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# Built environment correlates of active school transportation: neighborhood and the modifiable areal unit problem

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ABSTRACT

Researchers, practitioners and community-based organizations have emphasized built environment interventions to encourage active school transportation, a practice that can contribute to the overall physical activity needs of children. This paper examines the potential influence of the modifiable areal unit problem (MAUP) on statistical modeling of the relationship between the built environment and walking/cycling to school. Binomial logistic regressions of school travel mode choice for children aged 11–12 years, in the City of Toronto, Canada, were estimated, using six spatial units for measuring built environment characteristics. The results were suggestive of the presence of MAUP across different geographical units. Travel distance, block density, signalized intersections, walking density, and schools in low-income neighborhoods were associated with active travel. This research improves understanding of the sensitivity of school travel behavior analyses to the spatial representation of the neighborhood construct.



## 1. Introduction

An emerging literature in the past decade has explored children's school travel behavior (Pont et al., 2009; Sirard and Slater, 2008). This research is matched with a policy concern about declining levels of physical activity among children and youth (Faulkner et al., 2009; Frumkin et al., 2004; US Department of Health and Human Services, 1996). Walking or cycling for school transportation, a behavior that is also known as active school transportation (AST), has been identified as a potential opportunity for the accumulation of moderate to vigorous physical activity among children and youth. Researchers, professionals and community-based organizations have emphasized built environment interventions at the neighborhood level as one approach to facilitate AST (McMillan, 2007; National Center for Safe Routes to School, 2007; Ontario Professional Planners Institute, 2009; US Department of Health and Human Services, 2009).

Studies of adult travel behavior have demonstrated that the built environment, including land use distribution within a neighborhood, transportation infrastructure, and urban design characteristics, may encourage active transportation, particularly walking (Ewing and Cervero, 2010; Transportation Research Board, 2005). Empirical findings on children's school travel outcomes, however, remain less conclusive. Some studies have reported that children living in neighborhoods with higher residential density (Kerr et al., 2006; Lin and Chang, 2010; McDonald, 2008a) and mixed land use (Lin and Chang, 2010; Larsen et al., 2009; McMillan, 2007) were more likely to walk for school travel purposes, while in other studies the opposite effect has been reported (Ewing et al., 2004; Mitra et al., 2010; Yarlagadda and Srinivasan, 2008). With regard to transportation infrastructure, some researchers have found that higher street density associates with walking among children (Panter et al., 2010); others have reported a negative association between street intersection density and walking (Schlossberg et al., 2006). Positive correlations have been reported between the presence and density of sidewalks and AST (Boarnet et al., 2005; Ewing et al., 2004; Lin and Chang, 2010); in other studies no statistical association was found between sidewalk density and mode choice (Panter et al., 2010).

The effect of the neighborhood built environment has been explored using different spatial units in different studies. For example, in some studies, the built environment was measured within a 400 m (Mitra et al., 2010; Schlossberg et al., 2006), 800 m (Larsen et al., 2009; Panter et al., 2010) or 1 km (Kerr et al., 2006) straight line buffer distance of a child's home or school location; census boundaries have been used to represent the neighborhood construct in some other studies (Ewing et al., 2004; McDonald, 2008b). The main hypothesis of this paper is that some of the inconsistency in empirical findings of this literature may be related to the modifiable areal unit problem (MAUP), a measurement issue comprised of scale and zoning effects (Amrhein, 1995; Gehlke and Biehl, 1934; Openshaw, 1984; Openshaw and Alvandies, 1999). In

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the context of school travel behavior research, a scale effect may be present when analytical results exhibit sensitivity to the size of spatial units used for built environment measurement. For example, the use of a relatively small spatial unit, such as a 250 m buffer around a residential or school location, may produce unreliable statistical results, because the built environment variables are aggregated using a smaller sample. In contrast, generalizing the value of a built environment metric across a larger geographical unit (e.g., within a 1000 m versus a 250 m buffer) will typically reduce the sample variance for that particular metric, while increasing the correlation between separate built environment variables. As a result, an observed statistical association may mask meaningful differences that are obvious at a smaller scale (Bailey and Gatrell, 1995; Fotheringham and Wong, 1991). A zoning effect may be present when analytical results are sensitive to the partitioning of space. For example, different zone configurations under a fixed scale may produce dissimilar results.

Despite a long-standing recognition in the geography literature of the potential sensitivity of analytical results to the geographical definition of spatial units, the MAUP has received less attention in research that examines the built environment–transportation relationship. Some researchers have investigated the scale and zoning effects of different built environment metrics on adults' active travel and physical activity. For example, Zhang and Kukadia (2005) explored mode choice for work and non-work trips in Boston, Massachusetts, using two different scale and zoning schemes (five buffers and three census boundaries). The results indicated the presence of both scale and zoning effects across spatial units. Berke et al. (2007) examined the relationship between neighborhood walkability, and physical activity or obesity, among the elderly in King County, Washington. Their results suggested that the built environment influenced walking across all three buffer distances that were examined. Lastly, Duncan et al. (2010) investigated physical activity (i.e., walking for transportation) among adults living in 154 Census Collection Districts (CCD) in Adelaide, Australia. The authors found that the duration of walking trips had a stronger association with "corrected" measures of land use mix (i.e., standardized based on the geographical size of CCDs), compared to the uncorrected land use measures within CCDs. Adjusting for scale effects did not improve the results reported for models walking trip frequency. The MAUP is yet to be addressed in the AST literature.

This paper examines the previously unexplored issue of how the MAUP may be influencing the results of empirical research into the relationship between objectively measured built environment characteristics and children's school travel behavior, particularly the choice of active modes of travel to school. Two research questions are considered using data describing the travel behavior of 11–12 year olds in the City of Toronto, Canada: (1) at what scale and for what type of zone system does the neighborhood built environment have the strongest association with AST? and (2) which built environment characteristics near home and school locations are associated with the choice of an active mode for trips to school? The article contributes a refined understanding of how to model the built environment–active school transportation (BE–AST) relationship, with a view to enhancing cross-study comparison. The research also improves current knowledge of the environmental correlates of school travel mode choice in a North American context.

