.4	535.6
NAICS 54 Professional, scientific, and technical services	Density of professional, scientific, and technical services	10.6	9.8	27.6	22.5	0.0	695.1	661.1
NAICS 72 Accommodation and food services	Density of accommodation and food services	9.1	8.9	22.0	18.6	0.0	449.1	640.1
NAICS 92 Public administration	Density of public administration locations	7.1	5.7	32.1	21.3	0.0	793.0	657.7
NAICS 23 Construction	Density of construction locations	7.0	6.8	25.0	9.4	0.0	1,717.3	236.1
NAICS 53 Real estate	Density of real estate and rental leasing locations	6.0	5.9	12.4	9.3	0.0	337.5	206.8
NAICS 56 Waste management	Density of administrative and support and waste management and remediation services	4.0	3.9	12.0	7.0	0.0	706.2	195.4
NAICS 61 Educational services	Density of educational services	3.6	3.1	9.9	6.5	0.0	301.5	188.6
NAICS 31–33 Manufacturing	Density of manufacturing locations	3.5	3.5	6.8	4.3	0.0	316.2	50.8
NAICS 42 Wholesale trade	Density of wholesale trade locations	3.1	2.9	6.3	3.6	0.0	236.2	59.3
NAICS 51 Information	Density of information services	2.8	2.6	7.7	6.2	0.0	186.1	193.4
NAICS 71 Arts, entertainment, recreation	Density of arts, entertainment, and recreation locations	2.3	2.1	8.2	4.0	0.0	337.5	119.0
NAICS 48–49 Transportation and warehousing	Density of transportation and warehousing locations	1.5	1.5	3.9	2.3	0.0	160.5	57.7
NAICS 11 Agriculture, forestry, fishing, and hunting	Density of agriculture, forestry, fishing, and hunting locations	0.2	0.2	1.2	0.6	0.0	77.8	11.5
Control variables								
Age	Age of the individual in years	50.5	50.5	20.6	20.6	5	95	95
Sex (dummy)	Male or female					0 (male)	1 (female)	
Physical activity level (three categories)	The level of physical activity (rare or never, light or moderate, vigorous) in a typical week for an individual	na	na	na	na	Rare or never	Vigorous	
Intersection density	Number of intersections per acre within activity space	51.9	54.3	37.3	34.3	0.0	395.9	211.4
Proximity to transit stops	At least one transit stop is less than 1.2 Km for an individual	na	na	na	na	0 (false)	1 (true)	
Household income (11 categories)	Household annual income in US$	na	na	na	na	10,000–14,999	>200,000	

Note: SDEs = standard deviational ellipses; CHs = convex hulls; NAICS = North American Industry Classification System; na = not applicable.

Table 2. Results for Negative Binomial Models for SDE and CH Measurements

Variable	SDEs (**N** = 6,286) Estimate	Standard error	95% Confidence interval		CHs (**N** = 6,286) Estimate	Standard error	95% Confidence interval	
(Intercept)	1.5348	0.1259	1.2930	1.7828	1.6859	0.1273	1.4480	1.9306
44–45 Retail trade	0.0001	0.0007	−0.0014	0.0016	−0.00004	0.0012	−0.0023	0.0024
81 Other personal services	0.0008	0.0010	−0.0012	0.0029	−0.0010	0.0020	−0.0051	0.0031
23 Construction	0.0023	0.0014	−0.0002	0.0048	0.0005	0.0033	−0.0056	0.0065
52 Finance and insurance	**−0.0046**	**0.0013**	**−0.0071**	**−0.0020**	**−0.0054**	**0.0020**	**−0.0092**	**−0.0015**
62 Health care and social assistance	0.0001	0.0008	−0.0012	0.0017	0.0021	0.0013	−0.0004	0.0049
72 Accommodation and food services	0.0008	0.0012	−0.0015	0.0033	−0.0007	0.0019	−0.0043	0.0031
54 Professional, scientific, and technical	0.0011	0.0011	−0.0012	0.0037	**0.0046**	**0.0017**	**0.0013**	**0.0081**
92 Public administration	**0.0021**	**0.0007**	**0.0006**	**0.0037**	**0.0025**	**0.0011**	**0.0003**	**0.0046**
53 Real estate	0.0028	0.0023	−0.0018	0.0075	**0.0097**	**0.0037**	**0.0022**	**0.0174**
31–33 Manufacturing	−0.0048	0.0028	−0.0099	0.0006	−0.0096	0.0055	−0.0196	0.0006
42 Wholesale trade	0.0019	0.0034	−0.0042	0.0084	−0.0048	0.0071	−0.0180	0.0085
56 Waste management	−0.0035	0.0029	−0.0085	0.0020	**−0.0107**	**0.0054**	**−0.0209**	**−0.0005**
61 Educational services	**0.0116**	**0.0019**	**0.0075**	**0.0160**	**0.0076**	**0.0036**	**0.0007**	**0.0148**
48–49 Transportation and warehousing	**−0.0184**	**0.0057**	**−0.0287**	**−0.0078**	−0.0145	0.0100	−0.0330	0.0042
71 Arts, entertainment, and recreation	0.0010	0.0023	−0.0027	0.0058	0.0048	0.0066	−0.0075	0.0181
51 Information	**−0.0092**	**0.0038**	**−0.0172**	**−0.0010**	−0.0023	0.0058	−0.0145	0.0101
11 Agriculture	−0.0066	0.0132	−0.0304	0.0229	−0.0161	0.0281	−0.0654	0.0355
Age	0.0001	0.0008	−0.0014	0.0016	−0.0002	0.0008	−0.0017	0.0013
Sex (reference group: male)	**−0.0940**	**0.0301**	**−0.1532**	**−0.0349**	**−0.0869**	**0.0300**	**−0.1461**	**−0.0278**
Vigorous physical activity (reference group: rare physical activity)	**1.1538**	**0.0711**	**1.0118**	**1.2935**	**1.1533**	**0.0712**	**1.0118**	**1.2925**
Intersection density	−0.0006	0.0005	−0.0015	0.0003	**−0.0012**	**0.0006**	**−0.0024**	**−0.0001**
Proximity to transit stops	−0.0319	0.0349	−0.1013	0.0376	−0.0466	0.0342	−0.1141	0.0211
Household income 35,000–50,000 (reference group: <10,000)	**−0.5011**	**0.1044**	**−0.7150**	**−0.2950**	**−0.5850**	**0.1048**	**−0.7980**	**−0.3799**
Household income 100,000–125,000	**−0.5874**	**0.1059**	**−0.8034**	**−0.3791**	**−0.6742**	**0.1064**	**−0.8892**	**−0.4667**
Household income >200,000	**−0.6181**	**0.1183**	**−0.8564**	**−0.3848**	**−0.7089**	**0.1188**	**−0.9463**	**−0.4764**
Alpha		1.1993				1.1983		
AIC		35,571				35,566		
2×log likelihood		–35,501				–35,496		

