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Promoting active student travel: A longitudinal study

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ABSTRACT

This study investigates the effects of sidewalk modification and bike lane accommodation on students' active travel to schools. The modeling framework assumes that a student's choice for the mode of travel to school is impacted by numerous factors such as neighborhood crime rates, traffic safety, built environment amenities, and socio-demographic factors. A generalized linear model is employed to capture longitudinal changes in the mode share of students who walk or bike to school based on data collected from 53 schools in the city of Seattle, Washington. The modeling results indicate that (1) enhanced sidewalk modifications and bike lane accommodations encourage students walking and biking to school; (2) the implementation of Seattle's student assignment plan helps promote students walking to school possibly due to the change from school choice to neighborhood-based school assignment; (3) the size of the school attendance area is not significantly correlated with students' active travel activities, while the size of school enrollment is negatively associated with walking; (4) in school areas with high employment density, biking to school may be a more attractive option for students; (5) greater crosswalk density may encourage more students to walk to school; (6) the density of bike crashes is negatively associated with students biking to school. In terms of policy implications, transport planners should continually promote walking and biking supportive environments and implement policies to encourage active student travel.

1. Introduction

Existing research suggests that physical activity of all kinds plays an important role in promoting the health of school-age children (Pate et al., 2006). Conversely, a lack of physical exercise may increase the risk of chronic diseases, especially obesity-related diseases (Popkin et al., 2006), and may increase the likelihood of diabetes and cardiovascular diseases later in life (Goran et al., 2003). The United States (US) Department of Health and Human Services recommends that children engage in at least 60 min of physical activity each day (The U.S. Department of Health and Human Services, H, 2008). Walking or biking to school is an easy way to engage in physical activity and may promote better focus in the classrooms (Singh et al., 2012).

The Safe Routes to School (SRTS) program is a national initiative that aims to encourage school-age children to walk or bike to school by making walking and biking safer and more appealing (Safe routes to school national partnership, 2016). As part of SRTS programs, community stakeholders facilitate both infrastructure projects and non-infrastructure related projects. Interventions are usually categorized as one of the 4Es: engineering, education, encouragement, and enforcement. Engineering interventions are infrastructure improvement projects that enhance the travel environment that students use to walk and bike to school. These improvements might include sidewalk improvement, traffic calming, street crossings, and bike facilities. The engineering approach is the focus of this study. Non-infrastructure interventions include education, encouragement, and enforcement programs, such as students' active commuting skill promotion, public awareness campaigns of active commuting benefits, increased police presence to enforce speed limits in the vicinity of schools (McDonald et al., 2014a).

To date, SRTS have already played an important role in promoting active student travel. From 2005 to 2012, the US Congress created federal SRTS programs to implement necessary improvements to promote active school travel (AST). By June 2012, the US Congress passed a bill called MAP-21, which combine SRTS programs with local bicycle/pedestrian master planning actives, namely Transportation Alternatives Programs (TAP) (Safe routes to school national partnership, 2016). This act avoids repeated investment between SRTS programs and bicycle/pedestrian master plans. In December 2015, the US Congress passed another bill called Fixing America's Surface Transportation Act (FAST),

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which preserves SRTS programs' funding for the next five years (Safe routes to school national partnership, 2016). This act further highlights the importance of SRTS programs. Understanding the effect of completed SRTS projects on AST is therefore essential for policymakers to effectively lead future programs.

However, SRTS programs have not been entirely successful. Parents often still drive their children to school due to concerns about transportation safety (Evers et al., 2014; Oluyomi et al., 2014; Seraj et al., 2012). In addition, walking to school is not attractive for many students because schools are located far from student homes and a distance > 1 mile discourages walking for most school children (Beck and Nguyen, 2017; Coughenour et al., 2017; Deka, 2013; Gropp et al., 2012; Hatamzadeh et al., 2016; Lee et al., 2013; McDonald, 2008a; Müller et al., 2008; Rodríguez-López et al., 2017; Schlossberg et al., 2006). Moreover, the probability of walking or biking to school is much greater if the average travel time is < 15 min (Larouche et al., 2014) which is often not the case for students.

In terms of research that examines AST and SRTS programs directly, there are two major lines of research examining school travel. Many recently published studies focus on individual or household factors, such as parental preferences, the age and/or grade and the gender of school children, and the difficulty of walking and biking (Ahern et al., 2017; Gropp et al., 2012; Lang et al., 2011; Mammen et al., 2014; Mehdizadeh et al., 2017; Trapp et al., 2011), and many have employed interview or attitudinal survey for data collection (Ahern et al., 2017; Benson and Scriven, 2012; Mammen et al., 2012; McDonald et al., 2011; Seraj et al., 2012; Spinney and Millward, 2011). The other set of studies focuses on location-based factors, and largely rely on discrete choice models to examine contributing factors (Ermagun et al., 2015; Kamargianni and Polydoropoulou, 2013; Sidharthan et al., 2011). Additionally, most of these studies are cross-sectional, therefore very few studies have examined SRTS/AST in the terms of built environment interventions over prolonged periods of time (Gallimore et al., 2011). However, a few studies have suggested a positive relationship between implementation of SRTS programs and student AST (Atteberry et al., 2016; Buckley et al., 2013; Hoelscher et al., 2016; McDonald et al., 2013; Mitra and Buliung, 2014; Stewart et al., 2014), but overall robust evaluations of SRTS programs remain limited (Boarnet et al., 2005b; Cradock et al., 2012; Dumbaugh and Frank, 2007; McDonald et al., 2014b; Ragland et al., 2014).