## 2. Study design

The City of Toronto is the largest city in Canada, with a resident population of over 2.5 million (Statistics Canada, 2008). The inner-city neighborhoods in Toronto typically conform to what are known as main-street neighborhoods (i.e., residential neighborhoods with employment-related land uses along the main streets) in both the academic and popular literatures (Sewell, 1993). The re-urbanization trend of the last several decades, which has been hastened in recent years by favorable policy and market conditions, has brought pockets of high-rise and high-density residential developments to these neighborhoods. In contrast, the City of Toronto's suburban places are dominated by Modernist conventional neighborhoods typically characterized by single-use residential development and a street network design (e.g., curvilinear streets) that is often associated with auto-oriented travel behavior.

AST is reasonably well practiced in the City of Toronto. In 2006, 49% of children aged 11–13 years actively traveled to school. For the trips from school to home, the rate was even higher (56%) (Buliung et al., 2009). Toronto's diverse urban environment and high rates of walking/cycling for school transportation offer an excellent opportunity to explore the influence of the built environment characteristics on children's school travel mode choice processes.

This study aims to examine the potential influence of MAUP on the statistical modeling of the BE–AST relationship. Several recommendations have been made in the literature to explore scale and zoning effects (Fotheringham and Wong, 1991; Openshaw, 1984; Zhang and Kukadia, 2005). Some researchers have suggested an examination of the underlying pattern in the estimated coefficients of the built environment variables across different scales and zone systems (Fotheringham and Wong, 1991; Zhang and Kukadia, 2005). This approach is tested here by modeling the BE–AST relationship using different spatial units and analytical scales for the representation of neighborhoods. With regard to the correlates of AST, this study adopts a social–ecological approach and hypothesizes that household demographics, travel distance to school, and the neighborhood environment influence the selection of school travel modes (McMillan, 2005; Mitra, 2011; Sirard and Slater, 2008).

### 2.1. Travel data

Data were taken from the 2006 Transportation Tomorrow Survey (TTS). The TTS is a repeated cross-sectional survey of travel behavior in Southern Ontario, Canada, conducted on a 5% sample of all households in the study area. The 2006 TTS data were collected for a randomly selected weekday, using a computer assisted telephone interview procedure (Data Management Group, 2008, 2009). Household travel data (e.g., origin/destination of trips, trip start time, purpose, primary travel mode) for all trips by household members aged 11 years and older, associated with the day prior to the interview, were proxy reported by an adult household member. Previous research indicates that school travel behavior can change with a child's age (Buliung et al., 2009; Mitra, 2011; Panter et al., 2008). In order to limit the scope of this study to a relatively homogenous population, school travel data for children aged 11–12 years (i.e., likely attending grades 5 or 6) were explored. All home-to-school trips between the 6h00–9h30 time interval ($n = 2520$) were extracted. Travel modes were collapsed into active (i.e., walking and cycling trips) and passive (i.e., trips made by a private automobile, public transit or school-bus) modes, using the proxy reported data on primary mode of travel for school trips.

### 2.2. Neighborhood and built environment data

The modern conceptualization of the planned neighborhood unit emerged in the early 1900s (Banerjee and Baer, 1984; Perry, 1939). The design principles of a neighborhood unit emphasized Modernist concepts of spatial separation between home and work, and a hierarchical street system (Banerjee and Baer, 1984; Moudon et al., 2006). Elementary schools, community centers and other smaller urban facilities were planned as central features of a neighborhood, with surrounding residential development scaled to be within a convenient walking distance (e.g., a 0.25 mi, or 400 m, radial distance) from the these facilities. The post World War II suburban developments in Toronto were dominated by a widespread implementation of the neighborhood unit idea (Filion and Hammond, 2003; Hess, 2009). Urban planners assumed that within the boundaries of a neighborhood, non residential activities of residents will "flow toward the core" (Banerjee and Baer, 1984, pp 183–4). However, this planning goal never fully materialized, perhaps because most neighborhood centers did not offer essential and desired services. Instead, these suburban neighborhoods have led to an increased dependency on automobiles. Within this context, previous research has indicated that the physical extent of a neighborhood unit may be less important to households, and that a household's perceived neighborhood boundary can largely be defined based on the "action space" within which the household members perform their daily activities, and consume goods and services (Banerjee and Baer, 1984; Horton and Reynolds, 1971). This observation, perhaps, is applicable to the older inner-city residential areas as well, where the borders between the "neighborhoods" are less clear. In the context of this concern around the neighborhood boundaries, defining the neighborhood as a unit of empirical analysis can present a methodical challenge (Moudon et al., 2006).

In this paper, built environment characteristics were measured within six different geographies, and two different scale and zoning schemes (Fig. 1 and Table 1). The first scheme involved measuring the built environment within various buffer distances around a child's home and school locations (four buffer distances- 250 m, 400 m, 800 m and 1000 m). In the second approach, neighborhoods were defined using either the census boundary (dissemination area – DA) or traffic analysis zone (TAZ) within which a home or school was located. Selection of these spatial units was informed by the existing AST literature. The BE–AST associations were examined at each level of geography, and were compared across different scales/zoning systems. Environmental characteristics were measured at both the residence and school ends of a school trip. The individual environmental variables that were analyzed are listed in Table 2, where the hypothesized relationship with AST is also reported.

Minimum travel distance between home and school locations of a child was computed using Toronto's street network file (DMTI CanMap© RouteLogistics file, version 2007.3). Other neighborhood characteristics related to street network design were also obtained from the DMTI data. The employment-to-population ratio (EMP_POP) was calculated using the TTS data, based on the number of work-trip ends in each TAZ. TTS trip data were also used to calculate the density of walking trips (WALK_DSTY) near the home and school locations. To calculate block density, the geographical boundary files from the 2006 population census of Canada were used. This study situates school travel behavior within a social–ecological framework. Within this theoretical approach, the potential influence of neighborhood socio-economic status was examined. LOWINCOME was, thus, conceptualized as an environmental characteristic. In other words, socio-economic status was measured at the neighborhood level. The median household income data from the population census of Canada were aggregated, within six different geographies around home and school locations, to identify low income neighborhoods. Income data for individuals or households were not available for analysis. Lastly, data on pedestrian and cyclist collisions occurred during the 2002–2006 period were collected from City of Toronto's Transportation Department; the data included the locations of all fatal and non-fatal collisions reported to the Toronto Police Service.