Note: SDEs = standard deviational ellipses; CHs = convex hulls; AIC = Akaike information criterion. Bold font indicates statistical significance. NAICS prefaces the numbers in column 1. All household income categories are significant, only three categories are reported in this table.

where
the parameter μ_i = the expected number of walk plus bike trips within a week,
$\boldsymbol{\beta}$ = a vector of estimable regression coefficients,
X_i = a matrix of values of independent variables, and
$\exp(\varepsilon_i)$ = the error term which follows a gamma distribution with mean 1 and variance α.
In a negative binomial model, α is referred to as the overdispersion parameter, which allows the variance to differ from the mean. The negative binomial distribution has the form

$$Pr(Y = y_i|\mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(\alpha^{-1})\Gamma(y_i + 1)} \left(\frac{1}{1 + \alpha\mu_i}\right)^{\alpha^{-1}} \left(\frac{\alpha\mu_i}{1 + \alpha\mu_i}\right)^{y_i} \quad (2)$$

where y_i is the count of walk plus bike trips within a week for each individual, and $\Gamma(\cdot)$ is a gamma function. The Maximum Likelihood Estimation function of the model, $L(\cdot)$, is

$$L(\mu_i) = \Pi_i \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(\alpha^{-1})\Gamma(y_i + 1)} \left(\frac{1}{1 + \alpha\mu_i}\right)^{\alpha^{-1}} \left(\frac{\alpha\mu_i}{1 + \alpha\mu_i}\right)^{y_i} \quad (3)$$

Results

Economic Exposures

Table 2 presents the negative binomial model estimation results. Variable inflation factor (VIF) was applied to assess multicollinearity. VIFs are less than 2.4 and 2.7 for all predictors in SDE and CH measurements, respectively. This suggests low multicollinearity for both activity space measurements. If 0 does not fall in the 95% confidence interval for an estimate, this estimate is statistically significant at the 95% confidence level.

Both SDE and CH activity space measurements agree that exposure to educational services and public administration have a statistically significant positive association with the active travel behavior of walking and bicycling. Both measurements report a statistically significant negative association with exposure to finance and insurance. The CH measurement agrees with the SDE measurement for 13 out of 17 exposure variables with reference to the direction of effects. The other four sectors that failed to reach agreement are retail trade, other personal services, accommodation and food services, and wholesale trade.

For the SDE measurement alone, exposure to transportation and warehousing, as well as to information services, has significant negative effects on active travel behavior at the 95% confidence level. The additional exposures that had positive effects on active travel at the 95% confidence level for the CH measurement alone include professional, scientific, and technical services, and real estate. Exposure to waste management establishments in the CH had a significantly negative effect on active travel at the 95% confidence level.

Interpreting the negative binomial regression model results is not intuitive because the regression coefficients are the log count values of exposure. By exponentiating regression coefficients the incidence rate ratio is obtained—the change factor in active travel behavior in response to a one count per square mile change of exposure variable values. For example, the expected walking or bicycling trips within a week changes by a factor of $\exp(0.0116) = 1.0117$, which is a 1.17% increase, in response to an additional educational service establishment per square mile in an individual's activity space for the SDE measurement, holding other factors constant. The active travel behavior of walking plus bicycling has a mean of six times a week. On average, to increase the amount of active travel from six to seven times a week for an individual, exposure needs to be increased by $\ln(7/6)/\ln(1.0117) = 13.25$ more educational services per square mile in the individual's activity space.

