The Built Environment and Walking to School: Findings from a Student Travel Behavior Survey in Massachusetts

A thesis submitted by

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Abstract

The percent of children who walk or bike (active commute) to school in the United States has dropped from 48% in 1969 to only 13% of students today. Rates of obesity among children have tripled during this period. Public health advocates have identified active commuting to school as a strategy that may increase children's daily energy expenditure. However, the ability of a school's potential to include active commuting can only be properly understood if attributes of the built environment are assessed. Based on a student travel behavior survey of 18,713 responses from 105 schools in Massachusetts, a multilevel model was used to investigate the effects of route, neighborhood, and school characteristics on walking to school. The model results suggest that the built environment affects prevalence of walking to school. Specifically, short routes along less-trafficked streets with mixed land use are associated with the increased odds of children walking to school.

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1. Introduction

The percent of children who walk or bike (active commute) to school in the United States has dropped from 48% in 1969 to only 13% of students in 2009 while the percent of K-8 students driven to school increased to 45% (McDonald, Brown, Marchetti, & Pedroso, 2011). At the same time, there have been declining levels of physical activity, a rise in childhood obesity, and growing car dependence across the country (Davison, Werder, & Lawson, 2008; Lee, Orenstein, & Richardson, 2008; McDonald, 2007a, 2007b). Evidence suggests that active school commuters engage in more physical activity than passive commuters, and are more likely to meet recommendations for daily physical activity (Boarnet, Day, Anderson, McMillan, & Alfonzo, 2005; Davison et al., 2008).

Most walking and biking programs in the United States commonly fall under the umbrella of Safe Routes to School (SRTS), a federally funded program administered by the U.S. Department of Transportation (USDOT) and State Departments of Transportation. SRTS seeks to promote activities that reduce traffic and air pollution around schools and make walking and biking to school an easier, safer choice (National Center for Safe Routes to School, 2011). SRTS involves both infrastructure and non-infrastructure interventions, as parent schedules and perceptions, household characteristics, the social and built environment, and real and perceived safety all influence a child's mode of transportation to school (Davison et al., 2008; Stewart, 2011; Stewart, Vernez Moudon, & Claybrooke, 2012). For example, Boarnet and colleagues (2005) found SRTS construction projects (e.g. installation or widening of bicycle lanes and crosswalks; and sidewalk improvements including installing sidewalks and/or curb ramps) are associated with in increased walking or bicycling to school for children who would pass these projects on their way to school. A non-infrastructure strategy of the walking school bus—a group of children led to and from school chaperoned by adults—addresses parental concerns for safety and encourages active commuting. Walking school buses have shown promise toward increasing children's active commuting and physical activity, and a pilot cluster randomized controlled trial found that the walking school bus improved children's active commuting to school and daily moderate-to-vigorous physical activity (Mendoza et al., 2011).

The SRTS program faces a great challenge. SRTS interventions can only affect the mode choice for children that live close enough to walk or bike to school. Across most studies, distance to school is a crucial factor in a child's mode choice (Davison et al., 2008; Larsen, Gilliland, & Hess, 2012; Stewart, 2011; Stewart et al., 2012), so a school's mode shift potential and actual impacts can only be properly understood if we control for the distance and attributes of the built environment. SRTS programs must work within the context of the school's built environment—this is not a factor that can easily be changed by a SRTS program. Therefore, by further understanding the built environment's role, SRTS programs may more effectively implement strategies that increase walking and biking to school. However, less is known about the influences of the built environment on mode choice among children, particularly along the route to school (Ewing, Schroeer, & Greene, 2004; Larsen et al., 2012), when compared to evidence on the built environment and adult walkability (Larsen et al., 2012).

This thesis used a Massachusetts student travel behavior survey to investigate the role of the built environment as a determinant of walking to school. Specifically, we investigated route, neighborhood, and school level characteristics associated with walking to school using a dataset of 18,713 student travel behavior survey responses from 105 schools (an average of ~178 survey responses per school). The results of the model suggest evidence that built environment affected prevalence of walking to school. Specifically, short routes along less-trafficked streets with mixed land use were associated with increased odds of children walking to school. Moreover, with future study, the model provides a useful method for comparing walk-to-school rates across heterogeneous schools and can provide performance metrics that control for built environment factors beyond the control of the SRTS program.

This thesis is organized into six chapters. In the next section, we review previous work on the built environment and school travel, with specific focus on route-based methods and multilevel models. We then report our spatial analysis and statistical modeling methods and our results. Finally, we discuss our results and the role of the built environment and school travel.

2. Literature Review

2.1 Built Environment and School Travel

The built environment—such as urban form, land use patterns, and street connectivity—has been associated with physical activity (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Handy, Boarnet, Ewing, & Killingsworth, 2002). There is robust evidence that neighborhood environmental features, such as the presence of sidewalks, destination accessibility, the configuration of the street system (network connectivity and intersection density), population densities, and mix of land uses have been associated with walking among adults (Brownson et al., 2009; Ewing et al., 2011; L. D. Frank et al., 2006; Handy et al., 2002).

Less is known about the influences of the built environment on travel modes among children (Ewing et al., 2004; McMillan, 2007). Children have fewer transportation options and are generally more dependent on their parents and household context (Larsen et al., 2012). Consequently, the evidence in child-focused studies is much more mixed than in adult studies. Intersection density, a common measure of network connectivity, has been found in some studies to be positively associated with walking and biking to school (Braza, Shoemaker, & Seeley, 2004; L. Frank, Kerr, Chapman, & Sallis, 2007; Schlossberg, Greene, Phillips, Johnson, & Parker, 2006), but negatively associated with active school commuting in other studies (Timperio et al., 2006). Another measure used in previous studies (Panter, Jones, Van Sluijs, & Griffin, 2010; Schlossberg et al., 2006; Timperio et al., 2006), is the directness of the route. Route directness is typically measured as the ratio of the straight line distance from home to school to the network distance from home to school (Schlossberg et al., 2006). Three studies have found that more indirect pedestrian routes are associated with walking to school (Panter, Jones, Van Sluijs, et al., 2010; Schlossberg et al., 2006; Timperio et al., 2006). While adult commuting may be strongly influenced by travel time, children's travel may be more strongly influenced by traffic safety concerns, therefore parents and children may seek out less-trafficked routes that are less exposed to traffic (Timperio et al., 2006).

Children who live in urban areas are more likely to actively commute to school than children living in rural areas (Davison et al., 2008). However, no clear connection exists between mixed land uses and children's commuting to school (Larsen et al., 2012), even though increased land use mix—which increases the number of potential destinations accessible by foot—is commonly associated with higher rates of walking among adults.

Both Timperio et al. (2006) and Schlossberg et al. (2006) excluded land use mix from their studies due to this weak connection to school commuting. However, McMillian (2007) and Frank et al. (2007) found that land use mix around the school was a positive predictor of walking, while Larsen et al. (2012) found that land use mix along the route to school was a negative predictor of walking. With such uneven findings, this measure needs further clarification and consistency in its application.

Real and perceived safety from traffic are important to child commuting behavior. Perceived traffic safety is commonly cited as one of parents' primary concerns about whether or not the child can take an active form of transportation, particularly young children (Evers, Boles, Johnson-Shelton, Schlossberg, & Richey, 2014). Despite this perception, in terms of actual crashes, McDonald and colleagues (2015) found that riding with a teenage driver is the most dangerous mode on a per trip basis (McDonald et al., 2015). Several previous studies have examined the presence of major roads as a proxy of real and perceived traffic safety (Schlossberg et al., 2006; Timperio et al., 2006; Zhou, Zhao, Hsu, & Rouse, 2009). In general, crossing or walking along major roadways is negatively associated with walking to school (Panter, Jones, Van Sluijs, et al., 2010; Schlossberg et al., 2006; Timperio et al., 2006). Additionally, past school commuting route studies have used pedestrian networks comprised of on- and off-road facilities (Easton & Ferrari, 2015; Larsen et al., 2012; Panter, Jones, Van Sluijs, et al., 2010).

Finally, the relative location of school, as measured by indicators such as shorter distances to school and greater population density in the immediate area of a school, have been linked with higher active commuting rates (Davison et al., 2008). However, the research on school enrollment appears to be mixed. Braza and colleagues (2004) found a negative association between school size and active commuting while Ewing and colleagues found no significant relationship (Braza et al., 2004; Ewing et al., 2004).

2.1.1 Individual and Social Characteristics

Much of the active commuting to school literature focuses on individual and social characteristics. Research shows that boys, Latino and Black children, and those of lower socioeconomic status are more likely to actively commute to school (Davison et al., 2008). The influence of the age of the child is mixed. As children age and gain independence, they may be more likely to actively commute. However, it is possible that when they get old enough, they may acquire their drivers' licenses and begin to drive themselves or ride with peers to school, which could produce the opposite effect (Babey, Hastert, Huang, & Brown, 2009; Davison et al., 2008). Having siblings is also associated with higher rates of walking and biking for high school students, but there is no significant effect for elementary students (McDonald, 2008).

Internationally, evidence suggests that car ownership is associated with less walking and more driving to school (Timperio et al., 2006). However, studies in the United States are less uniform. Studies have found a negative association between car ownership and walking to school (Ewing et al., 2004; Timperio et al., 2006), and studies have found no statistically significant relationship with household vehicle availability (Carlson et al., 2014; McMillan, 2007). This may be due to the high car ownership rates across all income levels in the United States (Larsen et al., 2012).

Whether children engage in active commuting to school is consistently associated with parental perceptions. Common parental concerns include neighborhood safety, traffic, distance to school, and busy schedules (Davison et al., 2008; Stewart, 2011; Stewart et al., 2012). Under the pressure of busy schedules and safety concerns, parents may default to the most convenient option, which is typically to drive their children to school on the way to work (Easton & Ferrari, 2015).

2.2 Methods in Previous Research

In this section, we review methods from previous research that were used to answer our research question about the route, neighborhood, and school characteristics associated with walking to school. Here, we primarily focus on route-based studies because objective measures of route characteristics are less studied in the literature, and the methodology is developing (Larsen et al., 2012; Schlossberg et al., 2006; Timperio et al., 2006). This may be because it is difficult to obtain location data on where children are coming from using conventional survey methods and because it is computationally intensive to predict their likely route to school. We hope to build off and refine previous methods.

Timperio et al. (2006) and Schlossberg et al. (2006) appear to be two of the seminal articles on a geographic information systems (GIS) approach to the shortest travel route along the street network in the walk to school literature. Both studies use GIS to map the shortest route via the street network and examine variables based on these routes, assuming the child takes the shortest route. Timperio and colleagues (2006) conducted a cross-sectional study of 235 children aged 5-6 years and 677 children aged 10-12 years from 19 elementary schools in Melbourne, Australia, to examine personal, family, social, and environmental correlates of active commuting to school among children. They examined distance to school, busy roads along the route, pedestrian route directness, and incline along the route, all measures that did not require a buffer or area around the route.