### 2.3. Statistical analysis

Binomial logistic regression was used to explore the correlates of active versus passive mode choice for school trips (Pampel, 2000). A coefficient ($\hat{\beta}_i$) from the multivariate logistic regression models in this paper represent the un-confounded (i.e., adjusted)


**Fig. 1.** Built environment near a hypothetical household location in Toronto, Canada. *Note:* DA, Census dissemination area; TAZ, Traffic analysis zone.

**Table 1**
Spatial unit definitions.

| Definition | Description |
|---|---|
| 250 m buffer around home/school location<br>Area: 0.2 sq km | The use of a 200 or 250 m buffer is most common in empirical research that measures the built environment around travel routes (Schlossberg et al., 2006). A 250 m distance is roughly equivalent to a 2.5-min walking distance for an average adult. |
| 400 m buffer around home/school location<br>Area: 0.5 sq km | 400 m is equivalent to a 5-min walking distance for an average child (Mitra et al., 2010). Some researchers have assumed this distance to be a reasonable walking distance for children (McMillan, 2007; Mitra et al., 2010; Yarlagadda and Srinivasan, 2008). |
| 800 m buffer around home/school location<br>Area: 2.01 sq km | 800 m is equivalent to a 10-min walking distance for an average child (Panter et al., 2010). |
| 1000 m buffer around home/school location<br>Area: 3.4 sq km | Sometimes used in adult active-travel behavior research (Frank et al., 2007), a 1000 m (i.e., 1 km) distance is roughly equivalent to a 10-to-12 min walking distance for an average adult. One study on children's school travel has used this distance to define the neighborhood of residence (Kerr et al., 2006). |
| DA of home/school location<br>Area: Mean 0.18 sq km. (*sd* 0.39 sq km.) | Smallest geographical unit for which public census data (i.e., data from Statistics Canada) is available in Canada. Some researchers in the US have measured built environment at the block group level to explore school travel, and have cited a similar reason for their choice of geography (McDonald, 2008b). |
| TAZ of home/school location<br>Area: Mean 1.31 sq km. (*sd* 0.94 sq km.) | Small geographical areas defined for transportation research purposes. Used mostly to explore work-travel behavior. Some researchers have measured TAZ-level built environment to explore school travel behavior (Ewing et al., 2004). |

*Note: sd*, standard deviation; DA, census dissemination area; TAZ, traffic analysis zone.

**Table 2**
Independent variables and their hypothesized associations with active school transportation.

| Variable | Hypothesized relationship |
|---|---|
| **Socio-demographics** | |
| MALE: The child was a male (reference: female) | + |
| *CHILD: Number of school-age children below driving age (4–15 years) in the household* | +/− |
| VEH_LIC: Number of vehicles in the household per licensed driver | − |
| *FUL_EMP: Number of full-time employees per adult household member (ages 18 to 65 years)* | − |
| *UNEMP: There was unemployed adult(s) in the household (reference: no unemployed adult)* | + |
| **Built environment** | |
| DISTANCE: Minimum travel distance (i.e., shortest path using a street network) between the home and school (km) | − |
| EMP_POP: The ratio of employment to the population in a TAZ<br>Low (first tertile); Medium (second tertile- reference); High (third tertile) | − |
| WALK_DSTY: Walking density – total work and school related walking trips produced by residents of a TAZ, normalized by per sq km of area<br>Low (first tertile – reference); Medium (second tertile); High (third tertile) | + |
| BLOCK_DTY[a]: Number of street-blocks, normalized by per sq km of area | + |
| FOURWAY_DTY[a]: Proportion of 4-way street intersections – the ratio of 4-way intersections to total number of street intersections | +/− |
| *DEADEND_DTY[a]: Proportion of dead ends and cul-de-sacs - the ratio of dead-ends plus cul-de-sacs to total number of street intersections* | − |
| LIGHT_DTY[a]: Proportion of intersections with street lights- the ratio of signalized intersections to total number of street intersections | + |
| *LOCAL_RD_DTY[a]: Length of local roads (km), normalized by per sq km of area* | + |
| MAJOR_RD_DTY[a]: Length of major roads (km), normalized by per sq km of area. Major roads include expressways, arterials and collector roads | − |
| *COLLISION[a]: The number of pedestrian and cyclist collisions (fatal and non-fatal) per sq km of area per year, averaged based on the total number of collisions reported to the police between 2002 and 2006* | − |
| LOWINCOME[a,b]: The child's residence/school neighborhood was a low-income neighborhood, i.e., median household income was <CAD 39,400. Median household income was estimated by taking a median of the DA-level median household incomes at a child's residence/school location | + |

*Note:* DA, census dissemination area; TAZ, traffic analysis zone.
Each built environment variable has been estimated separately for the home, and the school location.
Variables in italics were excluded from the multivariate logistic regression specifications.
[a] Variables were calculated separately for each neighborhood definition (i.e., 250 m buffer, 400 m buffer, 800 m buffer, 1000 m buffer, DA and TAZ). Other environmental data were available only at the TAZ level.
[b] Individual household income data was not available. Median household income was calculated using 2006 population census data by Statistics Canada. Average household size for the sample was 4.3 (*sd* = 1.28). In a large metropolitan area such as Toronto (i.e., population > 500,000), the low income cut-off, defined by Statistics Canada, was CAD 39,399 for a four-member household (Statistics Canada, 2010).

correlation between an individual built environment metric and the log-odds of walking/cycling to school. The odds ratio or OR (i.e., $\exp\hat{\beta}_i$), thus, demonstrates the relationship between a variable $i$ and the odds of active travel (i.e., the change in the odds of an active mode choice in response to a unit change in the value of variable $i$). Separate binomial logistic regression models were specified with built environment variables and neighborhood income measured within each of the six spatial units outlined in Table 1. Researchers have argued that beyond a distance of 5 km (i.e., a 1-h walk for a child), the choice set may become restricted to motorized alternatives only (Ewing et al., 2004; McDonald, 2008a). For this reason, only children living within 5 km (shortest path network distance) from their schools were considered for modeling purposes (92% of all school trips by this age group). Adjusting for missing data and outliers, the final dataset included 2190 home-to-school trips.