This study contributes to the SRTS/AST literature in the following ways. First, it is a longitudinal study based on twelve-years of student travel records, which helps evaluate whether pedestrian and bicycle master plans have successfully promoted AST. Second, this study explores the effect of various features on student mode choice. This study begins with a literature review, followed by the research design and methodological details, then presents the results, and ends with discussion and conclusions. Findings from this study will assist policymakers future pedestrian/bicycle master plans, provide urban planners with effective ways to gradually alter the built environments, and promote a better environment that meets children's AST needs.

2. Literature review

2.1. Modeling frameworks

In response to various negative impacts of automobile-oriented development, researchers have produced a large amount of studies identifying determinants of travel mode choices: some of which concern the promotion of AST and SRTS programs for children. These studies analyze a wide variety of factors, including social, cultural, individual/household, and physical environmental elements. Several frameworks have been proposed to explain decision making in terms of travel mode. For instance, McMillan proposed a five-level model for the decision-making process of primary school students' AST, where urban form is identified as the key in parental perceptions of the relevant environment (McMillan, 2007). Building on McMillan's work, Panter et al. expanded on the analysis by including location-based neighborhood characteristics such as origins, destinations, and routes (Panter et al., 2008). Stewart et al. (2012) synthesize previous findings on AST and propose a conceptual framework consisting of eight groups of factors related to school children walking or bicycling to school, including distance to school, parental fear of traffic and crime, schedule constraints, value, weather, school characteristics, resources, and culture. Mitra (2013) reviewes related literature and proposes a framework of multiple levels of influence on mode choice for school transportation, including urban environment, household, characteristics of a child/youth, and other external factors. However, most studies do adopt a simplified framework by jointly focusing on individual/household and environmental factors (Atteberry et al., 2016).

2.2. Quantifying the built environment at different scales

Previous studies have examined the impact of built environments on school travel at different scales. Most previous research explores the relationship at the site-level, referring to areas nearby school or homes, but some studies have been implemented at the area-level, such as census tracts (Ewing et al., 2004; McDonald, 2008b) and traffic analysis zones (TAZs) (Mitra and Buliung, 2014); while several other studies are conducted as a corridor-level analysis, where the analysis unit is defined as the area along a home-to-school path. Among site-level studies, the buffer size quantifying the built environment varies, but the most commonly used buffer distances range from 250 m to 1000 m, based on the concept of normal walking distance. However, the appropriate analytical unit or units may depend on the target population or environment and may require empirical evaluation (Brownson et al., 2009).

2.3. Built environment factors associated with active school travel

Many studies have examined the effects of built environment factors on AST. While the results have some noticeable inconsistencies; several factors are commonly identified as key to explaining student preference for walking and bicycling. Distance to school is the most important factor in determining walking or bicycling among students. Even for students who live within a walkable or bike-able distance to school, distance acts as a strong determinant, influencing the likelihood of walking and biking (Stewart et al., 2012).The effect of density on school children AST has also been repeatedly examined. Many studies have suggested that either household density or population density is positively associated with AST (Broberg and Sarjala, 2015; Deka, 2013; Frank et al., 2007; Kerr et al., 2006; Kweon et al., 2006; McDonald, 2007, 2008b; Mitra et al., 2010). For example, Frank et al. collects AST choice data using a two-day travel diary of 3161 students and finds that the odds of walking are 3.7 times greater for students living in high-density neighborhoods comparing with those living in low-density ones (Frank et al., 2007). While some other studies (Bringolf-Isler et al., 2008; Ewing et al., 2004) suggest that household density is unrelated to student AST.

Existing studies show conflicting evidence in regard to the effect of mixed land use on student AST. Some studies find that students living in neighborhoods with high degrees of land use mixture are more likely to walk or bike to school (Broberg and Sarjala, 2015; Hatamzadeh et al., 2016; Lin and Chang, 2010). A few other studies suggest that only the land use mixture near schools is positively correlated with AST choices, while land use mixture near homes shows no significant effect (Larsen et al., 2009; McMillan, 2007). Still, other studies suggest there is no significant relationship between land use mixture either at home or school and student AST (Kerr et al., 2006; Mitra and Buliung, 2014).

Good street-connectivity contributes to the directness of routes as well as the ease of path-finding, hence encouraging walking and bicycling. Different methods have been applied to measure street-