To interpret the effect of finance and insurance for the CH measurement, the expected walking or bicycling trips in a week change by a factor of $\exp(-0.0054) = 0.9946$, which is a decrease of 0.54%, in response to an additional finance and insurance establishment per square mile in an individual's activity space, holding other factors constant. On average, increasing walking or bicycling trips in a week from six to seven times would require the expected density of finance and insurance establishment change by $\ln(7/6)/\ln(0.9946) = -28.50$. Figure 2 visualizes the effects of all statistically significant exposures on active travel measured by both SDEs and CHs.

Person and Urban Form Characteristics

Both SDE and CH activity space measurements report statistically significant results for several sociodemographic and physical activity level variables. When other factors are held constant, females walk or bike less than males, on average. Moreover, reporting a higher baseline level physical activity is significantly related to more active travel behavior.

Proximity to transit does not significantly associate with active travel. Intersection density within individuals' activity spaces is significantly negatively related to active travel for the SDE measurement. These results are counterintuitive because places with higher intersection density and more transit stops are considered more walkable, at least for urban environments. However, this is to some extent consistent with Joens-Matre et al. who have found that urban children are the least active overall (*49*). In addition, Fan et al. have suggested that physical activity did not vary unidirectionally with degree of urbanization (*50*). These findings also suggest that measuring travel physical activity at the individual level can yield different results from measuring it at the neighborhood level (*34*).

Higher income is associated with less active travel behavior. This may be because people with higher incomes tend to participate in more structured leisure time physical activities such as in the gym or parks, whereas people with lower income may tend to walk, bike, or use public transit in their daily travel.

Educational Services, Finance and Insurance, and Public Administration

A closer look was taken of the spatial patterns of the three types of economic establishments with significant effects agreed on by both activity space measurements: educational services, public administration, and finance and insurance. Figure 3 presents the densities of these three sectors on a 5- × 5-mi grid for Wisconsin. It was observed that the establishments cluster in urban areas, mainly Milwaukee, Madison, Wausau, Appleton, Green Bay, and Eau Claire. Table 3 presents information about subgroups within the three sectors, categorized by their four-digit NAICS code. Elementary and secondary schools account for most educational services establishments (60.1%). Public administration establishments are mainly executive, legislative, and other general government support activities, which account for 58.2% of