Schlossberg and colleagues (2006) conducted a similar study and examined the relationship between urban form, distance, and active transportation to school among middle school students. This study used a 200-meter buffer around the shortest route to calculate environmental characteristics such as distance, intersection density, dead end density, route directness, major roads on route, and railroad tracks along the route and found route distance, intersection density and dead-end density were significant predictors of walking to and from school (Schlossberg et al., 2006). A 200-meter buffer, which creates a 400-meter wide corridor, is a wide buffer that could include characteristics from other areas and streets. Neither study investigated land use mix along the route.

Larsen and colleagues (2012) built off this methodological foundation. They narrowed the buffer around the route to a 50-meter buffer and calculated an entropy measure of land use mix from parcel data within this buffer. They found land use mix to be a negative predictor, however their measure of land use included five categories: recreational, residential, institutional, commercial, and industrial. It is possible that these land uses do not all have the same effect on walking among children and this measure warrants further investigation. Because there are relatively few route-based studies, additional research is needed to develop the field. This study aims to apply these methods to a large dataset from several municipalities in Massachusetts and to refine these route-based methods by fitting a multilevel model to adjust for clustering of students within schools.

2.2.1 Multilevel Modeling Studies

Walk to school studies often gather data from multiple schools. By doing so, a hierarchical data structure is created (children within schools). By recognizing this data structure, multilevel models correct inferences such as independence, which may be violated and investigate group effects (Bristol University, 2016). Some studies that have evaluated multilevel influences simultaneously on whether children will walk to school (Carlson et al., 2014; Easton & Ferrari, 2015; Lu et al., 2015; Panter, Jones, Van Sluijs, et al., 2010; Panter, Jones, van Sluijs, & Griffin, 2010; Su et al., 2013). To our knowledge, only one multilevel modeling study examined route, neighborhood, and school characteristics (Easton & Ferrari, 2015; Panter, Jones, Van Sluijs, et al., 2010). Panter and colleagues (2010) analyzed a cross-sectional study of 2,012 children from 92 schools in Norfolk, UK, with a multilevel model that examined neighborhood, route, and school environments and active commuting. They found that objectively measured built environment characteristics such as higher neighborhood network connectivity, higher income neighborhoods, and more indirect routes were positively associated with walking to school and that longer routes and having a main road on the route were negatively associated with walking. Their findings suggest that creating environments which are safe, through improving urban design may influence children's commuting behavior (Panter, Jones, Van Sluijs, et al., 2010). This study is very relevant to our research question, however this study was conducted in the UK, which has a different urban form than the United States, with relatively few individuals from many schools (an average of approximately 22 students per school). This thesis will apply a similar framework to a large data set (an average of approximately 178 students per school) from the United States.

3. Methods

3.1 Student Travel Behavior Survey

This analysis used a safe routes to school (SRTS) student travel behavior survey tool. This thesis was determined to be Institutional Review Board (IRB) exempt under Category 4 because these are existing data. The tool collected the following information from parents about each student in the home:

- Grade
- Home location (nearest street intersection)
- Travel mode to school (most days)
- Travel mode from school (most days)
- If auto commute, whether the driver continued on to (or was returning from) work or another destination (a “chained trip”)
- Vehicle availability (number of vehicles and number of licensed drivers)

Google drive distances are also provided with these data. The survey was offered in English and translated into seven common languages: Spanish, Portuguese, French, Haitian Creole, Vietnamese, Chinese, and Arabic. The survey is administered to schools with a SRTS program, meaning these schools already have some level of commitment to walking because they have opted into the SRTS program. Schools can distribute the survey online, in paper, or both. Typically, the survey will be open for about two weeks. The online version of the survey, available at www.masaferoutessurvey.com, allows parents to use a mapping tool to “place the marker at a location near your house” or to provide the names of streets at a nearby intersection. Online survey responses have the added benefit of capturing if the child has a sibling. Printed versions of the survey offered English on one side of the page and an alternative language chosen by the school administrators on the other side. The paper survey must be collected by school administrators and entered into the online interface. The online interface generates an automated report for school administrators based on the survey responses. The paper survey can be found in Appendix A.

The survey tool was developed by the Metropolitan Area Planning Council (MAPC)—Metro Boston's regional planning agency—in 2011 (MAPC & WalkBoston, 2012) and has been administered by MassRIDES, a free program of the Massachusetts Department of Transportation (MassDOT) that aims to help reduce traffic congestion and improve air quality and mobility, since 2013 (MassRIDES, 2015). As part of this mission, MassRIDES coordinates the Massachusetts SRTS programs.

From 2011 to October 2015, there were 24,571 survey responses from 185 pre-kindergarten (pre-k) – grade 12 schools in Massachusetts (see Appendix B for descriptive statistics for the full sample). However, to investigate what built environment characteristics of the route, neighborhood, and school are associated with walking to school, we constrained our analysis to responses within two-miles of the school—consistent with past research as a typical distance threshold for active commuting—and to schools that had more than 35 survey responses. Additionally, we excluded responses from parents reporting children in grades 9-12 due to the low proportion of the sample coming from this grade category (164 responses or <1% of the survey responses). Finally, due to a low sample size of bicyclists (148 bicyclists or ~3% of active commuters), we limited our analysis to only walkers. Therefore, of the total sample, approximately 25% of the data were excluded: 4,880 responses were greater than 2 miles network-distance away from the school, 164 were high school responses, and 814 responses from schools that did not have more than 35 survey responses. The final analysis was conducted on the remaining sample of 18,713 survey responses obtained from 105 schools.

3.2 GIS Neighborhood and Route Delineation

Survey data were geocoded to the nearest intersection to the home using ArcGIS 10.3. The network analyst extension was then used to predict the shortest route to school for each survey response. The underlying network used in this study was a pedestrian network comprised of roadways with sidewalks on one or both sides of the road, low-volume residential roads (<1,000 vehicles per day), and off-road facilities. This network was also used to create half-mile school walksheds (the walking distance via the network) to define the school environment or the school neighborhood. These geographic units (route and school walkshed) were used to calculate neighborhood and route characteristics for the analysis. These measures are detailed below.

3.2.1 Land Use Measures

In order to explore land use mix, we used the Massachusetts Land Parcel Database developed by the Metropolitan Area Planning Council (MAPC). The Massachusetts Land Parcel Database is a statewide atlas of more than 2.1 million land parcel boundaries and associated tax assessor data. It standardized and summarized the assessor's land use code by parcel. However, there are occasions where there are multiple assessors records associated with a single parcel (e.g. condominiums), thus each parcel has a minimum and maximum land use code associated with it. While the vast majority of the codes are the same between the minimum and maximum, we chose the maximum adjusted land use code for each parcel to calculate land use mix because institutional land use may include some exempt land uses, which have high codes. Still, because the minimum and maximum codes were the same for the most part, we did not expect this to affect the results due to the land use codes of interest for this study.

Using the Massachusetts Land Parcel Database, we calculated an entropy measure of land use mix between four land uses: residential, commercial, recreational, and institutional land. Land use mix was calculated along a 50-meter buffer corridor along the route (Figure 1) using the following equation:

$$[LUM = - \Sigma_u(\rho_u \ln \rho_u)/\ln n]$$

where u is the land use classification, ρ is the proportion of land area dedicated to the particular land use, and n is the total number of land use classifications. Scores range from zero to one, with zero representing all land in a corridor as a single land use and one representing an even distribution of all four land use classifications. In addition to land use mix, the percent of industrial land use was calculated separately along the route to explore land use preferences along the route. Approximately 2/3 (12,562) routes did not have industrial land use.

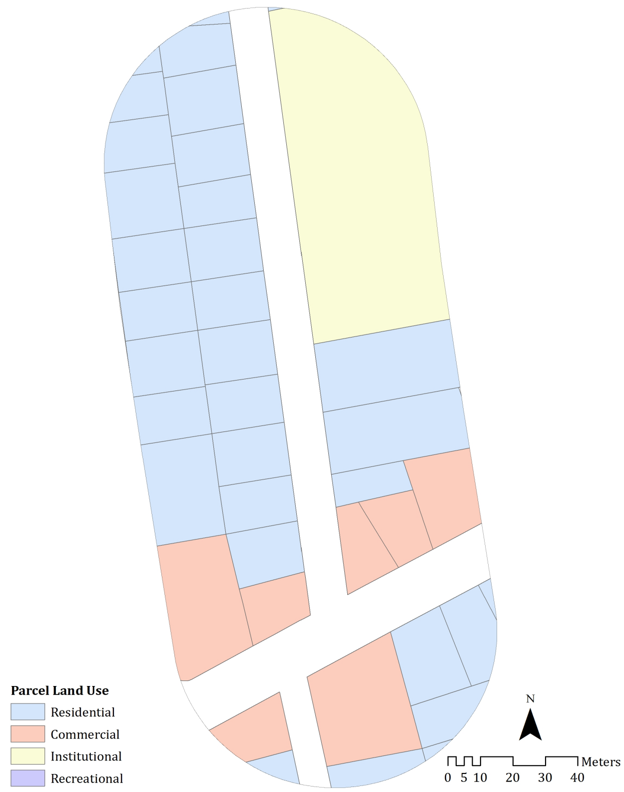

Figure 1: Route Buffer Cross-Section

3.2.2 Road Measures

Several measures of network connectivity were used. We calculated the number of intersections and number of intersections with major roads along the route as well as intersection density per kilometer squared of the school neighborhood. Data on road intersections came from the 2013 Massachusetts Department of Transportation's (MassDOT) roads layer. Major roads are defined by MassDOT as roads with a functional classification of 1-4 (i.e. highways, major arterial, and collector roads). The directness of the pedestrian route was another measure of network connectivity used. For this analysis, we defined this measure as the ratio of the pedestrian route distance to the Google driving distance. There are some differences between the pedestrian route distance and the Google driving distance. Google driving directions provides drivers with the fastest route, which may route them more on major roads while the pedestrian routes only include off-road facilities, low volume streets, and streets with pedestrian infrastructure. We standardized the ratio so that ratios where the drive distance was greater than the walk distance (or ratios less than 1) were the same distance from 1 as ratios where the walk distance was greater than the drive distance. Additionally, any ratio between 1.1 and (1/1.1) were considered to be the same distance (pedestrian route distance = drive route distance). The majority of the data were the same distance (57% had the same distance, 32% had shorter pedestrian distances, and 11% had longer pedestrian distances than driving distance). Finally, the ratio was restricted to double the ratio in either direction. Approximately 2% (325 responses) were outside this range (-2 to 2). Finally, we calculated the percent of major route mileage to the total route mileage.

3.2.3 Population Density and Median Household Income

The American Community Survey (ACS) 2010-2014 five-year block group estimates were used to estimate average population density and median household income for the school neighborhood. However, for the route, we calculated an area-weighted average population density and median household income by estimating the area of the block groups that intersected the 50-meter buffer around the route.