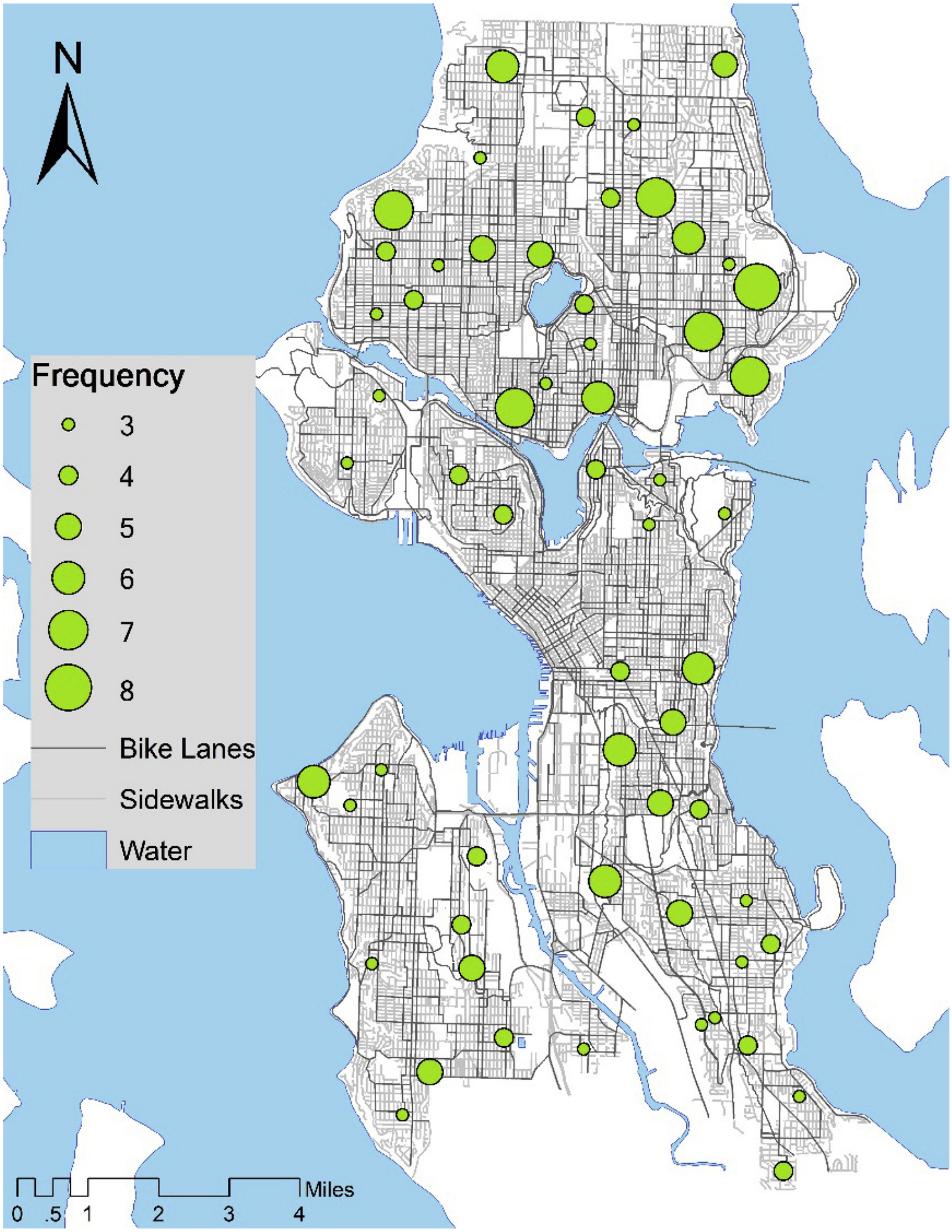

Fig. 1. Survey response frequency (≥3) of Seattle's 53 selected public schools, 2005–2016.

connectivity, including street dead-end density (Kweon et al., 2006; Schlossberg et al., 2006), intersection density (Broberg and Sarjala, 2015; Kerr et al., 2006; Kweon et al., 2006; Mitra et al., 2010; Mota et al., 2007; Schlossberg et al., 2006), average block size (Lin and Chang, 2010; McDonald, 2007), length of street segments (Bringolf-Isler et al., 2008; Yarlagadda and Srinivasan, 2008), and street centerline density (Ewing et al., 2004). Findings from these studies are also conflicting. Some report that AST is positively correlated with intersection density (Kerr et al., 2006; Mitra et al., 2010; Mota et al., 2007; Schlossberg et al., 2006) and negatively correlated with street dead-end density (Kweon et al., 2006; Schlossberg et al., 2006), while the others show no evidence of significant association (Ewing et al., 2004).

Finally, a few studies have examined the effect of non-motorized road infrastructures on student AST mode choice. The sidewalk coverage of a neighborhood (Ewing et al., 2004) and sidewalk modifications (Boarnet et al., 2005a) are positively associated with student AST, while the effect of bike infrastructure appeared to be insignificant. A study conducted in California suggests that the total length of bike lanes within a 400-m buffer near homes is not significantly associated with a difference in AST (Yarlagadda and Srinivasan, 2008). Similarly, another study assesses five state SRTS programs and finds that bike infrastructure improvement has no statistically significant effect on increasing the rate of biking to school (Stewart et al., 2012). Another study indicates that route conditions (including the presence of steep hills, speed and traffic, and insufficient daylight in the morning, etc.) have an effect on mode choice (Chillón et al., 2014). Lastly, an additional study looks at similar variables related to the comfort and attractiveness of the travel route, such as the presence of parks and

Table 1
Seattle's sidewalk and bike lane annual changes in total and near schools.

Year	Sidewalk modification in mile & percentage		Sidewalk modification near schools in mile			Bike lane accommodation in mile & percentage		Bike lane accommodation near schools in mile		
			¼-mile	½-mile	1-mile			¼-mile	½-mile	1-mile
2005	0.00	0.00%	0.00	0.00	0.00	0.00	0.00%	0.00	0.00	0.00
2007	0.00	0.00%	0.00	0.00	0.00	24.11	5.81%	5.34	15.63	23.99
2008	1.72	0.05%	0.00	0.92	1.72	31.10	7.09%	3.46	12.38	28.20
2009	8.45	0.27%	2.67	5.43	7.66	29.71	6.32%	5.02	18.62	27.43
2010	466.07	14.8%	82.88	260.32	421.46	19.79	3.96%	2.74	11.13	19.28
2011	89.11	2.83%	15.00	46.86	80.68	14.39	2.77%	2.15	7.67	12.96
2012	32.78	1.04%	7.93	21.11	29.49	17.56	3.29%	5.17	14.40	24.70
2013	28.28	0.90%	3.89	16.68	25.29	0.00	0.00%	0.00	0.00	0.00
2014	5.58	0.18%	0.30	1.47	5.06	4.71	0.85%	0.44	2.19	4.71
2015	35.76	1.14%	4.54	17.48	33.56	12.52	2.25%	4.16	11.10	12.52
2016	230.63	7.33%	33.12	129.12	221.54	6.80	1.20%	1.48	3.74	6.57
2017	142.30	4.52%	34.47	101.66	139.21	8.82	1.53%	1.25	6.57	8.71

Source: Seattle's ‘pedestrian master plan’ and ‘bicycle master plan’.

sidewalk maintenance, and again finds that the overall quality of walking and biking environments helps promote AST (Larsen et al., 2012; Lee et al., 2013).