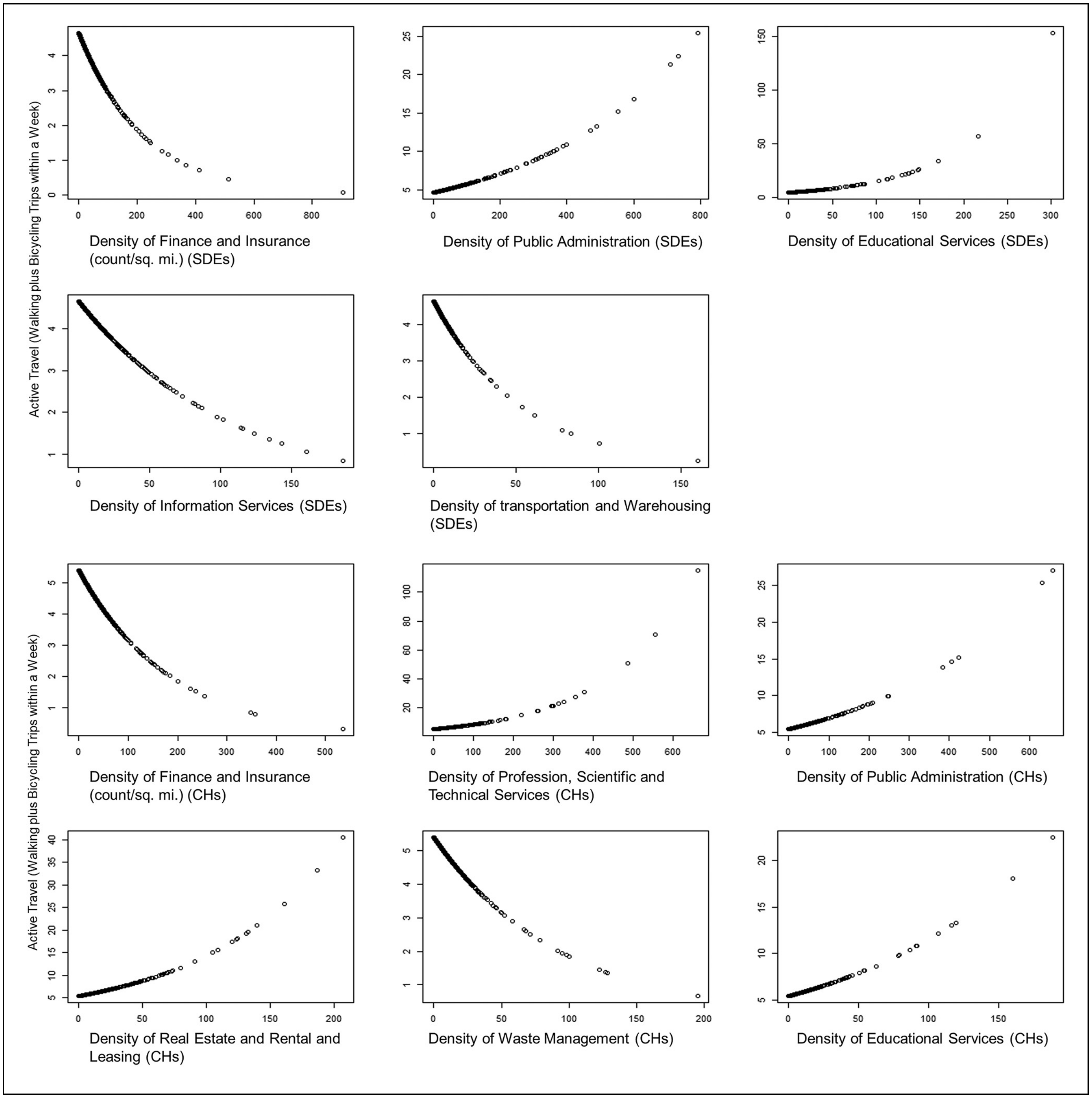

Figure 2. Visualization of statistically significant effects.

sites. Most finance and insurance establishments are depository credit intermediation establishments, that is, branch banks.

Discussion

The statistical analysis indicates that active travel behavior for individuals is associated with a higher exposure to educational services and public administration and a lower exposure to finance and insurance establishments. These establishment types may be closely related to walkability. Most educational services in the analysis are elementary and secondary schools. The walkability of areas around them could be high if schools are located within residential neighborhoods, and they may have been enhanced by programs such as the Safe Routes to School, which encourages children from kindergarten to eighth grade to walk and bike to school. The presence of

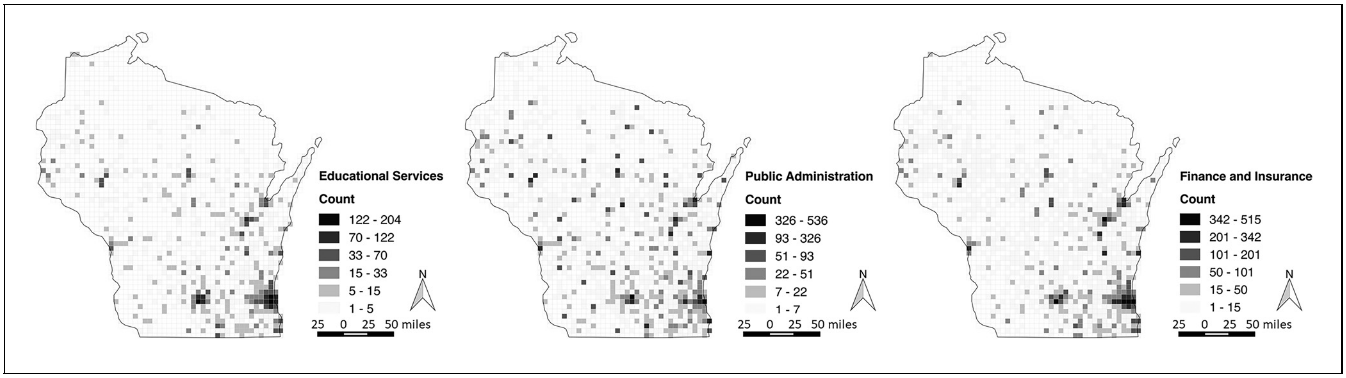

Figure 3. Densities of educational services, public administration, and finance and insurance.

Table 3. Count of Educational Services, Public Administration, and Finance and Insurance by Four-Digit NAICS Codes

Four-digit NAICS	Description	Count (%) in SDEs	Count (%) in CHs
Sector 61: Educational services (N_{SDEs} = 5,612, N_{CHs} = 5,577)			
6111	Elementary and secondary schools	3,371 (60.1)	3,355 (60.2)
6112	Junior colleges	1 (0.0)	1 (0.0)
6113	Colleges, universities, and professional schools	484 (8.6)	481 (8.6)
6114	Business schools and computer and management training	77 (1.4)	75 (1.3)
6115	Technical and trade schools	167 (3.0)	164 (2.9)
6116	Other schools and instruction (e.g., fine arts schools, sports and recreation instruction, language schools, exam preparation and tutoring, automobile driving schools)	1,262 (22.5)	1,253 (22.6)
6117	Educational support services	250 (4.5)	248 (4.4)
Sector 92: Public administration (N_{SDEs} = 11,105, N_{CHs} = 11,077)			
9211	Executive, legislative, and other general government support	6,460 (58.2)	6,442 (58.2)
9221	Justice, public order, and safety activities	2,442 (22.0)	2,434 (22.0)
9231	Administration of human resource programs	619 (5.6)	621 (5.6)
9241	Administration of environmental quality programs	383 (3.4)	373 (3.4)
9251	Administration of housing programs, urban planning, and community development	158 (1.4)	160 (1.4)
9261	Administration of economic programs	699 (6.3)	694 (6.3)
9271	Space research and technology	0	0
9281	National security and international affairs	344 (3.1)	353 (3.2)
Sector 52: Finance and insurance (N_{SDEs} = 20,307, N_{CHs} = 20,332)			
5211	Monetary authorities—central bank	0 (0.0)	0 (0.0)
5221	Depository credit intermediation	11,305 (55.7)	11,339 (55.8)
5222	Nondepository credit intermediation	1,266 (6.2)	1,262 (6.2)
5223	Activities related to credit intermediation	102 (0.5)	103 (0.5)
5231	Securities and commodity contracts intermediation and brokerage	255 (1.3)	251 (1.2)
5232	Securities and commodity exchanges	4 (0.0)	4 (0.0)
5239	Other financial investment activities	2,361 (11.6)	2,343 (11.5)
5241	Insurance carriers	83 (0.4)	83 (0.4)
5242	Agencies, brokerages, and other insurance related activities	4,865 (24.0)	4,882 (24.0)
5251	Insurance and employee benefit funds	54 (0.2)	53 (0.3)
5259	Other investment pools and funds	12 (0.1)	12 (0.1)