For each school trip, five socio-demographic variables, and ten neighborhood characteristics, in addition to the shortest path network distance between home and school locations, were initially measured (Table 2). Prior to the multivariate (i.e., adjusted) logistic regression estimation, a set of unadjusted logistic regressions (i.e., one model per correlate) were estimated to filter the initial set of independent variables down to only those variables holding a statistical significance at $p \leqslant 0.05$.

The degree of multi-collinearity across the built environment variables was also examined, for each level of spatial aggregation (Lee and Moudon, 2006; Mitra et al., 2010). The correlation between variables increased with the scale of spatial analysis. When two variables were correlated (i.e., DEADEND_DTY and FOURWAY_DTY; BLOCK_DTY and LOCAL_RD_DTY), those two were entered into the multivariate (i.e., adjusted) model one at a time, and the one with a weaker association (i.e., DEADEND_DTY; LOCAL_RD_DTY) was excluded from the final model specification. The built environment variables around the residence and near the school were also highly correlated. To overcome this collinearity problem, two sets of multivariate regression models were specified and estimated for each spatial unit, one for built environment measures near the residence, and the other for the built environment near the school. A total of 12 multivariate logistic regression models of active travel to school were estimated. Statistical analyses were performed with R© version 2.9.0 (The R Foundation for Statistical Computing).

The presence of scale effects was examined by observing whether or not the coefficient of a variable remained statistically significant across different scales of aggregation, and to a lesser extent, by assessing changes in the size and sign of the coefficient values across different scales of spatial aggregation, within each aggregation scheme (i.e., buffers or zones). The presence of potential zoning effects was examined by using the method suggested by Fotheringham and Wong (1991) and Zhang and Kukadia (2005), which involved an assessment of the built environment coefficients across two spatial units at a comparable scale, between the two zoning schemes (i.e., 250 m buffer versus DA, and 800 m buffer versus TAZ). The standard-difference-of-means test [1] was used to test the statistical difference in the estimated coefficients obtained from the logistic regression models:

$$t = \frac{\hat{\beta}_i - \hat{\beta}_j}{SE|\hat{\beta}_i - \hat{\beta}_j|} \tag{1}$$

where $\hat{\beta}_i$ = estimated coefficient of a built environment variable $i$; SE = Standard error (Fotheringham and Wong, 1991).

## 3. Results

Home-to-school trips by 11–12 year old children ($n = 2190$), and the associated socio-demographic and environmental attributes, were analyzed. Table 3 describes these attributes; summary of the built environment measures are presented for each of the six geographical units, around home and school locations, of all 11–12 year old children. Results from the multivariate logistic regression models are presented in Tables 4 and 5. Most children used an active mode for school transportation (58%); only 42% traveled to school using passive modes (Table 3). The average school travel distance (shortest path network distance) for these students was 1.25 km.

### 3.1. Scale effect

Table 3 suggested that the variance (square of the standard deviation) of these environmental variables typically decreased with an increase in neighborhood size. This type of "data smoothing" at larger geographies is not unexpected (Zhang and Kukadia, 2005), and adds empirical evidence in support of the hypothesis of decreasing sample variance with an increase in the scale of analysis, as previously mentioned in the introduction (Section 1). Scale effects were explored further using the results from the adjusted logistic regression models, presented in Tables 4 and 5.

The goodness of fit for the estimated models was very similar across all six specifications (although a general trend of a weaker

**Table 3**
Descriptive statistics ($n = 2190$ students).

| | | | Mean (*sd*) | | | | | % |
|---|---|---|---|---|---|---|---|---|
| Travel mode | | | | | | | | |
| Active | | | | | | | | 58.40 |
| Passive | | | | | | | | 41.60 |
| MALE | | | | | | | | 52.15 |
| VEH_LIC | | | 0.72 (0.42) | | | | | |
| DISTANCE (km) | | | 1.25 (1.00) | | | | | |
| | 250 m buffer | | | | 400 m buffer | | | |
| | Home | | School | | Home | | School | |
| | Mean (*sd*) | % | Mean (*sd*) | % | Mean (*sd*) | % | Mean (*sd*) | % |
| BLOCK_DTY (blocks/km$^2$) | 25.58 (15.10) | | 25.33 (14.90) | | 25.19 (13.62) | | 26.64 (12.83) | |
| FOURWAY_DTY (prop.) | 0.21 (0.19) | | 0.21 (0.20) | | 0.20 (0.14) | | 0.21 (0.15) | |
| LIGHT_DTY (prop.) | 0.12 (0.14) | | 0.11 (0.13) | | 0.11 (0.09) | | 0.10 (0.08) | |
| MAJOR_RD_DTY (km/km$^2$) | 3.32 (3.85) | | 2.39 (3.04) | | 2.99 (2.79) | | 2.36 (2.44) | |
| LOWINCOME | | 28.54 | | 20.41 | | 17.17 | | 7.53 |
| | 800 m buffer | | | | 1000 m buffer | | | |
| BLOCK_DTY (blocks/km$^2$) | 23.51 (11.82) | | 24.56 (11.32) | | 21.27 (10.34) | | 22.08 (10.14) | |
| FOURWAY_DTY (prop.) | 0.19 (0.10) | | 0.20 (0.10) | | 0.19 (0.09) | | 0.20 (0.10) | |
| LIGHT_DTY (prop.) | 0.10 (0.05) | | 0.10 (0.05) | | 0.10 (0.05) | | 0.09 (0.05) | |
| MAJOR_RD_DTY (km/km$^2$) | 2.55 (1.71) | | 2.36 (1.53) | | 2.28 (1.34) | | 2.16 (1.20) | |
| LOWINCOME | | 7.44 | | 3.52 | | 4.22 | | 3.70 |
| | DA | | | | TAZ | | | |
| BLOCK_DTY (blocks/km$^2$) | 27.60 (20.74) | | 22.83 (17.04) | | 23.70 (12.80) | | 24.46 (12.47) | |
| FOURWAY_DTY (prop.) | 0.20 (0.25) | | 0.21 (0.24) | | 0.20 (0.12) | | 0.20 (0.12) | |
| LIGHT_DTY (prop.) | 0.11 (0.18) | | 0.12 (0.20) | | 0.10 (0.09) | | 0.14 (0.07) | |
| MAJOR_RD_DTY (km/km$^2$) | 3.56 (4.81) | | 2.30 (2.91) | | 2.87 (1.88) | | 2.74 (1.75) | |
| LOWINCOME | | 22.10 | | 15.94 | | 10.27 | | 6.53 |