2.4. Traffic safety and environment security correlated with active school travel

Traffic calming strategies promote AST, and this positive effect has been continually confirmed by many studies (Larouche et al., 2014). Traffic calming improvements include the installment of traffic signals, stop signs, speed bumps, and traffic circles, the improvement of crosswalks, and the isolation of pedestrian/bicycle traffic from road traffic (Boarnet et al., 2005b; Dumbaugh and Frank, 2007). A high crime rate discourages students walking and biking to school (Deka, 2013; Larouche et al., 2014; Loukaitou-Sideris, 2006). Fear of strangers is a key deterrent discouraging walking to school (Schlossberg et al., 2006).

3. Research design

3.1. Research objective

Though AST mode choices have been examined, existing studies rarely investigate the longer-term effect of implementing pedestrian/bicycle plans. Some effects resulting from non-motorized infrastructure changes may not be observed in the short term, and previous cross-sectional studies using short-term observations may have biases in terms of understanding the intervention of pedestrian/bicycle plans. Therefore, this study initiates a longitudinal analysis to evaluate the influence of pedestrian and bicycle master plans. The objective of this study is to identify factors associated with changes in walking and biking mode share among school-age children.

3.2. Study area and data source

Washington's SRTS program was initiated in 2005. Since then, the Washington Department of Transportation has awarded almost $71 million to fund SRTS projects for 271 schools (Washington State Department of Transportation, 2017). Preliminary results suggest a 40% increase in student pedestrians and bicyclists (National Center for Safe Routes to School, 2017). The city of Seattle also works to promote AST over and above WSDOT efforts. As an example, the Seattle Department of Transportation (SDOT) completed 18 SRTS engineering projects at priority schools in 2015 (Seattle Department of Transportation, 2016). In addition to SRTS programs, Seattle has implemented a pedestrian master plan (PMP) and a bicycle master plan (BMP) to encourage walking and biking. SRTS programs have been integrated into the PMP and BMP implementation schedules.

In this study, the AST data was obtained from a twelve-year student travel survey, where students were asked their primary transportation mode for home-to-school travel, collected by the Seattle Department of Education and Early Learning (SDEEL) and SDOT. Samples were randomly drawn from public school children. To date, the data covers twelve years, including 2005, 2007, 2008, 2011, 2013, 2014, 2015, and 2016. However, not all schools continually participated in the survey. In total, 75 schools participated, but only 57 of them have responded more than three times, and only 53 of them have other student-related information documented and available, such as enrollment, race, and gender, as shown in Fig. 1. To estimate the longitudinal effects, only schools with at least three observed moments and with student-related information, are included in the final models.

The data used in this analysis was only collected from public schools. Furthermore, schools are divided into elementary schools, middle schools, high schools, alternative schools (which includes schools for special needs students, such as disabled children), and service schools (schools that meet specific demands, such as college preparation and personalized interests). The data used in this study was collected from elementary schools (K-5) or elementary and middle school (K-8) students.

This study considers a large set of variables, including land use, road network, street elements, traffic safety, crime rates, and socio-demographic factors. Since the analytical unit is the school, this study cannot adjust for individual, household, home-based, or path-based characteristics associated with AST. Built environment variables, including land use, road network, and street elements, are collected by the Puget Sound Regional Council (PSRC) and SDOT. Historical crime and collision data are collected by Seattle Police Department. The socio-demographic data are based on the State of Washington's OSPI Office of Superintendent of Public Instruction (WS OSPI) and American Community Survey data (ACS).

While built environment and socio-demographic factors around each school are continually changing, such changes are usually small. Therefore, most changes are well controlled across time. However, because of Seattle's ambitious implementation of the pedestrian master plan and bicycle master plan over the years, noticeable changes have been occurring to sidewalks and bike lanes since 2007. Table 1 presents the annual changes in terms of sidewalk modification[1] and bike lane accommodation[2] in Seattle.

In terms of crimes, threats and assaults that may occur along student routes to school are of great parental concern. However, this study only

[1] Sidewalk modification refers to improvements made on streets for walking, such as providing sufficient right-of-way, connecting to the existing sidewalk network, removing topographic limitations, promoting pedestrian safety, and replacing pavement.

[2] Bike lane accommodation refers to improvements made on streets for biking, such as adding cycle tracks, separated/buffered bike lanes, and markings for bicycle boulevards.

Table 2
Mean of crimes and crashes near school over years.

Year	Pedestrian crashes			Bike crashes			Threats		
	¼-mile	½-mile	1-mile	¼-mile	½-mile	1-mile	¼-mile	½-mile	1-mile
2005	152.87	192.36	201.91	392.36	356.69	355.73	20.45	20.00	18.43
2007	244.59	252.23	251.59	264.97	337.58	346.18	19.26	23.24	21.40
2008	219.11	275.16	264.01	305.73	294.27	316.88	21.18	20.23	18.53
2011	259.87	258.60	250.96	259.87	304.46	298.09	19.06	21.11	19.13
2013	208.92	275.16	278.66	224.20	310.83	306.69	21.77	25.06	22.76
2014	270.06	276.43	283.76	371.97	349.04	346.18	20.71	22.70	21.26
2015	280.25	345.22	334.08	336.31	328.66	358.60	17.60	22.05	21.10
2016	300.64	305.73	296.82	346.50	370.70	372.61	23.89	34.30	32.16

Pedestrian crashes: the number of historical pedestrian crashes per year per area, in counts per sq. mile.
Bike crashes: the number of historical bike crashes per year per area, in counts per sq. mile.
Threats: the number of historical threats per year per area, in 10^3 per sq. mile.