3.3 Socioeconomic Measures

The following indicators were used from the SRTS survey: grade (pre-K-1, 2-4, or 5-8, or 9-12), number of vehicles in the household, and number of licenses in the household. From the data on the number of vehicles and licenses in the household, we calculated the ratio of cars to licensed drivers in the household.

Additionally, the Massachusetts Department of Elementary and Secondary Education (DESE) provides information on all schools in the Commonwealth. The proportion of low-income students, the race/ethnicity of the student body, and the proportion of English language learners were incorporated in the most recent year, 2013-2014, for which all items were available. Finally, we used the school enrollment for the school year that the survey was administered.

3.4 Data Analysis

A multilevel model is useful in estimating active travel because the survey responses are socially and spatially grouped within schools. Therefore, using a single level model violates the independence assumption of standard ordinary least-squares regression models. Multilevel models can also handle both individual explanatory variables and school level explanatory variables by allowing the residual variance to be partitioned into between-group and within-group components (Bristol University, 2016). Figure 2 demonstrates that a multilevel model is needed to describe these data because many schools are significantly different from the mean. Therefore, we fit a two-level mixed-effects model (individuals within schools) using the melogit command to predict walking to school (1) or not (0). Analyses were conducted using Stata 14 (StataCorp 2015).

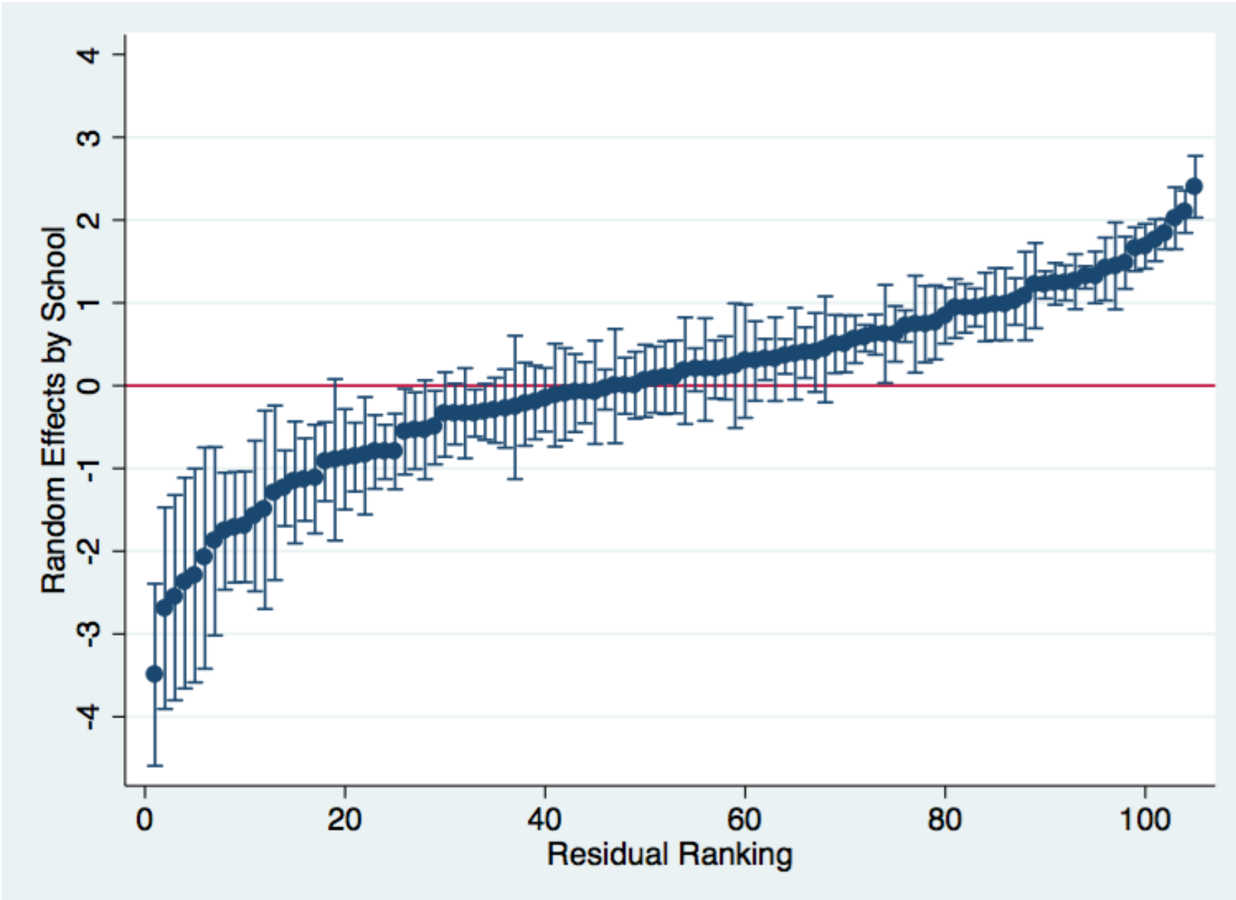

Figure 2: Null Model Residual Ranking Caterpillar Plot

Both partially adjusted models and a fully adjusted model were estimated. In the partially adjusted models, we examined the effects of the built environment measures separately, while adjusting for the hypothesized confounding effect of grade, year, household cars per driver, and distance to school. Because we used the most recent data (2013-2014) available from DESE on the proportion of low-income students, the race/ethnicity of the study body, and the proportion of English learners by school, we ran the partially adjusted model for these three indicators just from the 2013-2014 school year to further explore whether or not these three indicators have an effect on walking to school behavior. We then constructed a fully adjusted model where variables were retained in the model based on a statistical significance of ≤0.05 and if the direction of the effect was expected and consistent between the partially and fully adjusted models. We also examined the correlations between the model variables, and all associations were less than 0.55. Two models were created for walking to school and walking from school.

After constructing the final fully adjusted model, we conducted a variety of additional tests to understand our results. In this analysis, we did not include a municipal designation of urban or rural. Instead, our built environment characteristics, such as network connectivity, helped to objectively measure how urban or rural the environment was. We did however explore if adding a community type designation significantly affected the final model results. To do this, we used the MAPC community typology because it provides a more nuanced designation of urban, suburban or rural. There are five community types in this typology: Inner Core, Regional Urban Centers, Maturing Suburbs, Developing Suburbs, and Rural Towns (Metropolitan Area Planning Council, 2008). We also conducted a sensitivity analysis of the fully adjusted model by removing the school with the most responses (841 responses) to see if schools with large survey responses were skewing the model results.

Finally, we explored the online survey responses as a sub-model to understand if sibling pairs might affect our model results. Survey responses that had the same date created and date modified were considered online survey responses. Having a sibling may introduce another level in the model (individuals nested within households, nested within routes, nested within schools), however a three-level model with this data structure did not converge. Therefore, we ran the two-level model on the online survey sub-model and removed duplicate sibling responses to see if the model results changed. We compared this sub-model with sibling pairs and without sibling pairs.

4. Results

4.1 Descriptive Statistics

In this section, we report the descriptive statistics of our sample and online survey sub-model. Table 1 shows the descriptive statistics of the survey responses by the travel mode to and from school. Most responses came from the Boston metro region, New Bedford, and Worcester areas (Figure 3). No schools in rural towns participated in the survey. Survey responses by school ranged from 35 to 841 responses with an average of 178.5 responses per school.

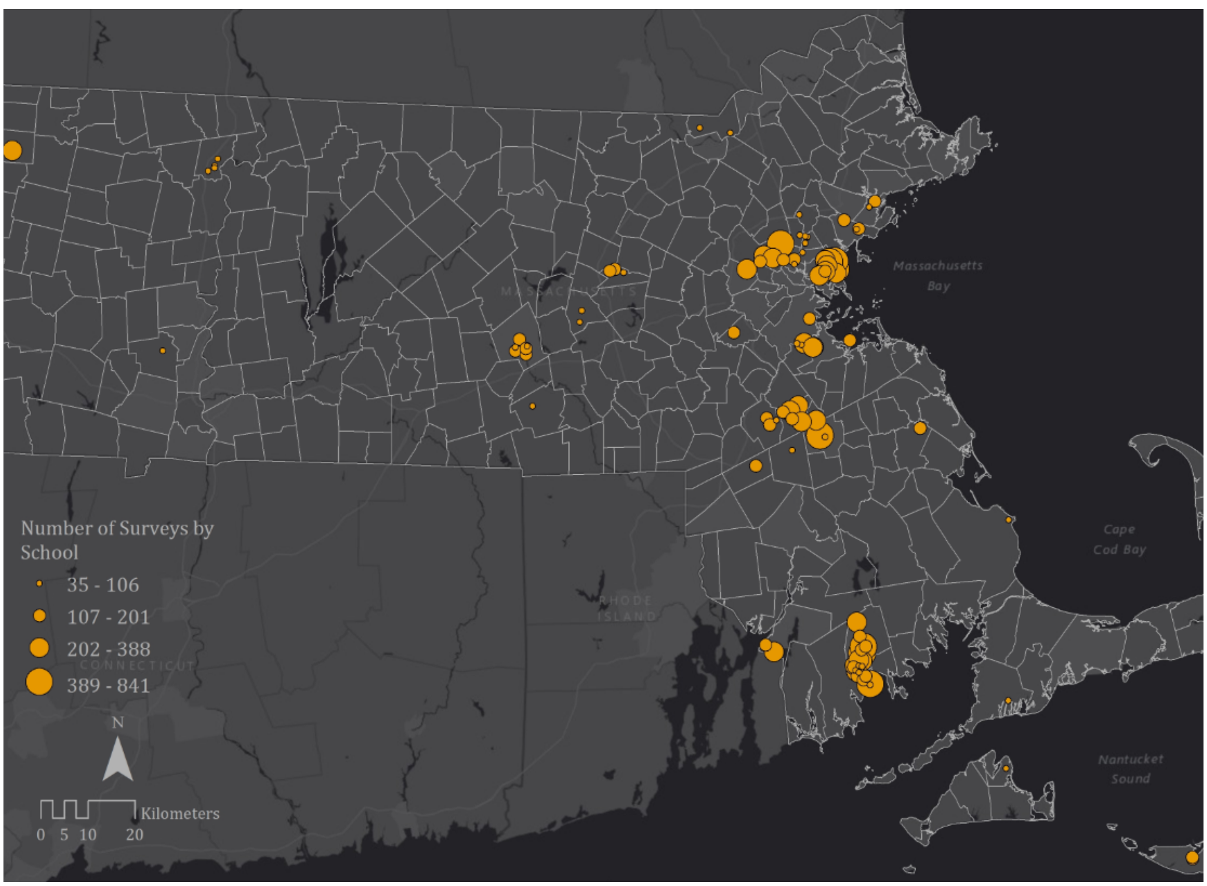

Figure 3: Number of Survey Responses by School

The mode split to and from school were similar. Approximately 4,835 (26%) respondents walked to school and 5,032 (27%) respondents walked from school. There were very few bicyclists in the sample. Biking accounted for approximately 1% of the sample both to and from school. Consequently, children bicycling to school were not analyzed further. Personal vehicles were the dominant mode share to and from school. Of the 46% of respondents that drove to school, 67% were dropped off on the parent's route to work or another destination, and of the 41% that drove home, 60% were picked up. The average distance to school was approximately ¾ of a mile (0.78 miles). Finally, approximately 45% of respondents had children in grades 2-4 and 70% owned at least one car per licensed driver.