*Note: sd*, standard deviation; DA, census dissemination area; TAZ, traffic analysis zone.
The variables that were measured only at the TAZ level (WALK_DSTY and EMP_POP) are not shown in this table. Values for these variables were categorized into three equal groups.

**Table 4**
AST–built environment relationship within different buffer distances around home and school locations ($n$ = 2190 students).

| | 250 m buffer | | | | 400 m buffer | | | | 800 m buffer | | | | 1000 m buffer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Home | | School | | Home | | School | | Home | | School | | Home | | School | |
| | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR |
| MALE (ref = FEMALE) | **0.33** (0.11) | **1.40** | **0.31** (0.11) | **1.36** | **0.32** (0.11) | **1.38** | **0.29** (0.11) | **1.34** | **0.32** (0.11) | **1.38** | **0.30** (0.11) | **1.35** | **0.32** (0.11) | **1.38** | **0.30** (0.11) | 1.35 |
| VEH_LIC | −**0.43** (0.13) | **0.65** | −**0.44** (0.13) | **0.65** | −**0.40** (0.13) | **0.67** | −**0.42** (0.13) | **0.65** | −**0.40** (0.13) | **0.67** | −**0.39** (0.13) | **0.68** | −**0.41** (0.13) | **0.66** | −**0.40** (0.13) | **0.67** |
| DISTANCE | −**1.83** (0.09) | **0.16** | −**1.84** (0.09) | **0.16** | −**1.84** (0.09) | **0.16** | −**1.83** (0.09) | **0.16** | −**1.84** (0.09) | **0.16** | −**1.82** (0.09) | **0.16** | −**1.84** (0.09) | **0.16** | −**1.82** (0.09) | **0.16** |
| WALK_DSTY (ref = Low) | | | | | | | | | | | | | | | | |
| Medium | **0.37** (0.13) | **1.45** | **0.46** (0.13) | **1.59** | **0.38** (0.13) | **1.47** | **0.45** (0.13) | **1.57** | **0.39** (0.13) | **1.48** | **0.47** (0.13) | **1.60** | **0.38** (0.13) | **1.47** | **0.44** (0.13) | **1.56** |
| High | **0.78** (0.15) | **2.18** | **0.86** (0.15) | **2.36** | **0.76** (0.15) | **2.13** | **0.84** (0.15) | **2.31** | **0.75** (0.16) | **2.12** | **0.66** (0.17) | **1.93** | **0.79** (0.16) | **2.21** | **0.58** (0.17) | **1.79** |
| EMP_POP (Ref = Medium) | | | | | | | | | | | | | | | | |
| Low | 0.09 (0.13) | 1.09 | 0.16 (0.13) | 1.17 | 0.05 (0.14) | 1.05 | 0.06 (0.13) | 1.06 | 0.05 (0.14) | 1.05 | 0.07 (0.13) | 1.07 | 0.05 (0.14) | 1.05 | 0.06 (0.13) | 1.07 |
| High | 0.09 (0.14) | 1.09 | 0.09 (0.14) | 1.10 | 0.13 (0.14) | 1.13 | 0.11 (0.14) | 1.12 | 0.11 (0.14) | 1.12 | 0.10 (0.14) | 1.10 | 0.12 (0.14) | 1.12 | 0.12 (0.14) | 1.13 |
| BLOCK_DTY[a] | *0.04* (0.02) | *1.04* | 0.03 (0.02) | 1.03 | ***0.02*** (0.01) | ***1.02*** | 0.01 (0.14) | 1.01 | *0.01* (0.00) | *1.01* | 0.00 (0.00) | 1.00 | 0.00 (0.00) | 1.00 | 0.00 (0.00) | 1.00 |
| FOURWAY_DTY[a] | −0.33 (0.32) | 0.72 | −***0.65*** (0.31) | ***0.52*** | −0.63 (0.47) | 0.53 | −***0.80*** (0.44) | ***0.45*** | −0.65 (0.75) | 0.52 | −0.23 (0.75) | 0.79 | −0.99 (0.85) | 0.37 | −1.09 (0.86) | 0.33 |
| LIGHT_DTY[a] | ***1.03*** (0.45) | ***2.80*** | −0.20 (0.55) | 0.82 | 0.80 (0.70) | 2.21 | −0.34 (0.86) | 0.71 | −0.12 (1.28) | 0.88 | 1.08 (1.36) | 2.96 | 0.36 (1.50) | 1.43 | 1.91 (1.72) | 6.76 |
| MAJOR_RD_DTY[a] | −0.01 (0.01) | 0.99 | −*0.04* (0.02) | *0.96* | 0.01 (0.02) | 1.01 | −0.04 (0.03) | 0.96 | 0.03 (0.03) | 1.03 | 0.01 (0.04) | 1.01 | 0.02 (0.05) | 1.02 | −0.03 (0.05) | 0.97 |
| LOWINCOME(ref = No)[a] | −0.12 (0.13) | 0.88 | 0.00 (0.14) | 1.00 | 0.15 (0.16) | 1.16 | **0.59** (0.25) | **1.81** | 0.36 (0.26) | 1.44 | 0.60 (0.39) | 1.83 | 0.15 (0.31) | 1.17 | ***0.89*** (0.40) | ***2.43*** |
| Intercept | **2.06** (0.23) | **7.83** | **2.27** (0.23) | **9.66** | **1.97** (0.24) | **7.16** | **2.39** (0.24) | **10.94** | **20.1** (0.25) | **7.47** | **2.05** (0.25) | **7.79** | **2.08** (0.25) | **7.97** | **2.06** (0.26) | **7.87** |
| Summary statistics | | | | | | | | | | | | | | | | |
| $-2\ [L(0) - L(\mathrm{B})]$ | 900.4 | | 894.9 | | 898.4 | | 892.7 | | 897.6 | | 885.7 | | 895.5 | | 290.9 | |
| AIC | 2099.5 | | 2105.0 | | 2101.5 | | 2107.2 | | 2102.3 | | 2114.2 | | 2104.4 | | 2109.0 | |
| McFadden's $\rho^2$ (adj.) | 0.303 (0.298) | | 0.301 (0.297) | | 0.303 (0.298) | | 0.300 (0.296) | | 0.302 (0.297) | | 0.298 (0.293) | | 0.301 (0.297) | | 0.300 (0.295) | |