Table 3
Mean of student-related time varying variables: race, gender, enrollment, and free meals.

Year	White student	Black student	Asian student	Latino student	Indian student	Male student	Enrollment	Free or reduced-price meals
2005	45.24%	19.40%	20.84%	12.55%	1.96%	51.33%	351.11	41.88%
2007	46.80%	17.58%	20.83%	12.99%	1.80%	51.54%	366.56	40.68%
2008	47.38%	17.46%	20.55%	12.79%	1.76%	51.73%	377.15	41.33%
2011	46.05%	16.05%	16.17%	13.41%	0.84%	51.20%	398.61	42.59%
2013	45.64%	15.87%	15.02%	13.52%	0.59%	50.86%	403.93	43.03%
2014	45.88%	15.62%	14.37%	13.29%	0.55%	50.46%	404.03	42.07%
2015	45.86%	15.53%	13.74%	13.25%	0.45%	50.56%	403.28	40.76%
2016	43.77%	15.20%	13.31%	13.35%	0.41%	50.39%	406.17	39.74%

controls for threats and excludes assaults due to multicollinearity issues. To account for traffic safety, historical crash data has been employed to calculate pedestrian and bicycle crash frequency per area. Both crashes and crimes are measured as time-varying variables, as shown in Table 2.

Many street element variables were initially considered but excluded because of multicollinearity, such as traffic circle count, stop sign count, road signal count, and the presence of cameras, because they are mostly installed at intersections. As a convention, density, diversity (i.e. land use mixture), and design (i.e. intersection/crosswalk density) of the built environment are also included. The percentage of steep areas (slope > 40%), the density of street trees, and the percentage of recreational areas, are further included. Finally, as discussed, children living in larger neighborhoods are less likely to walk or bike to school due to the increment of travel distance and thus the attendance area of each school is included.

To adjust for socio-demographic factors, data obtained from WS OSPI are major inputs into the final models. Variables obtained from WS OSPI are coded as time-varying variables, as shown in Table 3, including the percentage of students of different races, the percentage of male students, the enrollment of each school, and the percentage of students having access to free or reduced-price lunch. Because of multicollinearity, only the percentages of white and black students, the percentage of male students, and annual enrollment are included. To attempt to account for income, the percentage of poverty households[3] is obtained from American Community Survey data (5-year).

3.3. Generalized linear model

This study fits a generalized linear model (GLM) to capture the longitudinal changes in the mode share of walking and biking to school. Statistical analysis is implemented with a R package called 'blme'. The GLM is expressed by Equations (Eqs.) (1) to (4). A conditional expectation function model can predict changes in the mode share of walking or biking at school i and occasion t. The school survey in total has 8 occasions from 2005 to 2016. This GLM has subject-specific intercepts and slopes, which allows the walking and biking rate at each school to vary by the initial mode share and the rate of change over time. Eq. (1) represents the level-1 model, which follows the traditional linear model specification. The level-2 model estimates the fixed effects and the random effects that depart from group-specific changes with subject-specific intercepts and slopes that are estimated from the level-1 model, as shown in Eqs. (2) and (3). The composite model is specified by Eq. (4).

$$Y_{it} = \beta_{0i} + \beta_{1i} Time_{it} + \varepsilon_{it} \tag{1}$$

$$\beta_{0i} = \beta_{00} + \beta_{0i} X_{it} + \zeta_{0i} \tag{2}$$

$$\beta_{1i} = \beta_{10} + \beta_{1i} X_{it} + \zeta_{1i} \tag{3}$$

$$Y_{it} = \beta_{00} + \beta_{0i} X_{it} + \beta_{10} Time_{it} + \beta_{1i} X_{it} Time_{it} + \zeta_{0i} + \zeta_{1i} Time_{it} + \varepsilon_{it} \tag{4}$$

where β_{0i} and β_{1i} are the estimated parameters that vary across schools i; μ_{it} is the mean of walking and biking mode share at the 53 schools over the 8 occasions t; β_{00} is the overall intercept; $Time_{it}$ is a level-1 time variable, with the fixed effect parameters β_{1i}. X_i refers to the fixed effects; X_i*$Time_{it}$ is the cross-level product for time changes that interact with the fixed effect parameters β_{1i}. The composite error is made of $\zeta_{0i} + \zeta_{1i} Time_{it} + \varepsilon_{it}$, *where* ζ_{0i} and ζ_{1i} are random effects of each subject that depart from group-averaged intercept and slope, and ε_{it} is the error term. In this study, only time-varying variables, cumulative sidewalk modification or bike lane accommodation, threats, and crashes, are included for modeling the cross-level interaction effects.

This study estimates elasticity of significant variables. Direct elasticity and arc elasticity formulas for continuous and discrete variables for the generalized linear models are as follows (Ewing and Cervero, 2010; Train, 2003):

$$E_{Direct} = \overline{\beta} * \frac{\overline{X}}{\overline{Y}} \tag{5}$$

[3] Poverty (US Census): People who live in households with low income are in poverty. "Income thresholds by the official poverty measure are established by tripling the inflation-adjusted cost of a minimum food diet in 1963 and adjusting for family size, composition and the age of the householder."