Table 1: Descriptive Statistics

Variables	Walk to School	Walk from School
Mode to School	**Number (%)**	**Number (%)**
Walk	4,835 (26%)	5,032 (27%)
Bike	148 (1%)	146 (1%)
Family Vehicle	8,692 (46%)	7,617 (41%)
Drop-off	5,803 (67%)	-
Pickup	-	4,568 (60%)
Carpool	750 (4%)	766 (4%)
School Bus	4,043 (22%)	4,820 (26%)
Transit	173 (1%)	196 (1%)
Other	72 (0%)	136 (1%)
Grades pre-k-1	6,148 (33%)	6,148 (33%)
Grades 2-4	8,359 (45%)	8,359 (45%)
Grades 5-8	4,206 (22%)	4,206 (22%)
Carless Households	2,513 (13%)	2,513 (13%)
<Cars per Driver	3,135 (17%)	3,135 (17%)
At Least One Car per Driver	13,065 (70%)	13,065 (70%)

Approximately half of those living within a half-mile of the school walk (Figure 4 and Figure 5). However, those that are driven in personal vehicles make up a large portion of the mode share across all distance categories.

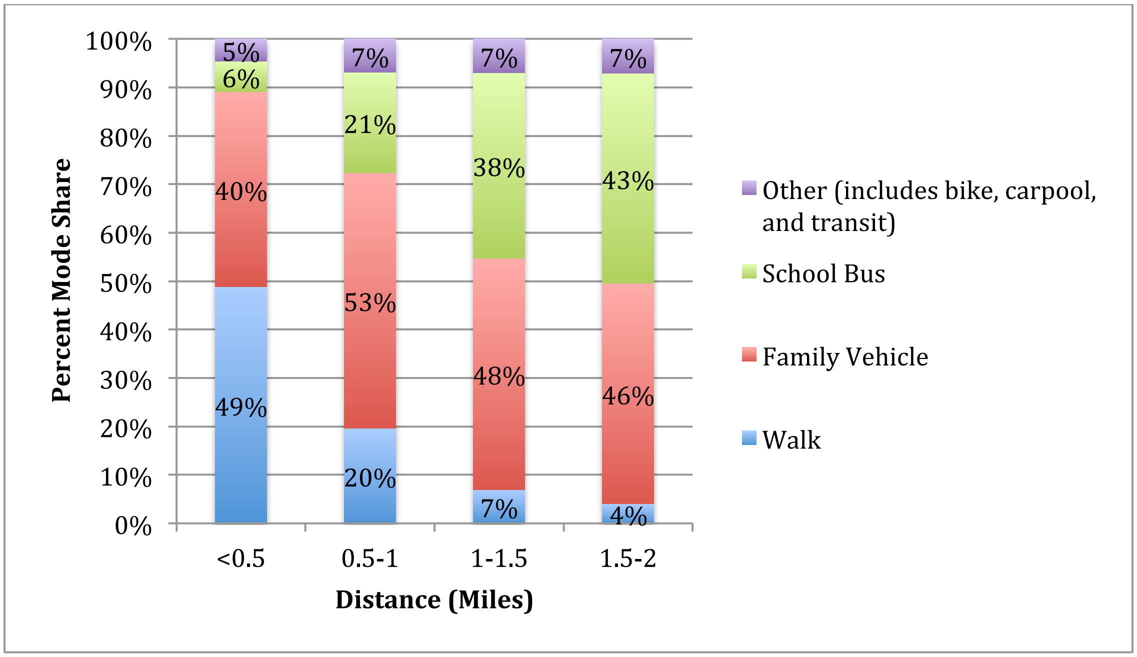

Figure 4: Mode to School by Distance

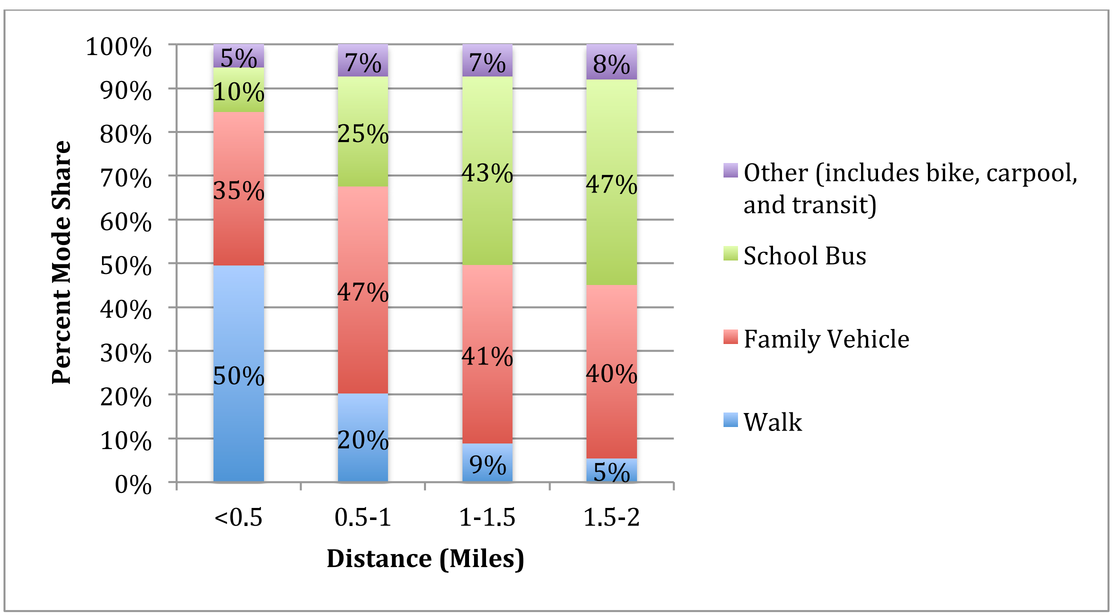

Figure 5: Mode from School by Distance

The majority of the survey responses were paper survey responses. Approximately, 18% (3,343) of surveys were filled out online (Table 2). The average distance to school was approximately 0.71 miles. Of the online surveys, 86% of survey responses did not report having a sibling.

Table 2: Online Sub-Model Descriptive Statistics

Variables	Walk to School	Walk from School
Mode to School	**Number (%)**	**Number (%)**
Walk	1,072 (32%)	1,104 (33%)
Bike	38 (1%)	35 (1%)
Family Vehicle	1,567 (47%)	1,433 (43%)
Drop-off	1,058 (68%)	-
Pickup	-	896 (63%)
Carpool	129 (4%)	134 (4%)
School Bus	525 (16%)	614 (18%)
Transit	11 (0%)	18 (1%)
Other	1 (0%)	5 (0%)
Grades Pre-K-1	1,195 (36%)	1,195 (36%)
Grades 2-4	1,525 (46%)	1,525 (46%)
Grades 5-8	623 (19%)	623 (19%)
Carless Households	359 (11%)	359 (11%)
<Cars per Driver	648 (19%)	648 (19%)
At Least One Car per Driver	2,336 (70%)	2,336 (70%)
Siblings		
No Siblings	2,888 (86%)	2,888 (86%)
2 Siblings	388 (12%)	388 (12%)
3 Siblings	63 (2%)	63 (2%)
4 Siblings	4 (0%)	4 (0%)

4.2 Partially Adjusted Models

Partially adjusted models were estimated to ascertain the magnitude and direction of effect from each indicator individually (Table 3). All indicators were tested in the partially adjusted models while adjusting for the hypothesized confounding effect of year, grade, distance, and household cars per driver. Similar to previous research, distance and walking along major roads were significantly negatively associated with walking while indirect pedestrian routes and intersection density around the school were significantly positively associated with walking. Land use mix along the route, a less commonly explored indicator, was also significantly associated with walking. Additionally, school enrollment (measured in 100s of students) was positively associated with walking. The number of intersections along the route; industrial land use percent along the route; population density along the route and in the school neighborhood; and the school level measures of the proportion of low-income students, the race/ethnicity of the study body, and the proportion of English learners were not significant predictors. To further test the school level measures of the proportion of low-income students, the race/ethnicity of the study body, and the proportion of English learners, we ran additional partially adjusted models with these three indicators individually with data only from the 2013-2014 school year. The proportion of low-income students, the race/ethnicity of the study body, and the proportion of English language learners were still not significant predictors in these tests.

Table 3: Partially Adjusted Models with Direction of Association and Statistical Significance

Variable	Direction
Route	
Population Density	-n.s.
Median Household Income [a]	+**
Land Use Mix	+**
Industrial Land Use Percent	-n.s.
Number of Intersections	-n.s.
Number of Major Intersections	+n.s.
Proportion of Major Road Miles	-**
Indirect Pedestrian Route	+**
School	
Population Density	+n.s.
Median Household Income [a]	+**
Intersection Density	+*

Percent Not White	+n.s.
Percent English Language Learners	+n.s.
Percent Low Income	-n.s.
School Enrollment [b]	+**
-adjusted for grade, year, distance, and cars per driver -direction indicates direction of association (+ = positive association, - = negative association -significance: n.s. = not significant; * = p <0.05; ** = p<0.01 -a = in $1,000s - b = in 100s of students	

4.3 Fully Adjusted Model

Table 4 below summarizes the results of the final fully adjusted multilevel model predicting whether children walked to school. Using the partially adjusted model as a guide, measures of interest were added in and examined for a statistical significance of p ≤0.05 and a consistent direction of the effect between the partially and fully adjusted models. The fully adjusted model explained some of the between school variance. After adjusting for the built environment variables in the multilevel model, approximately 16% of the residual variation in the propensity to walk to school is attributable to unobserved school characteristics as compared to the null two-level model, which had a variance partition coefficient of 30%.

The adjusted multilevel model found that greater land use mix along the route (OR: 4.59, 95% CI = 2.50 – 8.44 to school and OR: 3.75, 95% CI = 2.08 – 6.74 from school), less direct walking routes (OR: 1.89, 95% CI = 1.70 – 2.10 to school and OR: 1.74, 95% CI = 1.57 – 1.92 from school), children in grades 5-8 (OR: 1.59, 95% CI = 1.39 – 1.81 to school and OR: 1.92, 95% CI = 1.68 – 2.19 from school), and larger schools (OR: 1.14, 95% CI = 1.06 – 1.24 to school and OR: 1.20, 95% CI = 1.11 – 1.30 from school) was associated with increased likelihood of walking to school. Conversely, distance (OR: 0.03, 95% CI = 0.03-0.04 to school and OR: 0.04, 95% CI = 0.04 – 0.05 from school), households with at least one car per driver (OR: 0.16, 95% CI = 0.15 – 0.19 to school and OR: 0.21, 95% CI = 0.19 – 0.24 from school), and major roads along the route (OR: 0.56, 95% CI = 0.47-0.67 to school and OR: 0.58, 95% CI = 0.49 – 0.69) were strongly negatively associated with active commuting.