*Note:* AST, active school transportation; DA, census dissemination area; TAZ, traffic analysis zone; OR, odds-ratio; AIC, Akaike information criterion.
Coefficients in **bold** are significant at $p \leqslant 0.01$, coefficients in ***bold italics*** are significant at $p \leqslant 0.05$; coefficients in *italics* are significant at $p \leqslant 0.10$.
[a] Variables were calculated separately for each neighborhood definition (i.e., 250 m buffer, 400 m buffer, 800 m buffer, 1000 m buffer). Other environmental data were available only at the TAZ level.

**Table 5**
AST–built environment relationship within the DA and TAZ of home and school ($n = 2190$ students).

| | DA | | | | TAZ | | | |
|---|---|---|---|---|---|---|---|---|
| | Home | | School | | Home | | School | |
| | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR | Coef. (S.E.) | OR |
| MALE (ref = FEMALE) | **0.32** (0.11) | **1.37** | **0.29** (0.11) | **1.34** | **0.32** (0.11) | **1.37** | **0.30** (0.11) | **1.34** |
| VEH_LIC | −**0.45** (0.13) | **0.64** | −**0.43** (0.13) | **0.65** | −**0.40** (0.13) | **0.67** | −**0.40** (0.13) | **0.67** |
| DISTANCE | −**1.84** (0.09) | **0.16** | −**1.85** (0.09) | **0.16** | −**1.84** (0.09) | **0.67** | −**1.83** (0.16) | **0.16** |
| WALK_DSTY (ref = Low) | | | | | | | | |
| Medium | **0.40** (0.13) | **1.49** | **0.44** (0.13) | **1.55** | **0.38** (0.13) | **1.46** | **0.48** (0.13) | **1.61** |
| High | **0.85** (0.14) | **2.34** | **0.86** (0.15) | **2.37** | **0.78** (0.16) | **2.17** | **0.75** (0.16) | **2.13** |
| EMP_POP (Ref = Medium) | | | | | | | | |
| Low | 0.09 (0.13) | 1.10 | 0.03 (0.13) | 1.03 | 0.05 (0.14) | 1.05 | 0.00 (0.13) | 1.00 |
| High | 0.11 (0.14) | 1.11 | 0.11 (0.14) | 1.12 | 0.13 (0.14) | 1.14 | 0.13 (0.14) | 1.14 |
| BLOCK_DTY[a] | ***0.01*** (0.00) | ***1.01*** | ***0.01*** (0.00) | ***1.01*** | 0.01 (0.01) | 1.01 | 0.00 (0.01) | 1.00 |
| FOURWAY_DTY[a] | −0.40 (0.24) | 0.67 | 0.25 (0.27) | 1.29 | −0.57 (0.56) | 0.56 | 0.23 (0.62) | 1.25 |
| LIGHT_DTY [a] | 0.54 (0.36) | 1.72 | −0.20 (0.82) | 0.82 | 0.48 (0.77) | 1.62 | ***1.95*** (0.89) | ***7.02*** |
| MAJOR_RD_DTY [a] | −0.00 (0.01) | 1.00 | −0.02 (0.02) | 0.98 | 0.03 (0.03) | 1.03 | *0.06* (0.03) | *1.06* |
| LOWINCOME (ref = No) [a] | −0.16 (0.14) | 0.85 | ***0.32*** (0.16) | ***1.38*** | 0.19 (0.21) | 1.21 | 0.31 (0.27) | 1.36 |
| Intercept | **2.14** (0.21) | **8.49** | **2.40** (0.22) | **10.98** | **2.04** (0.24) | **7.68** | **1.75** (0.31) | **5.73** |
| Summary Statistics | | | | | | | | |
| −2 [L(0) − L(B)] | 899.4 | | 893.2 | | 896.2 | | 891.2 | |
| AIC | 2100.5 | | 2106.7 | | 2103.7 | | 2108.7 | |
| McFadden's $\rho^2$ (adj.) | 0.302 (0.298) | | 0.300 (0.296) | | 0.301 (0.297) | | 0.300 (0.295) | |

*Note:* AST, active school transportation; DA, census dissemination area; TAZ, traffic analysis zone; OR, Odds-ratio; AIC, Akaike information criterion.
Coefficients in **bold** are significant at $p \leqslant 0.01$, coefficients in ***bold italics*** are significant at $p \leqslant 0.05$; coefficients in *italics* are significant at $p \leqslant 0.10$.
[a] Variables were calculated separately for each neighborhood definition (i.e., 250 m buffer, 400 m buffer, 800 m buffer, 1000 m buffer). Other environmental data were available only at the TAZ level.