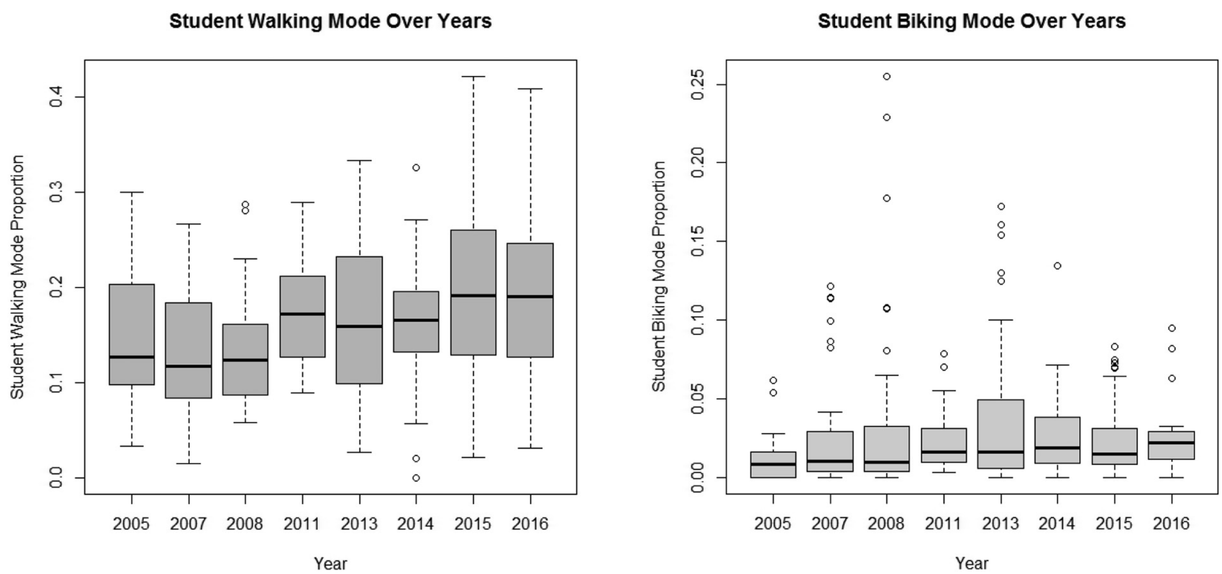

Fig. 2. Proportions of student walking and biking to school in Seattle, Washington, 2005–2016.

$$E_{Arc} = \frac{P_{X=1} - P_{X=0}}{P_{X=1} + P_{X=0}} \quad (6)$$

4. Results

4.1. Descriptive analysis

91.39% of surveyed schools were either elementary (K-5) schools or elementary and middle (K-8) schools. As shown in Fig. 2, the mode share of student walking and biking to school generally increases over time. The mean number of students walking to school increased from 15.01% in 2005 to 18.82% in 2016, and the mean of students biking to school increased from 1.33% in 2005 to 2.49% in 2016. The average percentage of students walking to school (16.39%) is much higher than the percentage of adults walking to workplaces (6.82%), while the mode share of students biking to school is like the level of adult commuting by bikes.

This study considers three buffer sizes to quantify the built environment near schools which are 0.25-mile, 0.5-mile, and 1-mile buffers. As shown in Table 4, the values of some built environment such as the density of sidewalk modification and bike lane accommodation, intersection/crosswalk density, street tree density, and school bus stop density decrease from the 0.25-mile buffer to the 1-mile buffer. This indicates non-motorized infrastructures are generally better provided near schools. Finally, the values of some density measures increase with a change of buffer sizes, such as the percentage of recreational land and land use mixture.

Built environment variables	¼-mile		½-mile		1-mile		Description	Source	Year
	Mean	S.D.	Mean	S.D.	Mean	S.D.			
Sidewalk increment	4.17	9.26	3.96	7.07	3.45	5.32	The annual sidewalk modification since 2005, in mile per sq. mile	SDOT	2017
Bike lane accommodation	6.15	3.69	5.51	2.95	4.91	2.57	The accumulative bike lane accommodations since 2005, in mile per sq. mile	SDOT	2017
Number of school bus stops	43.80	30.93	14.78	8.66	10.88	5.90	The number of school bus stops, in counts per sq. mile	SDOT	2016
Number of street trees	1.73	1.23	1.61	0.96	1.40	0.73	The number of street trees, in 103 per sq. mile	SDOT	2016
Number of crosswalks	66.49	36.75	50.83	33.60	48.40	35.14	The number of marked crosswalks, in counts/sq. mile	SDOT	2016
Number of intersections	0.22	0.07	0.20	0.06	0.17	0.05	The number of intersections, in 103 per sq. mile	SDOT	2016
Percent of steep areas[a]	10.34	11.05	6.36	4.63	6.01	2.88	The percent of steep areas, in % (0–100)	SDOT	2016
Recreational land use	0.02	0.02	0.08	0.07	0.37	0.23	The proportion of recreational land use near school (0–1)	PSRC	2010
Land use mixture	0.40	0.13	0.44	0.13	0.49	0.12	The entropy of four types of land use, including residential, commercial, recreation, and offices (0–1)	PSRC	2010

SDOT: Seattle Department of Transportation.
PSRC: Puget Sound Regional Council.
[a] Seattle's Design & Planning Department designates slopes greater than or equal to 40% are counted as steep areas.

Table 4
Data summary and variable description.