Table 4: Adjusted Multilevel Model

Fully Adjusted Model	Walk To School	Walk from School
	Odds Ratio (95% CI)	**Odds Ratio (95% CI)**
Grades 2-4 [a]	1.10 (1.00, 1.21)*	1.15 (1.05, 1.26)**
Grades 5-8 [a]	1.59 (1.39, 1.81)**	1.92 (1.68, 2.19)**
Distance (miles)	0.03 (0.03, 0.04)**	0.04 (0.04, 0.05)**
More Drivers Than Cars [b]	0.19 (0.17, 0.22)**	0.25 (0.22, 0.29)**
At Least One Car per Driver [b]	0.16 (0.15, 0.19)**	0.21 (0.19, 0.24)**
Route Land Use Mix	4.59 (2.50, 8.44)**	3.75 (2.08, 6.74)**
Major Road on Route	0.56 (0.47, 0.67)**	0.58 (0.49, 0.69)**
Indirect Pedestrian Route	1.89 (1.70, 2.10)**	1.74 (1.57, 1.92)**
School Enrollment [c]	1.14 (1.06, 1.24)**	1.20 (1.11, 1.30)**
School Neighborhood Intersection Density	1.01 (1.01, 1.02)**	1.01 (1.00, 1.01)**
School Neighborhood Median Household Income [d]	1.01 (1.01, 1.02)**	1.01 (1.00, 1.01)**
Constant	0.36 (0.14, 0.90)*	0.53 (0.22, 1.30)

All adjusted for year
* - significant at $p<0.05$
** - significant at $p<0.01$
a – reference = grades pre-k - 1
b – reference = carless households
c – in 100s of students
d – in $1,000s

To further explore the final model, we compared it with community types and without the school with the largest survey response. When we tested whether or not community type was significant in the model, we found the models with community type did not significantly improve our final model in a likelihood ratio test so we concluded that community type does not significantly affect the model even though more urban municipalities (inner core and regional urban centers) were associated with walking to school—though these were not significant in the walk from school model—as compared to the least dense community type (developing suburbs) in the sample. Then, to test the model's sensitivity, we dropped the school with the most survey responses. The magnitude and direction of effects were similar when the school with the largest survey response was dropped; therefore, this school did not markedly impact the model results. Lastly, we ran an online survey response sub-model to test the affect of sibling-pair responses. Again, the magnitude and direction of effects were similar so it did not appear that sibling-pairs majorly affected the model (the sensitivity analysis and online sub-model results can be found in Appendix C).

5. Discussion

5.1 Summary of Findings

This analysis investigated a unique data source to take its place among the relatively few number of studies that have simultaneously analyzed route, neighborhood, and school characteristics associated with walking to school. We found evidence that built environment features of the neighborhood, route, and school affect walking behavior to school. Specifically, short routes along low volume streets with mixed land use are associated with increased odds of children walking to school.

Consistent with previous research, we found that older children, particularly those in grade 5-8, are more likely to walk to school (Su et al., 2013); and that greater distance to school, vehicle ownership, and higher proportion of major roads on the route were negatively associated with walking to school (Easton & Ferrari, 2015; Larsen et al., 2012; Panter, Jones, Van Sluijs, et al., 2010; Schlossberg et al., 2006; Su et al., 2013; Timperio et al., 2006). Moreover, this analysis demonstrates that busy roads are still a barrier to walking to school even if pedestrian infrastructure is present. As specified above, the routes are based on a pedestrian network, thus only major roads with sidewalks on one or both sides of the road are included. This suggests that even if pedestrian facilities are present, the parent or child still may prefer to avoid busy roads.

Furthermore, we investigated a novel measure of route directness by examining the ratio of walking distance to the Google driving directions in order to examine a network-based measure of directness, and found that less direct pedestrian routes were positively associated with walking to school. While at first counterintuitive, three past studies reported the same finding (Panter, Jones, Van Sluijs, et al., 2010; Schlossberg et al., 2006; Timperio et al., 2006). Combined with our finding of the effect of major roads on odds of walking to school, it is possible that children and parents may go out of their way to seek out a less trafficked route to walk to school. While adult commuting may be strongly influenced by travel time, children's travel may be more strongly influenced by traffic safety concerns (Timperio et al., 2006).

While there are many similarities to previous research, this thesis investigated some measures that are unique or seldom looked at in the literature. Contrary to some previous studies, land use mix along the shortest walking route to school was a positive predictor of walking to school. At first glance, this is a surprising finding because the walk to school literature has found that correlates of adult walking behavior, such as population density and land use mix, are unlinked to school travel behavior (Ewing et al., 2004). Due to this, few studies investigate this measure and the few that do report mixed findings. Moreover, the entropy measure of land use mix is a crude measure that depends on the land use categories used to define it. Nevertheless, land use mix, as defined in this thesis, demonstrates that land use mix may have a modest positive effect on walking to school. This could be indicative of living in a more walkable environment. This finding provides new evidence and warrants further study.

Surprisingly, school enrollment (in 100s of students) was the only significant and influential school level predictor. We found that larger schools were associated with walking to school. Larger schools may be sited in urban or densely populated areas of communities, where walking is more feasible. Other studies (Su et al., 2013) found that schools with a greater percentage of students in the Free and Reduced Price Meals program were associated with a greater likelihood of walking to school. However, this indicator, along with the proportion of students who were English language learners and the proportion of the student body that was not white, were not significant in our model, even after looking specifically at the 2013-2014 school year. This may indicate a lack of heterogeneity in these variables among the schools and represent a common feature of the schools that opt into the SRTS program in Massachusetts. For example, no schools in the rural towns conducted the survey and the most of the data came from more urban municipalities (Table 5). When we tested to see if a municipal urban, suburban, or rural designation (defined by the MAPC community typology) affected the model, we found that community type does not significantly affect the model. This could mean that our objectively defined measures of the built environment are already capturing this designation and/or that the schools in this sample are situated in similar sub-environments within the communities (i.e. a school in a developing suburb may be located near the downtown area, which may have a similar environment to a regional urban center).

Table 5: Number of Schools and Percent of Survey Responses by Community Type

Community Type	Number of Schools	Percent of Survey Responses
Inner Core	24	30%
Regional Urban Centers	39	39%
Maturing Suburbs	21	20%
Developing Suburbs	21	12%
Rural Towns	0	0%

5.2 Policy and Planning Implications

Despite the differences from some previous studies, taken together, this thesis provides strong evidence that built environment features of the route, neighborhood, and school are associated with walking to school. Specifically, short routes along less-trafficked streets with mixed land use are associated with increased odds of children walking to school. This may be because streets with less traffic and vehicles moving at slower speeds are perceived to be safer and friendlier walking environment by parents and children.

These findings may have many planning and policy implications. First, these findings elevate the importance of school siting. Schools should be sited in less trafficked neighborhoods near population centers, which may minimize the distance to school and there is more likely to be mixed land use along the route (Easton & Ferrari, 2015; Schlossberg et al., 2006; Steiner et al., 2008). These also may be the types of schools that are more likely to opt into the SRTS program. Second, and related, these findings encourage schools to engage in additional infrastructure and non-infrastructure strategies to improve the real and perceived route environment by slowing and deterring vehicle traffic. Evidenced-based strategies exist to create these types of environments. For example, traffic calming measures may slow and reduce car and cut-through traffic on residential roads

(Ewing & Dumbaugh, 2009) and "complete streets" policies—roads designed for all users of all abilities—may improve the safety and attractiveness of the pedestrian environment (Burden & Litman, 2011).

Moreover, the findings of this analysis suggest that route built environments that are quiet, with little traffic may increase the odds of walking. Therefore, off-road paths, neighborhood greenways (bicycle boulevards), and placemaking efforts may all be effective built environment strategies to reclaiming streets as welcoming environments for active commuting. For example, Portland, Oregon has a neighborhood greenway (formally known as bicycle boulevard) program. Neighborhood greenways are low-volume, slow-speed residential streets designed to prioritize bicyclists and pedestrians. The neighborhood greenways program began in the 1980s from concerned residents living in neighborhoods with a high amount of cut-through vehicle traffic. The city and residents undertook traffic-calming projects to reduce the volume and speed of cars on these residential roadways. A recent evaluation of the program found that nearly three-fourths of the locations had vehicle volumes at or below the desired 1,000 vehicles per day (Portland Bureau of Transportation, 2015).

Finally, these findings have implications on the broader municipal, state, and national level. In the 19th and early 20th centuries, public health and planning once worked together to prevent the spread of infectious diseases and exposure to hazardous materials in crowded cities and towns. However, by the mid 20th century, the disciplines drifted apart. Health and safety risks caused by building designs and the mixing of certain types of land uses had reduced, but at the same time, these decisions influenced how and where people lived (Kochtitzky et al., 2006). The changes also influenced where certain population groups lived and the choices they had for homes, jobs and schools (Kochtitzky et al., 2006). These national and local zoning codes and related land-use regulations made it difficult to create mixed-use neighborhoods (Schilling & Linton, 2005) that may promote walking behavior in children and adults. Movements across the country are working towards planning interventions with a public health lens. For example, tactical urbanism, healthy community design, crime prevention through environmental design, smart growth, and Health In All Policies strategies all work to create integrated communities to live, work, play, and learn (CDC, 2016; WHO, 2016).

Planning interventions can only address some of the barriers to walking to school. In fact, while built environment factors appear to have strong influences on walking to school as our model reduced the residual variation by approximately half (16%) from the null model (30%), there are still factors over and above what was included in this model that influence walking to school. Therefore, non-infrastructure interventions are needed as well (e.g. walking school bus programs show great promise in increasing walk to school behavior).

In conducting this analysis, we explored the role of the built environment and found that it is a critical component in influencing active commuting. However, this also illuminates a challenge. For example, parents may still drive their children to school despite investments in the built environment for a variety of reasons (scheduling constraints, convenience, weather, carrying books/supplies, safety concerns, parking availability, etc.) (McDonald & Aalborg, 2009; Schlossberg et al., 2006). Our data showed while nearly half (49%) of the survey respondents living within a ½ mile of school walk to school, the second largest mode share (40%) is driven in a family vehicle (Figure 4 and Figure 5). Again, this reinforces that both infrastructure and non-infrastructure strategies are required to positively move the needle on walk to school behavior.