model fit with increased neighborhood size is noticeable), but the individual coefficients related to the neighborhood environment characteristics were inconsistent. The signs of observed associations changed for some variables across spatial unit specifications. For example, for the models estimated with the environmental variables measured within a 250 m buffer of residence and school locations (hereafter called the 250 m models), both MAJOR_RD_DTY and LOWINCOME near the home location were negatively associated with AST. But, when these measures were aggregated at the scale of a 400 m buffer (i.e., 400 m models), positive correlations were observed for both variables. However, signs of the statistically significant environmental variables remained largely unchanged by adjustments in the scale of geographic aggregation. In contrast, the statistical significance and the size of the coefficients varied noticeably across different scales of analysis (Tables 4 and 5). In other words, the impact of each variable on AST odds was inconsistent across scales of analysis. The largest number of environmental associations with active travel mode choice (3 coefficients at $p \leqslant 0.05$; combined from home-end and school-end models) was found for the 400 m models and the DA models. At larger scales (i.e., 800 m models, 1000 m models, TAZ models), fewer environmental characteristics were shown to associate with the odds of taking active transportation.

Fig. 2 summarizes the variation in the statistically significant built environment coefficient values across different neighborhood definitions. The purpose of this figure was to examine the difference in the coefficient size of a variable, across the scales of measurement. Although LOWINCOME was conceptualized in this study as a neighborhood attribute, Fig. 2 focuses specifically on neighborhood design characteristics, and compares estimated coefficients for four built environment measures only. None of the built environment variables were associated (at $p \leqslant 0.05$) with AST at the scales of 800 m and 1000 m; these two spatial units were therefore not included in this figure. Fig. 2 indicated the presence of scale effects in all built environment measures except MAJOR_RD_DTY, which was not a statistically significant predictor of AST at any scale/zone system. Among the three other variables, only FOURWAY_DTY near the school location remained statistically significant in both 250 m and 400 m models. No other built environment measures were significant (or not-significant) at $p \leqslant 0.05$ consistently across all scales of geographical aggregation, within each zoning scheme. In addition, the coefficient values clearly changed between geographical units of analysis. The figure also demonstrated that there was no obvious trend in how the coefficient values changed with geographical scale.

### 3.2. Zoning effect

The spatial data aggregation methods tested in this study demonstrated some zoning effects. Both the statistical significance and size of the built environment variables changed, somewhat inconsistently, across different zoning schemes at a comparable scale (e.g., 250 m buffer versus DA) (Tables 4 and 5). In order to examine the potential zoning effects in further detail, the built environment coefficients across spatial units at a similar scale were compared using the standard-difference-in-means test [1]. The estimated coefficients from the 250 m models were compared with the coefficients from the DA models, and the coefficient values from the 800 m models were compared with the values obtained from the TAZ models. The results are presented in Table 6. The estimated coefficients of half of the built environment variables statistically varied between the two aggregation schemes. No particular pattern, however, was present in the observed variation in coefficient estimates. The statistical significance, size and direction of the BE–AST association varied inconsistently between the buffers and census boundaries at different scales.

### 3.3. Correlates of AST

All estimated models included the same variables, but the environmental measures were aggregated based on a different neighborhood construct for each set of models. Tables 4 and 5 indicated that male students were more likely to use an active travel mode for trips to school. A household's access to private automobiles was negatively associated with AST. Children were also more likely to walk/cycle to school if they lived close to their

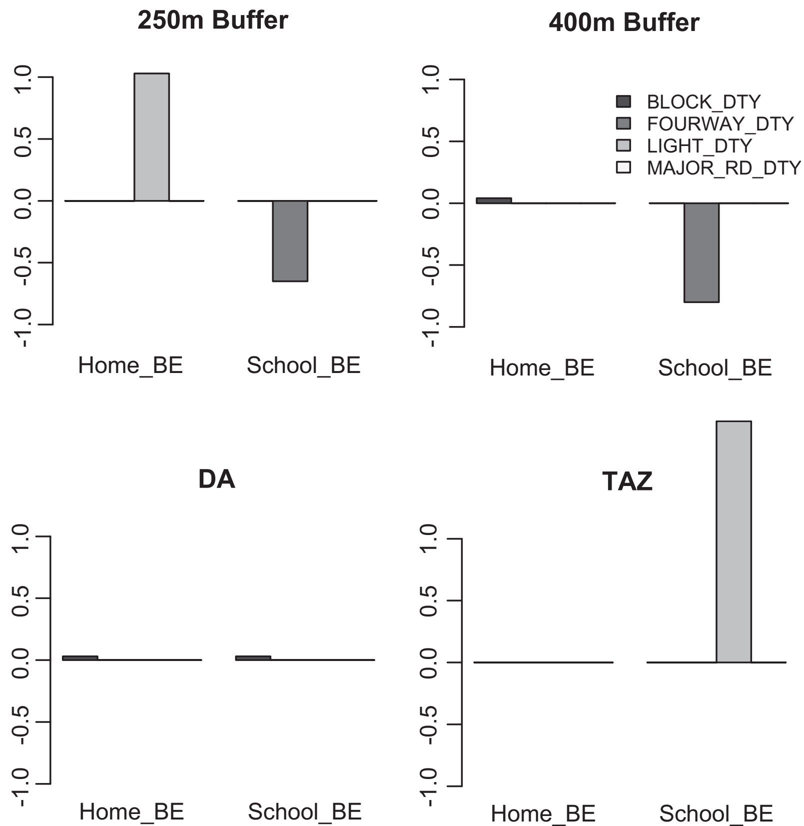


**Fig. 2.** Coefficient values for statistically significant built environment variables. *Note:* Home_BE, built environment near home location; School_BE, built environment near school location; DA, census dissemination area; TAZ, traffic analysis zone. *Y*-axis values represent the size of the estimated built environment coefficients.