Note: SDEs = standard deviational ellipses; CHs = convex hulls; NAICS = North American Industry Classification System.

safe and comfortable walking and bicycling routes around schools could benefit schoolchildren, as well as their communities more broadly. In Wisconsin, higher education may also play a role. University and college campuses can be large employment centers, and for residential campuses, they are the location of student housing. These physical and social environments may generate a higher frequency of walking and cycling.

Explanations for the other two significant factors agreed on by both activity space measurements are less intuitive than educational services. Establishments in the public administration sector are mainly local government offices, which can be clustered in central urban areas with relatively more walkable environments. Finance and insurance establishments mainly include branches of banks and credit unions. As a result of the deregulation and geographic liberalization of banking services since the 1980s, locations of financial services are based on demography, local trade areas, and market conditions (*51*, *52*). Access to banking services may be more automobile dependent in the suburbs, small towns, and rural areas because of low population density.

Several other exposures were identified as significant by either the SDE or the CH measurement but not both. These other exposures that potentially positively influence active travel include professional, scientific, and technical services (CHs) and real estate (CHs). Other exposures that are potentially negatively associated with active travel include transportation and warehousing (SDEs), information (SDEs), and waste management (CHs). This can be explained by their relevance to people's everyday activities. For instance, transportation and warehousing and waste management establishments are highly specialized, often located in peripheral areas with access to freeways, and are mainly accessed by workers. This also implies that workers at these locations have inferior conditions for walking or cycling to their workplaces. Therefore, public health professionals may consider giving higher priority to developing physical activity opportunities around these workplaces.

The effects of the remaining exposures are unclear. Noticeably, retail trade establishments are the most prevalent establishment type in the study and they are closely related to the activities of daily life. However, both activity space measurements found a very small and insignificant association between retail trade exposure and active travel. This may be because many retail trade establishments are located within big-box stores or strip malls, not walkable main streets. Some previous research has assumed that retail stores are positively related to walkability, or have even used the proximity to retail stores as an indicator of walkability (*25, 53–55*). Although this might be true at the neighborhood level, particularly in dense urban areas, this current study does not support this assumption at the population level. Planners and policy makers need to instead consider improving walkability around retail establishments that are not always pedestrian or bicycle friendly.

It is not realistic to build more schools or government offices solely for the purpose of promoting more walking or bicycling trips. Nevertheless, schools, government buildings, and other "anchor institutions" can influence larger populations, not just their users. The built environments around these anchor institutions could be prioritized when making decisions about investment in pedestrian and bicycle infrastructure, green infrastructure, and transit station area design, for example.

Limitations

Although no previous studies have examined the economic exposure and active travel using the activity space as the unit of analysis, several limitations of this study should be noted. First, this study did not identify certain colocation effects among establishments to reflect the effect of land use mix. Land use mix, however, has a complicated relationship with travel behavior. In a metaregression analysis, Stevens found that people actually drive more when land use mix increases (*11*). We have tested this effect by introducing interaction terms among economic categories and the result was not significant in general. Because of the scope of this study, the result was not presented. Second, active travel behavior was measured by the frequency of walking and cycling, rather than total minutes of walking and cycling, which could capture the intensity of active travel more precisely. Third, the categorization of economic establishment was based on the two-digit NAICS code. This is a fairly rough classification. More detailed examinations of economic establishments within specific industrial types could be more revealing. Fourth, the density of economic exposure variables used in this study only indicates the proximity of these exposures for individuals, rather than their actual accessibility. The accessibility of these economic establishments may be determined by microscale built environment features such as pedestrian paths, bike lanes, street furniture, and other elements and their combination. How these microscale built environment features mediate the accessibility to economic establishments could be an area for future research.

Conclusion

This study uses the activity space as the spatial unit of analysis to examine the types of economic establishments that individuals would potentially encounter in their daily activities beyond their residential neighborhoods. Exposures to economic establishments were systematically quantified and they represent a wider range of land use types beyond residential, commercial, recreational, office, and educational, which have been analyzed in previous studies (*23–25*). The analysis identified schools and public buildings as anchor institutions that merit urban design attention because of their positive relationship to active transportation at the population level. Communities may take advantage of educational services to develop more pedestrian-oriented infrastructures or introduce more health-promoting programs to the surrounding communities.

This study has challenged the conventional assumption found in previous research that retail stores are a positive feature in promoting active travel. This assumption may hold when focusing on a neighborhood, corridor, or zone within a metropolitan area. However, in this study of an entire state, we did not find evidence of a relationship between retail stores and active travel. Consequently, we see designing walkable retail environments as an ongoing concern for research and community development.