Variables	Mean	S.D.	Min.	Max.	Description	Source	Year
Walking to school	16.39	7.34	1.49	42.12	The percentage of walking mode share among school children, in % (0 − 100)	SDEEL	2016
Biking to school	2.79	3.90	0.00	25.50	The percentage of biking mode share among school children, in % (0–100)	SDEEL	2016
Year	6.39	3.75	1.00	12.00	The survey has implemented in 2005, 2007, 2008, 2011, 2013, 2014, 2015 and 2016, coded for 1, 3, 4, 7, 9, 10, 11, 12.		
Student assignment plan	0.51	-	0.00	1.00	Seattle Public Schools Board of Directors approved a Student Assignment Plan in 2009, which changed school assignment policy from a school choice to a neighborhood-based one as of 2010. The policy states: "unless the school designated by a student's home address does not have the appropriate services, the student shall be assigned to a school that has the appropriate services." This policy potentially contributes to travel distance reduction of school trips.		
School type	0.09	-	0.00	1.00	If it is an elementary (K-5) 0; else elementary-middle school (K-8), 1	SDEEL	2016
Commute by walking	0.06	0.08	0.00	0.33	The proportion of employers walking to workplace (0–1)	ACS	2015
Commute by biking	0.03	0.03	0.00	0.15	The proportion of employers biking to workplace (0–1)	ACS	2015
Poverty proportion	0.13	0.11	0.00	0.59	The proportion of poverty households in the census block group (0–1)	ACS	2015
Attendance area	1.48	0.69	0.40	3.54	The attendance area of each school, in sq. mile	SDEEL	2014
Household density	3.73	2.30	0.34	12.99	The number of households in the census block group, in 10^3 per sq. mile	PSRC	2015
Employment density	4.75	3.77	0.81	18.57	The number of jobs in the census block group, in 10^3 per sq. mile	PSRC	2015

SDEEL: Seattle Department of Education and Early Learning
PSRC: Puget Sound Regional Council
ACS: American Community Survey

4.2. Inferential analysis

As shown in Table 5, the modeling outcomes of the three models for student walking are broadly consistent. Even though the percentage of students walking to school is negatively associated with annual sidewalk modification, it is positively correlated with accumulation of sidewalk modifications over the years. This indicates that despite the fact that the amount invested in sidewalk improvement declined over the years, it creates a strong accumulative effect in terms of promoting students walking to school. This reflects the joint effect of SRTS programs and pedestrian master plans on student access to school by walking. In addition, the policy interventions that occurred during the research period, noted by the student assignment plan, show a significant positive relationship with the percentage of students walking to school. Another interesting finding is that the annual enrollment of students is negatively correlated with the percentage of students walking to school. In addition, K-5 school students are more likely to walk to school as compared to students from K-8 schools. A greater crosswalk density is associated with a greater percentage of students walking to school within ¼ mile from the school. Pedestrian crashes are less likely to happen near schools. The values of intra-class correlation (ICC) for the three models range from 29% to 32%. This indicates that temporal autocorrelations across multiple-year data are not large in this study.

None of the estimated elasticities are great than 1.0, indicating that the effect of abovementioned strategies alone that contribute to the growth of students walking to school is minor. However, the joint effect of various strategies cannot be ignored. It is worth noting that a 1% increase in sidewalks over time is associated with a 0.10–0.20% increase in the share of students walking to school. The implementation of the student assignment plan is associated with a 0.1% increment of students walking to school. Additionally, a 1% increase in crosswalk density is associated with a 0.18–0.27% increase in students walking to school. Comparatively speaking, modifying sidewalks and densifying crosswalks seems like the most efficient means of encouraging students to walking to school.

Table 6 presents the modeling outcome on student biking to school. First and foremost, bike lane accommodation creates a positive effect in terms of encouraging students to bike to school. However, over the years, the accumulative effect of bike lane accommodation seems not as pronounced. In areas with a higher employment density, students are more likely to bike to school. In school areas with a higher household density, students are less likely to bike. The density of historical bike collision has a negative effect on student biking to school, and such an effect is only marginally significant when the buffer increases to 1-mile distance. In terms of race, the percentage of white students is positively associated with an increased mode share of students biking to school. As for gender, the greater percentage of male students the greater the mode share of students biking to school. Finally, the ICC values of the bike models are 32% to 33%, which suggest that temporal autocorrelations over years do not create strong effects on various fixed effects.

Regarding calculated elasticities, a 1% increment in bike lane accommodation is associated with a 0.38–0.44% increment of students biking to school. However, the effect of the student assignment plan on students biking to school is not significant.

5. Discussion

As the above models show, crime, traffic safety, built environments, and socio-demographics jointly impact student walking and biking to school. Non-motorized infrastructure-related factors and the policy variable are key focuses in this study. Over multiple years, both accumulative sidewalk modification and bike lane accommodation present positive effects in terms of promoting student AST. Such results confirm that the efforts to improve AST are effective. In addition, densifying crosswalks create positive effects on students walking to school. Seattle's school assignment plan circa 2009, seems to create a strongly positive effect in terms of encouraging student walking to school. In sum, the joint effort of SRTS program, bicycle/pedestrian master plans, and Seattle's school assignment plan highly conducive in promoting students walking to school.

This study also investigated several other time-varying variables, including crimes rates and crashes per year per unit area, and demographic-related variables, such as enrollment and gender. The first hypothesis was that security and safety concerns may discourage students from walking or biking to school. However, the effects of historical crimes (threats) are insignificant. In terms of collisions, if the unit of analysis for biking is increased to 1-mile, student bike mode share is negatively associated with bike collision density. Also, this study assumes that the rate of students walking and biking to school is lower in neighborhoods with a larger attendance area or a greater enrollment due to an increased travel distance. Such a relationship is verified for walking but remains unclear for biking. As expected, the

Table 5
Factors correlated with student walking to school.