5.3 Limitations, Strengths, and Future Study

We analyzed a large cross-sectional sample of survey responses from a unique student travel behavior survey that is administered to SRTS programs in Massachusetts in order to investigate route, neighborhood, and school characteristics associated with walking to school. These data were cross-sectional so we cannot infer causality to the observed relationships. We assessed the usual travel mode to and from school so our findings do not elucidate any temporal or weather-related relationships. We also limited our analysis to survey responses within two miles of the school. Approximately 20% (4,880) survey responses lived beyond that cut off point. However, the mode shift goal for those that live over two miles from the school may be different (i.e. encouraging bus ridership, carpooling, or remote drop off zones).

Moreover, school administrators administer the surveys themselves. Therefore, there was variability in the survey response rate by school, which affects how representative the survey is of the school as a whole. Furthermore, the school student body changes from year to year. While we controlled for year in the model, we used all data from 2011 to 2015 and there may have been changes in the students and the schools during that time. Finally, our analysis of the online surveys showed that while similar to the full sample, there did appear to be some small differences. Therefore, there is a possibility that those that opt to take the online survey over the paper survey have different characteristics (i.e. differences in access and proficiency with internet, socioeconomic status, etc.). This should be further explored.

The routes used in this study were generated from responses from the travel behavior survey. These routes were based on the shortest path algorithm on a pedestrian network comprised of roadways with sidewalks on one or both sides of the road, low-volume residential roads (<1,000 vehicles per day), and off-road facilities. Thus, we assumed that the child's probable route may be the shortest route with some pedestrian infrastructure, but this may not be the child's actual route. This pedestrian network also would not include all shortcuts, such as routes that cut through properties. Furthermore, the route is based on an intersection near the home and not the actual home location. Finally, to our knowledge, route directness has not been calculated using to network-based distances. The drive distance was based off of the Google driving directions. There may have been some errors in geocoding. We found 22 data points that were identified as being less than two miles from their school via a pedestrian network were assigned a Google drive distance of over 20 miles. This is one reason we decided to restrict the range of the directness ratio. Additionally, because only the Google drive distance is reported in the survey data, we did not determine what the actual network route was. In future studies, the Google drive route could be compared to the pedestrian network route to further explore what is truly being captured in this measure.

We also recognize that there are strong influences on children's walking to school behavior that were not included in this analysis. This was apparent in our model in which approximately 16% of the residual variation in the propensity to walk to school is attributable to unobserved school characteristics not in the model. Therefore, while it is important to understand the built environment context, additionally study is required to fully understand why schools, after controlling for the built environment context of the school and its survey responses, have high or low walking rates.

Despite its limitations, this approach opens the door to new planning and policy research questions and applications. We found strong evidence that the built environment matters in the decision to walk to school, however it is not the whole story. Much more can be explored. The Massachusetts travel behavior survey used in this analysis is a rich and ongoing data source. This dataset could be compared to additional school or health data overtime (e.g. SRTS goal monitoring, health impact assessment monitoring, etc.). It could also be used to look at different modes of transportation (e.g. school bus routing and policy, spatial variation in mode at specific schools, etc.) and their relationship to walking. For example, there were some schools with high survey responses (100-300 survey responses) that did not report any walkers that lived within two miles of the school. However, closer examination revealed that while there were no walkers, the school bus mode share was very high (Table 6).

Table 6: Mode Share to School in Two Elementary Schools in Dracut, Massachusetts

Mode to School	Joseph A Campbell Elementary School		George H. Englesby Elementary School	
	Number	**Percent**	**Number**	**Percent**
Carpool	0	0%	5	1%
Family Vehicle	23	22%	93	26%
School Bus	83	78%	265	73%
Total	106	100%	363	100%

Finally, with further study, another potential application of this analysis is to evaluate SRTS programs. This framework could be used to more fairly compare and contextualize schools baseline walk share, set appropriate and measurable mode shift goals, and track their progress overtime. This is an exciting prospect because there has been little evaluation of SRTS programs across the country (Boarnet et al., 2005).

After accounting for route, neighborhood, and school environment variables in a multilevel model, we saw a significant improvement in prediction (Figure 6) compared to the null model (Figure 2). In other words, accounting for built environment variables helps make schools more comparable, but there are still other random effects (non-built environment factors) that make schools different from one another (e.g. school programs and policies). Table 7 shows ten schools that were either lower or higher that the model's prediction. These schools should be further studied to understand what other factors are contributing to their student body's mode choice in order to apply appropriate infrastructure or non-infrastructure strategies to help encourage walking to school. Understanding these schools may uncover best practices or barriers to walking to school.

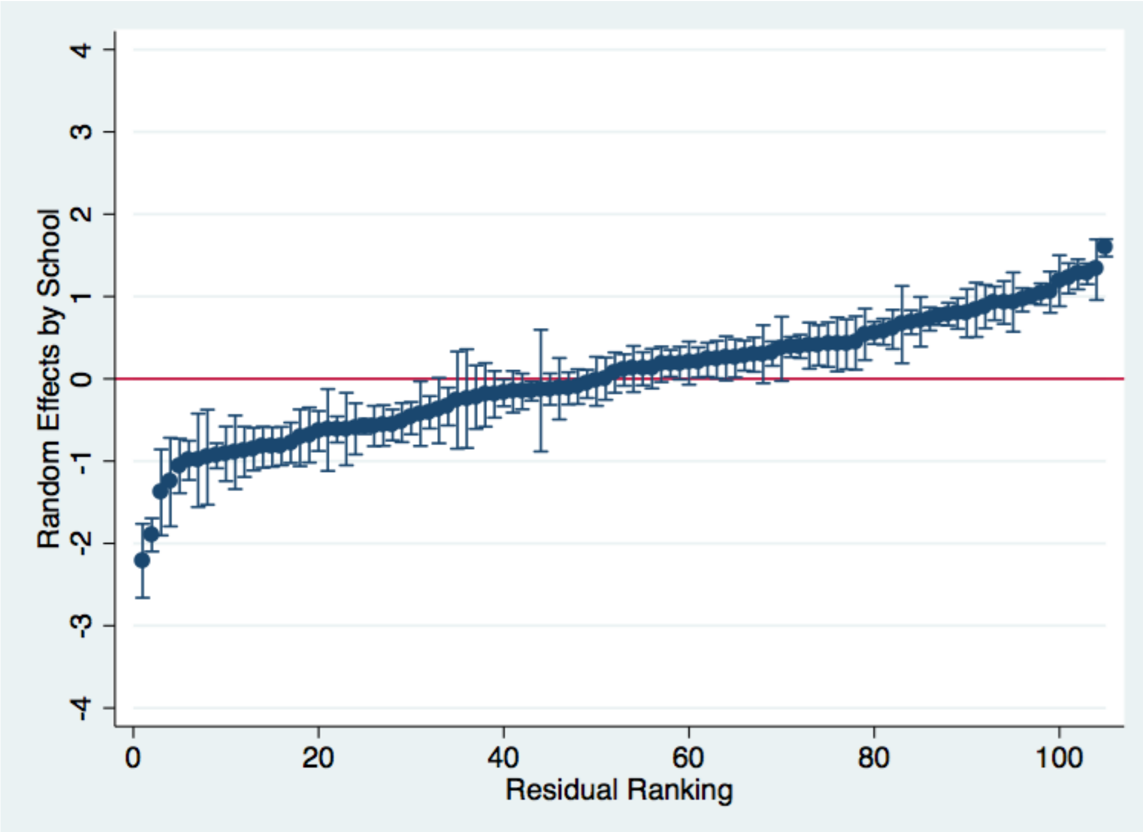

Figure 6: Full Model Caterpillar Plot

Table 7: Higher or Lower than Predicted Schools

School	Town	Walk Share	Number of Walkers	Number of Survey Responses
Higher Than Predicted Schools				
Lincoln Elementary School	Winchester	59%	281	478
William E Norris School	Southampton	17%	11	64
Roosevelt Middle School	New Bedford	32%	154	484
John F Kennedy School	Brockton	9%	38	418
Renaissance Community School for the Arts	New Bedford	51%	77	152
Lower Than Predicted Schools				
George H. Englesby Elementary School	Dracut	0%	0	363
Betsey B Winslow School	New Bedford	16%	30	188
Marion E Zeh School	Northborough	0%	0	83
Joseph A Campbell Elementary School	Dracut	0%	0	106
Casimir Pulaski School	New Bedford	3%	7	208

6. Conclusion

This analysis provides strong evidence that built environment features of the route, neighborhood, and school affect walking to school. Specifically, short routes along quieter, low volume streets with mixed land use increase the odds of children walking to school. We applied a multilevel model to a large cross-sectional dataset of 18,713 travel behavior survey responses from 105 schools in Massachusetts. Using a multilevel model allowed us to parse out individual built environment predictors of walking to school while controlling for school differences. While we confirmed that the built environment has a strong effect on walking to school, we also recognize that there are many influences on children's walking to school behavior that were not included in this analysis. Still, controlling for built environment characteristics are important to understanding what types of SRTS interventions may be effective. These findings should encourage schools to engage in additional infrastructure (i.e. traffic calming and complete streets policies) and non-infrastructure strategies (i.e. walking school bus programs) to improve the real and perceived route environment by slowing and reducing traffic and incentivizing more children to actively commute.

Appendix

Appendix A: Paper Student Travel Behavior Survey

[INSERT SCHOOL NAME] School

Important School Travel Survey

Dear Parent or Guardian,

[INSERT SCHOOL NAME] would like to learn how students get to and from school.

This information will be used to plan safe and healthy walking options for students.

The survey will take less than 3 minutes to complete.

Please complete one survey for each child at [INSERT SCHOOL NAME] by **Friday, May 20**.

Encontra-se uma tradução em português no verso deste questionário.

Español: En caso necesario, por favor traduzca esta encuesta en papel o visite [INSERT WEB ADDRESS FOR ONLINE SURVEY] para completar una versión online en español.

Français: Si nécessaire, veuillez faire traduire ce questionnaire sur papier, ou visitez [INSERT WEB ADDRESS FOR ONLINE SURVEY] pour répondre à une version en ligne en français.

Tiếng Việt: Nếu cần, hãy cho dịch bản khảo sát ý kiến bằng giấy này hoặc vào thăm trang mạng [INSERT WEB ADDRESS FOR ONLINE SURVEY] để hoàn tất bản khảo sát trực tuyến bằng tiếng việt.

如果必要，请翻译本纸质调查问卷，或登录 [INSERT WEB ADDRESS FOR ONLINE SURVEY]，填写中文网上版本。

Your school earns money when you complete this survey! If surveys are completed for [50%] students, WalkBoston (a nonprofit group) will donate $250 to the [INSERT DONATION TARGET]. If surveys are completed for [75%] students, WalkBoston will donate $400!

You can also fill out the survey online at [INSERT WEB ADDRESS FOR ONLINE SURVEY]

Please complete EITHER the online survey or this form -- NOT BOTH!