Public health professionals have the expertise to provide health promotion recommendations that target individual-level behavior change, such as suggesting individual physical activity plans. One implication of this research for health experts is that their work may want to focus on people who are known to have exposure to less walkable economic establishments, such as finance and insurance, transportation and warehousing, information services, and waste management services. Specifically, more physical activity opportunities may need to be provided to employees of these workplaces.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: Y. Yang, C. McAndrews; analysis and interpretation of results: Y. Yang, C. McAndrews; draft manuscript preparation: Y. Yang, C. McAndrews. Both authors reviewed the results and approved the final version of the manuscript.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Data Accessibility Statement

The Wisconsin Add-On to the NHTS data supporting the results reported in the paper are available on request from the NHTS: https://nhts.ornl.gov/. The data are not publicly available because of their containing information that could compromise the privacy of survey participants.

The business establishments data that support the findings of this study are available from Esri. Restrictions apply to the availability of these data, which were used under license for the study. Esri Business Analyst Desktop is available from https://desktop.arcgis.com/en/arcmap/10.3/guide-books/extensions/business-analyst/installing-esri-business-analyst-data.htm. Esri, © (2020). All rights reserved.

The urban form data supporting the results reported in the study are openly available at https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7B251AFDD9-23A7-4068-9B27-A3048A7E6012%7D.

References

1. Kelly, P., S. Kahlmeier, T. Götschi, N. Orsini, J. Richards, N. Roberts, P. Scarborough, and C. Foster. Systematic Review and Meta-Analysis of Reduction in All-Cause Mortality from Walking and Cycling and Shape of Dose Response Relationship. *International Journal of Behavioral Nutrition and Physical Activity*, Vol. 11, No. 1, 2014, p. 132. http://ijbnpa.biomedcentral.com/articles/10.1186/s12966-014-0132-x.
2. Booth, F. W., C. K. Roberts, and M. J. Laye. Lack of Exercise is a Major Cause of Chronic Diseases. In *Comprehensive Physiology* (R. Terjung, ed.), John Wiley & Sons, Inc., Hoboken, N.J., 2012, pp. 1143–1211.
3. World Health Organization. *Global Recommendations on Physical Activity for Health*. World Health Organization, Switzerland, Geneva, 2010.
4. U.S. Department of Health and Human Services. *Physical Activity Guidelines for Americans*, 2nd ed. Department of Health and Human Services, Washington, D.C., 2018.
5. Centers for Disease Control and Prevention. *Strategies to Prevent Obesity and Other Chronic Diseases: The CDC Guide to Strategies to Increase Physical Activity in the Community*. U.S. Department of Health and Human Services, Atlanta, Ga., 2011.
6. Frank, L. D., and P. O. Engelke. The Built Environment and Human Activity Patterns: Exploring the Impacts of Urban Form on Public Health. *Journal of Planning Literature*, Vol. 16, No. 2, 2001, pp. 202–218.
7. Gojanovic, B., J. Welker, K. Iglesias, C. Daucourt, and G. Gremion. Electric Bicycles as a New Active Transportation Modality to Promote Health. *Medicine & Science in Sports & Exercise*, Vol. 43, No. 11, 2011, pp. 2204–2210.
8. Marcus, B. H., L. H. Forsyth, E. J. Stone, P. M. Dubbert, T. L. McKenzie, A. L. Dunn, and S. N. Blair. Physical Activity Behavior Change: Issues in Adoption and Maintenance. *Health Psychology*, Vol. 19, No. 1, 2000, pp. 32–41.
9. Transportation Research Board. Institute of Medicine. *Does the Built Environment Influence Physical Activity?: Examining the Evidence – Special Report 282*. Transportation Research Board, Washington, D.C., 2005. https://www.nap.edu/catalog/11203.
10. Ewing, R., and R. Cervero. Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association*, Vol. 76, No. 3, 2010, pp. 265–294.
11. Stevens, M. R. Does Compact Development Make People Drive Less? *Journal of the American Planning Association*, Vol. 83, No. 1, 2017, pp. 7–18.
12. Xiao, C., Y. Goryakin, and M. Cecchini. Physical Activity Levels and New Public Transit: A Systematic Review and Meta-Analysis. *American Journal of Preventive Medicine*, Vol. 56, No. 3, 2019, pp. 464–473.