Fixed Effects	¼ mile buffer			½ mile buffer			1-mile buffer		
	Estimate	T value	Elasticity	Estimate	T value	Elasticity	Estimate	T value	Elasticity
Intercept	19.155***	3.281		21.298****	3.597		19.311***	3.202	
Year	−0.205	−0.183		−0.050	−0.044		−0.048	−0.043	
Sidewalk increment	−0.448**	−2.319	−0.119	−0.531**	−2.039	−0.127	−1.083***	−2.780	−0.226
Pedestrian crashes per area	−0.177*	−1.666	−0.036	−0.178	−1.014	−0.039	−0.317	−0.867	
Threats per area	0.749	0.105		−0.915	−0.126		−0.569	−0.078	
White Pct.	−0.451	−0.137		−0.792	−0.225		2.075	0.559	
Black Pct.	−6.216	−1.301		−5.793	−1.177		−4.785	−1.004	
Male Pct.	0.459	0.068		0.655	0.096		−0.159	−0.024	
Enrollment	−0.020**	−2.369	−0.481	−0.020**	−2.258	−0.469	−0.018**	−2.153	−0.435
Student assignment plan	4.194***	2.910	0.006	4.457***	2.913	0.006	5.909****	3.441	0.009
School bus stop density	−0.017	−0.642		0.002	0.019		−0.163	−1.000	
Attendance area	0.825	0.769		−0.206	−0.183		−0.659	−0.623	
Street tree density	0.578	0.847		1.198	1.278		0.668	0.416	
Crosswalk density	0.065**	2.430	0.273	0.041	1.385		0.058*	1.852	0.175
Commute by walking	−0.496	−0.077		0.616	0.094		1.338	0.206	
Poverty proportion	−3.742	−0.702		−1.326	−0.256		−2.317	−0.450	
Household density	0.258	0.655		−0.007	−0.019		0.052	0.134	
Employment density	−0.032	−0.151		−0.130	−0.608		−0.102	−0.471	
Steep area Pct.	−0.059	−0.748		0.099	0.559		0.250	1.015	
Recreational Pct.	−1.594	−0.222		−1.012	−0.156		−0.529	−0.147	
Land use mix	−3.361	−0.694		−3.013	−0.570		2.616	0.438	
School type	−7.538***	−3.115	−0.012	−7.659***	−3.031	−0.011	−7.692***	−3.080	−0.007
Year*Sidewalk increment	0.063***	2.782	0.107	0.075***	2.574	0.115	0.119***	2.786	0.203
Year*Ped. crashes per area	0.019	1.209		0.034	1.540		0.063	1.334	
Year*Threats per area	0.832	0.257		−1.119	−0.349		−4.398	−0.844	
Year*White student Pct.	0.107	0.214		0.063	0.124		−0.198	−0.388	
Year*Black student Pct.	−0.802	−0.726		−0.815	−0.731		−0.923	−0.827	
Year*Male Pct.	−0.757	−0.456		−0.676	−0.410		−0.609	−0.383	
Year*Enrollment	0.001	0.892		0.001	0.502		0.001	0.506	

Level of significance: "****", 0.1%; "***", 1%; "**", "5%"; and "*" for "10%".

Random effects							
Groups		Variance	S.D.	Variance	S.D.	Variance	S.D.
School ID	Intercept	15.754	3.969	16.840	4.104	16.758	4.094
	Year	1.679	1.296	1.735	1.317	1.739	1.319
	Residual	8.499	2.915	8.656	2.942	8.507	2.917
Intra-class Correlation		−0.32		−0.29		−0.30	

gender difference among students is not significant for walking, but significant for biking to school.

Lastly, we find that students from schools located in areas with greater employment density usually are more likely to bike to school (Broberg and Sarjala, 2015). In areas of greater employment density, traffic speed is generally lower, and bike lanes are better planned and provided, which contributes to a safer environment for student biking. Crosswalk placement is a cogent part of street connectivity, which is helpful in promoting student walking to school which this study demonstrates.

6. Limitations and future research

A noticeable limitation of this study is bias in school selection. First, the included schools are all public schools, which leaves students of private schools undiscussed. Students who attend private schools are often from households with higher income and better parental education, and their parents may be more encouraging of healthy activities like walking and biking. How walking and biking to school might change for private school students remains unanswered. Similar studies need to be done if private school student travel data can be obtained. Second, the survey assigns a much greater weight to elementary school students. The findings of student biking to school are therefore somewhat biased towards younger children. Future surveys should work to include more middle school and high school students. Third, as noted in Fig. 2 and Table 4, the maximum percentage of students biking to school is 25.50% (in 2008), which is roughly ten times the mean. This may be due to inconsistencies in data collection or survey administration such as different ways of invoking students to respond, the surveyors' unclear definitions, or some students wanting to advocate sustainable transportation. Yet, there is no clear way to net out inaccurate cases which creates bias in the data. In the future, careful instruction of surveyors should control these types of errors. Fourth, this paper uses area-level averages to infer relationships among various factors for specific sites. Such a design means that factors and outcomes are averaged for the population in each geographical or temporal unit. Although this study is valid for hypothesis generation, it is not considered valid for hypothesis testing regarding area-level variables because of unmeasured and uncontrolled confounding variables (Cohen, 2005; Freudenheim, 1999). Fifth, the modifiable areal unit problem (MAUP) may contribute to the inconsistency between findings (Mitra and Buliung, 2014). MAUP is defined as a source of spatial bias when analytical results are sensitive to changes of scale and zoning of units that are used to measure the built environment (Mitra and Buliung, 2014; Parenteau and Sawada, 2011). In such a context, the relationship between independent and dependent variables may vary largely across space and thus one analytical unit cannot be representative for the entire analysis (Swift et al., 2008). Though this study tries to mitigate the impact of MAUP through careful research design under different spatial units (Parenteau and Sawada, 2011; Swift et al., 2008), it does not completely get rid of the risk of biased estimation resulting from MAUP.