1. What grade is your child in? K 1 2 3 4 5 6 7 8

1a. On what day of the month was your child born? ☐☐

2. What street do you live on?

Name of your street:

Name of nearest cross-street:
(nearest intersection)

3. How does your child get TO school *on most days*? (choose one)

- O School Bus
- O Bike
- O Family Vehicle (only children in your family)
- O Carpool (with children from other families)
- O Walk
- O Transit (city bus, subway, etc.)
- O Other (skateboard, scooter, inline skates, etc.)

3a: If you selected "family vehicle" or "carpool" for travel to school, do you usually drop off your child on your way to work or another destination?

O Yes O No O Not applicable

4. How does your child get home FROM school *on most days*? (choose one)

- O School Bus
- O Bike
- O Family Vehicle (only children in your family)
- O Carpool (with children from other families)
- O Walk
- O Transit (city bus, subway, etc.)
- O Other (skateboard, scooter, inline skates, etc.)

4a: If you selected "family vehicle" or "carpool" for travel home from school, do you usually pick up your child on your way from work or another location?

O Yes O No O Not applicable

5. How many vehicles do you have in your household? ☐

6. How many people in your household have a driver's license? ☐

That's all! Thank You!

Appendix B: Descriptive Statistics of Full Sample

The data for this thesis were downloaded on October 29, 2015. There were 24,753 raw survey responses from 185 schools across Massachusetts and 127 schools (of the 185) have over 25 responses (Figure 7).

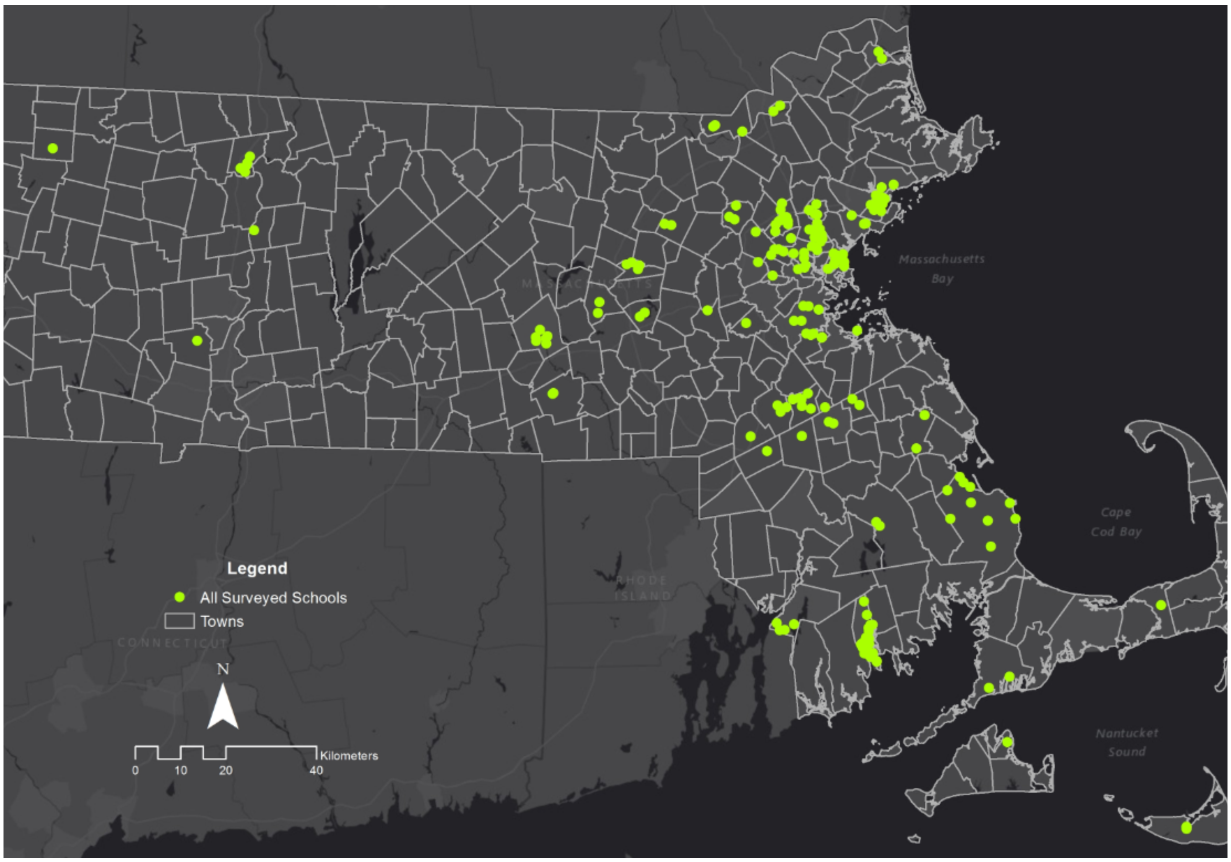

Figure 7: Locations of Surveyed Schools in Massachusetts

There are responses from 2011-2015. Almost half of the responses were within the calendar year 2014 (44% or 11,401 responses) (Figure 8). While there are responses for all schools pre-K-12, the highest responses are in grades pre-k-8 (Figure 9).

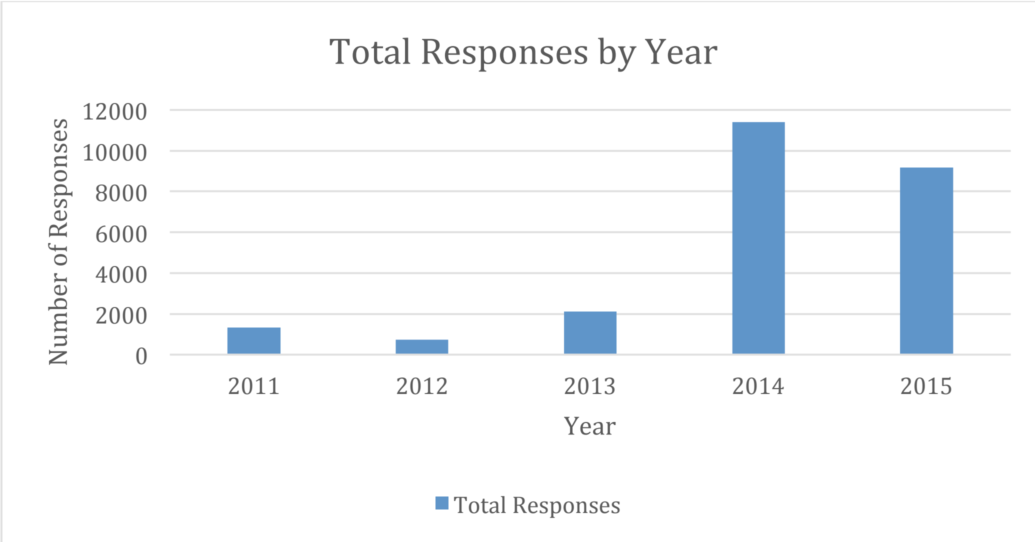

Figure 8: Total Survey Responses by Year

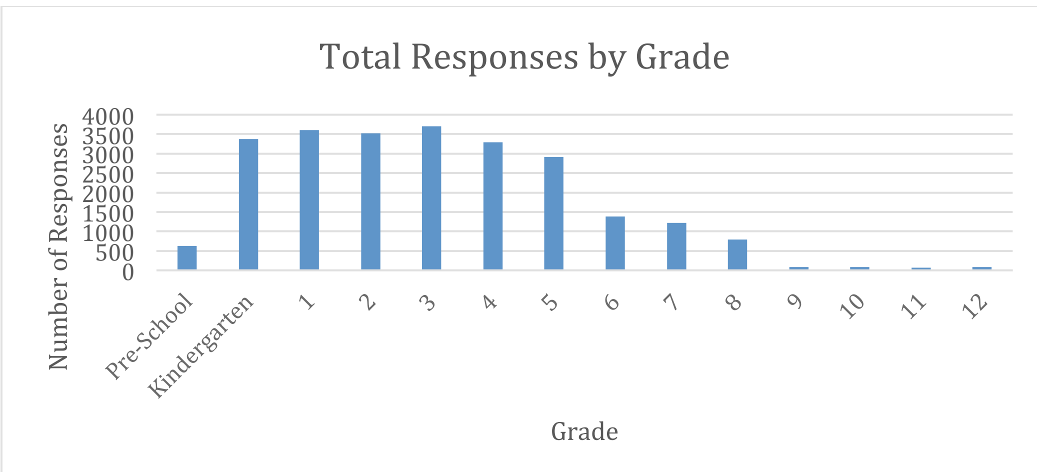

Figure 9: Total Responses by Grade

These raw mode split data show that family vehicle (~40%) is the dominant travel mode to and from school, followed by the school bus (~30%) and then walking (~20%) (Figure 10). Additionally, nearly 30% of parents (7,273) drop their child off at school and about 23% (5,716) pick up their child from school.

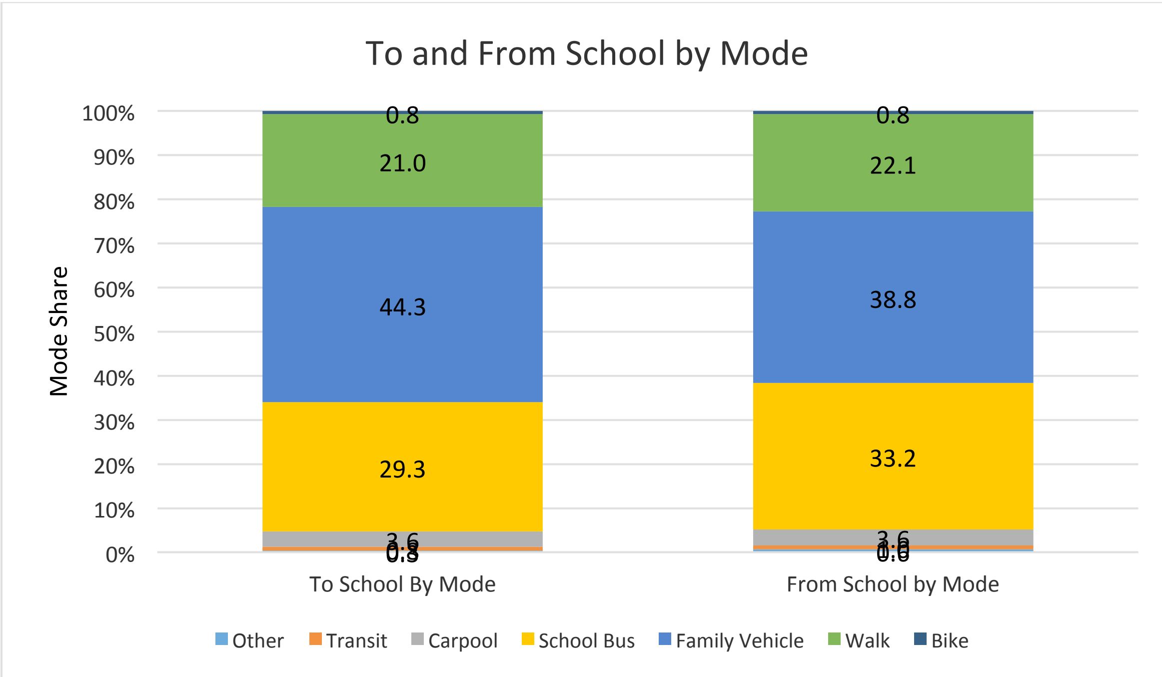

Figure 10: Total Survey Responses To and From School by Mode

The 36% of respondents live within a half-mile of school and nearly two-thirds (62%) live within a mile of school (Figure 11).