13. Golan, Y., J. Henderson, N. L. Wilkinson, and A. Weverka. Gendered Walkability: Building a Daytime Walkability Index for Women. *Journal of Transport and Land Use*, Vol. 12, No. 1, 2019, pp. 501–526.
14. McAndrews, C., J. Flórez, and E. Deakin. Views of the Street: Using Community Surveys and Focus Groups to Inform Context-Sensitive Design. *Transportation Research Record: Journal of the Transportation Research Board*, 2006. 1981: 92–99.
15. Kegler, M. C., I. Alcantara, R. Haardörfer, A. Gemma, D. Ballard, and J. Gazmararian. Rural Neighborhood Walkability: Implications for Assessment. *Journal of Physical Activity and Health*, Vol. 12, 2015, pp. S40–S45.
16. Cervero, R., and K. Kockelman. Travel Demand and the 3Ds: Density, Diversity, and Design. *Transportation Research Part D: Transport and Environment*, Vol. 2, No. 3, 1997, pp. 199–219.
17. Zhang, L., A. Nasri, J. H. Hong, and Q. Shen. How Built Environment Affects Travel Behavior: A Comparative Analysis of the Connections Between Land Use and Vehicle Miles Traveled in US Cities. *Journal of Transport and Land Use*, Vol. 5, No. 3, 2012, pp. 40–52. https://www.jtlu.org/index.php/jtlu/article/view/266.
18. Naess, P. Urban Form and Travel Behavior: Experience from a Nordic Context. *Journal of Transport and Land Use*, Vol. 5, No. 2, 2012, pp. 41–45. https://www.jtlu.org/index.php/jtlu/article/view/314.
19. Milakis, D., T. Vlastos, and N. Barbopoulos. Relationships Between Urban Form and Travel Behaviour in Athens, Greece. *European Journal of Transport and Infrastructure Research*, Vol. 8, No. 3, 2008, pp. 201–215.
20. Gunn, L. D., S. Mavoa, C. Boulangé, P. Hooper, A. Kavanagh, and B. Giles-Corti. Designing Healthy Communities: Creating Evidence on Metrics for Built Environment Features Associated with Walkable Neighbourhood Activity Centres. *International Journal of Behavioral Nutrition and Physical Activity*, Vol. 14, No. 1, 2017, p. 164. https://doi.org/10.1186/s12966-017-0621-9.
21. Forsyth, A., M. Hearst, J. M. Oakes, and K. H. Schmitz. Design and Destinations: Factors Influencing Walking and Total Physical Activity. *Urban Studies*, Vol. 45, No. 9, 2008, pp. 1973–1996.
22. Brown, B. B., I. Yamada, K. R. Smith, C. D. Zick, L. Kowaleski-Jones, and J. X. Fan. Mixed Land Use and Walkability: Variations in Land Use Measures and Relationships with BMI, Overweight, and Obesity. *Health & Place*, Vol. 15, No. 4, 2009, pp. 1130–1141.
23. Bordoloi, R., A. Mote, P. P. Sarkar, and C. Mallikarjuna. Quantification of Land Use Diversity in the Context of Mixed Land Use. *Procedia - Social and Behavioral Sciences*, Vol. 104, 2013, pp. 563–572.
24. Christian, H. E., F. C. Bull, N. J. Middleton, M. W. Knuiman, M. L. Divitini, P. Hooper P, A. Amarasinghe, and B. Giles-Corti. How Important is the Land Use Mix Measure in Understanding Walking Behaviour? Results from the RESIDE Study. *International Journal of Behavioral Nutrition and Physical Activity*, Vol. 8, No. 1, 2011, p. 55. https://doi.org/10.1186/1479-5868-8-55.
25. Wei, Y., W. Xiao, M. Wen, and R. Wei. Walkability, Land Use and Physical Activity. *Sustainability*, Vol. 8, No. 1, 2016, p. 65. https://doi.org/10.3390/su8010065.
26. Cao, X., P. L. Mokhtarian, and S. L. Handy. Do Changes in Neighborhood Characteristics Lead to Changes in Travel Behavior? A Structural Equations Modeling Approach. *Transportation*, Vol. 34, No. 5, 2007, pp. 535–556.
27. Kestens, Y., A. Lebel, B. Chaix, C. Clary, M. Daniel, R. Pampalon, M. Theriault, and S. V. p Subramanian. Association between Activity Space Exposure to Food Establishments and Individual Risk of Overweight. *PLoS One*, Vol. 7, No. 8, 2012, p. e41418.
28. Cervero, R., and M. Duncan. Walking, Bicycling, and Urban Landscapes: Evidence from the San Francisco Bay Area. *American Journal of Public Health*, Vol. 93, No. 9, 2003, pp. 1478–1483.
29. Chen, P. Built Environment Factors in Explaining the Automobile-Involved Bicycle Crash Frequencies: A Spatial Statistic Approach. *Safety Science*, Vol. 79, 2015, pp. 336–343.
30. Sherman, J. E., J. Spencer, J. S. Preisser, W. M. Gesler, and T. A. Arcury. A Suite of Methods for Representing Activity Space in a Healthcare Accessibility Study. *International Journal of Health Geographics*, Vol. 4, No. 1, 2005, p. 24. https://doi.org/10.1186/1476-072X-4-24.
31. Golledge, R. G., and R. J. Stimson. *Spatial Behavior: A Geographic Perspective*. Guilford Press, New York and London, 1997.
32. Dijst, M. Two-Earner Families and Their Action Spaces: A Case Study of Two Dutch Communities. *GeoJournal*, Vol. 48, No. 3, 1999, pp. 195–206.
33. Hanson, S., and P. Hanson. The Impact of Married Women's Employment on Household Travel Patterns: A Swedish Example. *Transportation*, Vol. 10, No. 2, 1981, pp. 165–183.
34. Howell, N. A., S. Farber, M. J. Widener, and G. L. Booth. Residential or Activity Space Walkability: What Drives Transportation Physical Activity? *Journal of Transport & Health*, Vol. 7, 2017, pp. 160–171.
35. Federal Highway Administration. *2017 National Household Travel Survey*. U.S. Department of Transportation, Washington, D.C., 2017. https://nhts.ornl.gov. Accessed July 30, 2019.
36. Crawford, T. W., S. B. Jilcott Pitts, J. T. McGuirt, T. C. Keyserling, and A. S. Ammerman. Conceptualizing and Comparing Neighborhood and Activity Space Measures for Food Environment Research. *Health & Place*, Vol. 30, 2014, pp. 215–225.
37. Kestens, Y., B. Thierry, M. Shareck, M. Steinmetz-Wood, and B. Chaix. Integrating Activity Spaces in Health Research: Comparing the VERITAS Activity Space Questionnaire with 7-Day GPS Tracking and Prompted Recall. *Spatial and Spatio-Temporal Epidemiology*, Vol. 25, 2018, pp. 1–9.
38. Lee, N. C., C. Voss, A. D. Frazer, J. A. Hirsch, H. A. McKay, and M. Winters. Does Activity Space Size Influence Physical Activity Levels of Adolescents?—A GPS