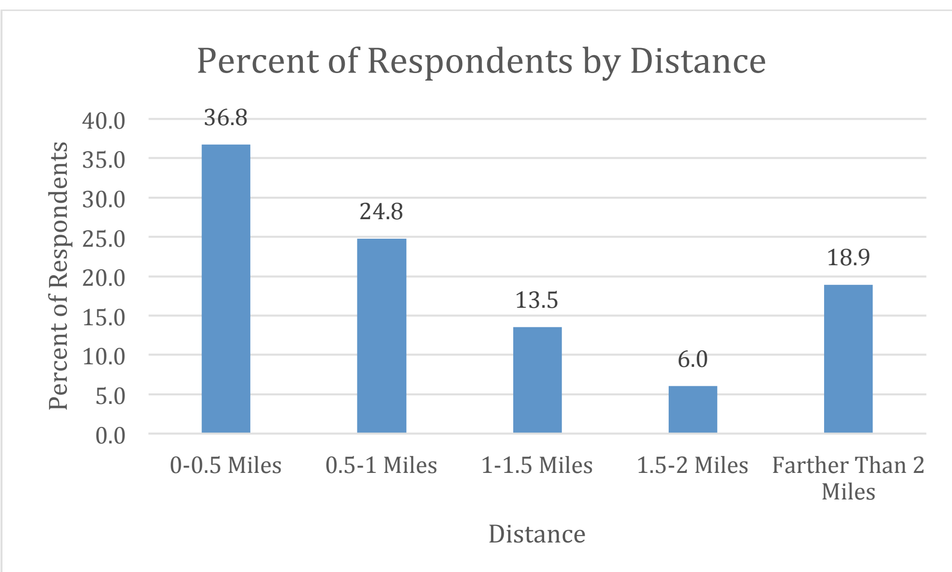

Figure 11: Percent of Respondents by Distance

Of the respondents living within a half mile of school, about 45% of children walk to school. However, about 43% are driven to school by a family vehicle (Figure 12).

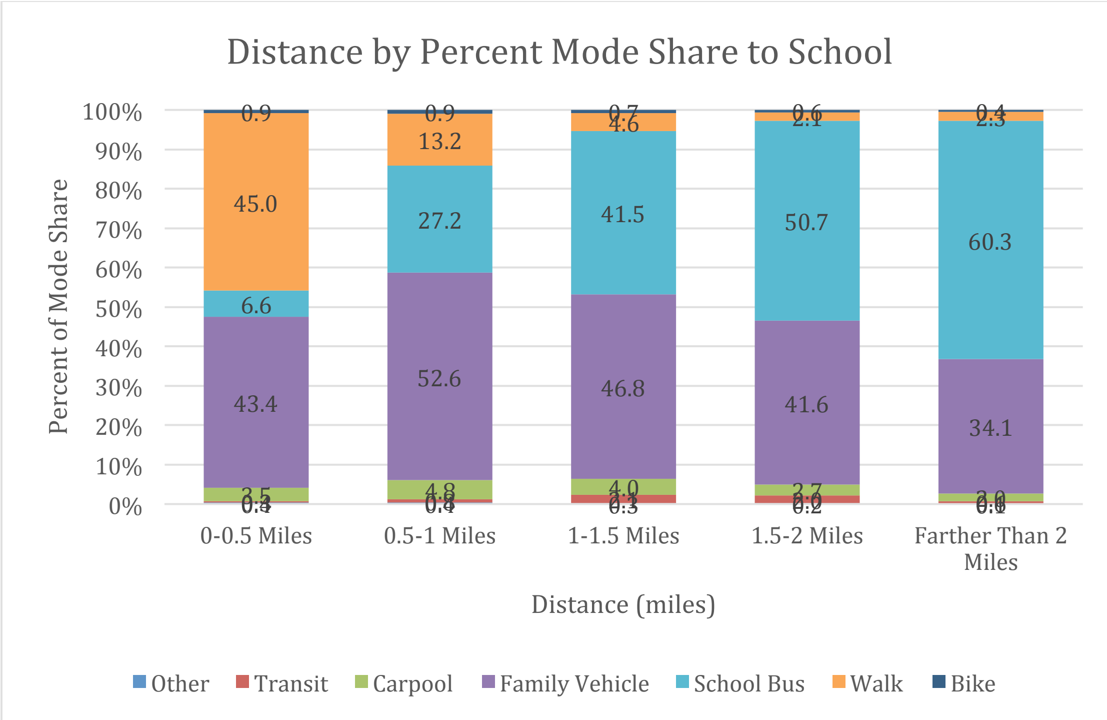

Figure 12: Distance by Percent Mode Share to School

Appendix C: Sensitivity Analysis and Online Sub-Model Results

After constructing the final fully adjusted model, we conducted a variety of additional tests to understand our results. We conducted a sensitivity analysis of the fully adjusted model by removing the school with the most responses (841 responses) to see if schools with large survey responses were skewing the model results. The magnitude and direction of effects were similar when the school with the largest survey response was dropped; therefore, this school did not impact the model results (Table 8).

Table 8: Sensitivity Analysis Results

Sensitivity Model Results	Walk to School	Walk from School
	Odds Ratio (95% CI)	**Odds Ratio (95% CI)**
Grades 2-4 [a]	1.11 (1.00, 1.22)*	1.17 (1.07, 1.29)**
Grades 5-8 [a]	1.63 (1.41, 1.87)**	1.99 (1.74, 2.28)**
Distance (miles)	0.03 (0.03, 0.04)**	0.04 (0.03, 0.05)**
More Drivers Than Cars [b]	0.20 (0.17, 0.23)**	0.26 (0.22, 0.30)**
At Least One Car per Driver [b]	0.17 (0.15, 0.19)**	0.22 (0.19, 0.24)**
Route Land Use Mix	5.27 (2.83, 9.81)**	3.95 (2.17, 7.21)**
Major Road on Route	0.54 (0.45, 0.65)**	0.58 (0.48, 0.69)**
Indirect Pedestrian Route	1.93 (1.73, 2.14)**	1.80 (1.62, 1.99)**
School Enrollment [c]	1.13 (1.04, 1.22)**	1.19 (1.10, 1.29)**
School Neighborhood Intersection Density	1.01 (1.01, 1.02)**	1.01 (1, 1.01)**
School Neighborhood Median Household Income [d]	1.01 (1.01, 1.02)**	1.01 (1, 1.02)**
Constant	0.32 (0.12, 0.81)*	0.54 (0.22, 1.35)

All adjusted for year
* - significant at p<0.05
** - significant at p<0.01
a – reference = grades pre-k - 1
b – reference = carless households
c – in 100s of students
d – in $1,000s

We also explored the online survey responses as a sub-model to understand if sibling pairs might affect our model results. We ran the two-level model on the online survey sub-model (Table 9) and removed duplicate sibling responses to see if the model results changed (Table 10). We compared this sub-model with sibling pairs and without sibling pairs. Again, the magnitude and direction of effects were similar so it did not appear that sibling-pairs affect the model.

Table 9: Online Sub-Model Results

Online Sub-Model Results	Walk to School	Walk from School
	Odds Ratio (95% CI)	**Odds Ratio (95% CI)**
Grades 2-4 [a]	1.01 (0.83, 1.23)	1.06 (0.88, 1.29)
Grades 5-8 [a]	1.18 (0.89, 1.56)	1.31 (1.00, 1.72)
Distance (miles)	0.03 (0.02, 0.04)**	0.03 (0.02, 0.04)**
More Drivers Than Cars [b]	0.28 (0.21, 0.38)**	0.31 (0.23, 0.41)**
At Least One Car per Driver [b]	0.28 (0.22, 0.36)**	0.33 (0.26, 0.42)**
Route Land Use Mix	5.18 (1.35, 19.98)*	3.14 (0.82, 11.97)
Major Road on Route	0.54 (0.35, 0.84)**	0.69 (0.45, 1.07)
Indirect Pedestrian Route	2.22 (1.82, 2.70)**	1.87 (1.54, 2.27)**
School Enrollment [c]	1.22 (1.05, 1.41)**	1.00 (1.00, 1.00)**
School Neighborhood Intersection Density	1.01 (1.00, 1.02)*	1.01 (1.00, 1.02)
School Neighborhood Median Household Income [d]	1.01 (1.00, 1.02)*	1.00 (1.00, 1.00)
Constant	0.15 (0.02, 1.30)	0.24 (0.03, 2.10)

All adjusted for year
* - significant at p<0.05
** - significant at p<0.01
a – reference = grades pre-k - 1
b – reference = carless households
c – in 100s of students
d – in $1,000s

Table 10: Online Sub-Model Sibling Drop Results

Sibling Drop Sub-Model Results	Walk to School	Walk from School
	Odds Ratio (95% CI)	**Odds Ratio (95% CI)**
Grades 2-4 [a]	0.99 (0.81, 1.21)	1.02 (0.83, 1.25)
Grades 5-8 [a]	1.18 (0.88, 1.57)	1.34 (1.01, 1.77)*
Distance (miles)	0.03 (0.02, 0.04)**	0.03 (0.02, 0.05)**
More Drivers Than Cars [b]	0.27 (0.2, 0.36)**	0.28 (0.21, 0.38)**
At Least One Car per Driver [b]	0.27 (0.21, 0.35)**	0.31 (0.24, 0.40)**
Route Land Use Mix	3.82 (0.94, 15.57)	2.78 (0.69, 11.22)
Major Road on Route	0.61 (0.39, 0.94)*	0.69 (0.44, 1.07)
Indirect Pedestrian Route	2.11 (1.73, 2.59)**	1.93 (1.59, 2.36)**
School Enrollment [c]	1.21 (1.04, 1.40)*	1.00 (1.00, 1.00)**
School Neighborhood Intersection Density	1.01 (1.00, 1.02)*	1.01 (1.00, 1.01)
School Neighborhood Median Household Income [d]	1.01 (1.00, 1.02)*	1.00 (1.00, 1.00)
Constant	0.18 (0.02, 1.57)	0.39 (0.04, 3.49)

All adjusted for year
* - significant at p<0.05
** - significant at p<0.01
a – reference = grades pre-k - 1

b – reference = carless households
c – in 100s of students
d – in $1,000s

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