Study of an Urban Environment. *Preventive Medicine Reports*, Vol. 3, 2016, pp. 75–78.
39. Zenk, S. N., S. A. Matthews, A. N. Kraft, and K. K. Jones. How Many Days of Global Positioning System (GPS) Monitoring Do You Need to Measure Activity Space Environments in Health Research? *Health & Place*, Vol. 51, 2018, pp. 52–60.
40. Thierry, B., B. Chaix, and Y. Kestens. Detecting Activity Locations from Raw GPS Data: A Novel Kernel-Based Algorithm. *International Journal of Health Geographics*, Vol. 12, No. 1, 2013, p. 14. https://doi.org/10.1186/1476-072X-12-14.
41. Cranshaw, J., R. Schwartz, J. I. Hong, and N. Sadeh. The Livehoods Project: Utilizing Social Media to Understand the Dynamics of a City. *Proc., 6th International AAAI Conference on Weblogs and Social Media*, Dublin, Ireland, 2012, pp. 58–65.
42. Buliung, R. N., and P. S. Kanaroglou. Urban Form and Household Activity-Travel Behavior. *Growth and Change*, Vol. 37, No. 2, 2006, pp. 172–199.
43. Schlich, R., and K. W. Axhausen. Habitual Travel Behaviour: Evidence from a Six-Week Travel Diary. *Transportation*, Vol. 30, No. 1, 2003, pp. 13–36.
44. Esri. *Esri Business Analyst 2015*. Esri, Redlands, Calif., 2020.
45. Executive Office of the President Office of Management and Budget. *North American Industry Classification System*. 2017. https://www.census.gov/eos/www/naics/. Accessed July 30, 2019.
46. Handy, S., X. Cao, and P. L. Mokhtarian. Self-Selection in the Relationship between the Built Environment and Walking: Empirical Evidence from Northern California. *Journal of the American Planning Association*, Vol. 72, No. 1, 2006, pp. 55–74.
47. United States Environmental Protection Agency. *Walkability Index*, 2015. https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7B251AFDD9-23A7-4068-9B27-A3048A7E6012%7D. Accessed January 2, 2020.
48. Cameron, A. C., and P. K. Trivedi. Regression-Based Tests for Overdispersion in the Poisson Model. *Journal of Econometrics*, Vol. 46, 1990, pp. 347–364.
49. Joens-Matre, R. R., G. J. Welk, M. A. Calabro, D. W. Russell, E. Nicklay, and L. D. Hensley. Rural–Urban Differences in Physical Activity, Physical Fitness, and Overweight Prevalence of Children. *The Journal of Rural Health*, Vol. 24, No. 1, 2008, pp. 49–54.
50. Fan, J. X., M. Wen, and L. Kowaleski-Jones. Rural–Urban Differences in Objective and Subjective Measures of Physical Activity: Findings From the National Health and Nutrition Examination Survey (NHANES) 2003–2006. *Preventing Chronic Disease*, Vol. 11, 2014, p. E141. http://dx.doi.org/10.5888/pcd11.140189.
51. Bernad, C., L. Fuentelsaz, and J. Gómez. Deregulation and its Long-Run Effects on the Availability of Banking Services in Low-Income Communities. *Environment and Planning A: Economy and Space*, Vol. 40, No. 7, 2008, pp. 1681–1696.
52. Evanoff, D. D., and E. Ors. The Competitive Dynamics of Geographic Deregulation in Banking: Implications for Productive Efficiency. *Journal of Money, Credit and Banking*, Vol. 40, No. 5, 2008, pp. 897–928.
53. Jensen, W. A., T. K. Stump, B. B. Brown, C. M. Werner, and K. R. Smith. Walkability, Complete Streets, and Gender: Who Benefits Most? *Health & Place*, Vol. 48, 2017, pp. 80–89.
54. Leslie, E., N. Coffee, L. Frank, N. Owen, A. Bauman, and G. Hugo. Walkability of Local Communities: Using Geographic Information Systems to Objectively Assess Relevant Environmental Attributes. *Health & Place*, Vol. 13, No. 1, 2007, pp. 111–122.
55. Naess, P. 'New Urbanism' or Metropolitan-Level Centralization? A Comparison of the Influences of Metropolitan-Level and Neighborhood-Level Urban Form Characteristics on Travel Behavior. *The Journal of Transport and Land Use*, Vol. 4, No. 1, 2011, pp. 25–44.