**Table 6**
Standard-difference-in-means test of zoning effects in the built environment measures.

| | 250 m buffer Coef. (S.E.) | DA Coef. (S.E.) | *t*-diff. | 800 m buffer Coef. (S.E.) | TAZ Coef. (S.E.) | *t*-diff. |
|---|---|---|---|---|---|---|
| *Home model* | | | | | | |
| BLOCK_DTY | 0.04 (0.02) | 0.01 (0.00) | **6.000** | 0.01 (0.00) | 0.01 (0.01) | −0.500 |
| FOURWAY_DTY | −0.33 (0.32) | −0.40 (0.24) | 0.835 | −0.65 (0.75) | −0.57 (0.56) | −0.417 |
| LIGHT_DTY | 1.03 (0.45) | 0.54 (0.36) | **5.644** | −0.12 (1.28) | 0.48 (0.77) | −1.186 |
| MAJOR_RD_DTY | −0.01 (0.01) | −0.00 (0.01) | **−3.000** | 0.03 (0.03) | 0.03 (0.03) | ***−2.00*** |
| *School model* | | | | | | |
| BLOCK_DTY | 0.03 (0.02) | 0.01 (0.00) | 1.471 | 0.00 (0.00) | 0.00 (0.01) | 0.667 |
| FOURWAY_DTY | −0.65 (0.31) | 0.25 (0.27) | **−21.116** | −0.23 (0.75) | 0.23 (0.62) | **−3.496** |
| LIGHT_DTY | −0.20 (0.55) | −0.20 (0.82) | 0.004 | 1.08 (1.36) | 1.95 (0.89) | −1.831 |
| MAJOR_RD_DTY | −0.04 (0.02) | −0.02 (0.02) | **−17.000** | 0.01 (0.04) | 0.06 (0.03) | **−5.875** |

*Note:* DA, census dissemination area; TAZ, traffic analysis zone.
Coefficients in **bold** are significant at $p \leqslant 0.01$, coefficients in ***bold italics*** are significant at $p \leqslant 0.05$.

schools. The density of walking trips near both home and school locations were associated with AST; a child was more likely to walk/cycle to school in places where other people also walked.

The correlation between AST and the neighborhood environment varied across the estimated models. Block density within 400 m of a child's home, and in the DA of a child's residence and school locations, were positively associated with the odds of AST participation (demonstrated by OR > 1, in Tables 4 and 5). Higher density of four-way intersections (i.e., the proportion of total street intersections that are four-way) within 250 m and 400 m of the school location reduced the odds of active versus passive travel. The abundance of signalized intersections close to home (i.e., within 250 m buffer distance), and within the TAZ of school increased the odds of AST. Children attending schools located in low-income neighborhoods (measured using a 400 m or 1000 m buffer, and within the DA of a school) were more likely to actively travel to school than others; socio-economic status of the home neighborhood was not statistically associated with walking/cycling. Land use mix (i.e., employment-to-population ratio) and the density of major roads near the residence or school were also not associated with mode choice.

## 4. Discussion and conclusions

This research is the first to explore the potential impact of the MAUP, more specifically, the presence of scale and/or zoning effects in the measurement of the neighborhood environment, on an observed association between built environment characteristics and AST. Objective measures of built environment characteristics were estimated for six different spatial units and entered into six sets of logistic regression models of school travel mode choice for trips to school. Only small variation in model fit was observed across different geographical representations, which is not surprising given that the objectively measured built environment was only moderately associated with AST. If the MAUP did not exist across different geographical aggregation schemes, there would also be little variation in the coefficients of the built environment variables among the estimated models (Fotheringham and Wong, 1991). Instead, the results indicated that the statistical significance, size, and in a few cases, the direction (i.e., the sign) of the built environment coefficients changed with a change in the scale for spatial data aggregation. Statistically significant differences in regression coefficients across different zoning schemes suggested the presence of zoning effects.

While these results were suggestive of the presence of the MAUP (i.e., scale and zoning effects) in statistical analysis of the BE–AST relationship, they were not prescriptive. The statistically significant environmental coefficients were not uniformly at their largest value at any particular scale/zone system. A statistically consistent/reliable spatial unit specification for the study of school travel behavior therefore may not exist, as different environmental factors may operate on the mode choice process at different scales. In general, for the City of Toronto, more built environment characteristics were associated with mode choice when these environmental measures were generalized to a 400 m buffer around home and school locations, compared to buffers at other scales, and spatial units taken from census or the TTS (i.e., producing different zoning effects).

Implicit to this and other studies that attempt to quantify relationships between local built environments and mode choice is the assumption that the decision maker has complete and directionally invariant environmental information around the origin, destination, and/or the travel route (e.g., the built environment within a buffer distance or within a census boundary) (Lee and Moudon 2004; Schlossberg et al., 2006). In reality, perhaps, an individual's sense of place is more heavily influenced by the places he/she actually possesses some knowledge about (i.e., the action space) or experiences directly (i.e., the activity space) within a neighborhood, city, or region (Horton and Reynolds, 1971). The way in which space and place are conceptualized in this study and others like it, packaged as abstract and modifiable digital geographies containing objectively measured data about the environment, might evolve through additional engagement with the theoretical and empirical studies of behavioral geography and more recent research situated within a similar framework (Buliung and Kanaroglou 2006; Horton and Reynolds 1971).

With regard to the environmental correlates of AST, the school transportation literature conceptualizes proximity to school and safety as two major domains through which the built environment influences walking/cycling (McMillan, 2005; Mitra, 2011). Similar to previous research (e.g., Ewing et al., 2004; McDonald, 2008a; Mitra et al., 2010), this paper indicates that school travel distance, and thus, longer walk/cycle travel time, was an important factor in mode choice for school transportation. Grade 5 students who travel 1 mi (translated as 1.5 or 1.6 km straight line distance) or more are eligible for the school bus service offered by Toronto's public and catholic school boards, which may also reduce the propensity of active traveling to school beyond that distance. This consistent finding is particularly important in the context of the economic rationalization of public school systems that is currently underway in the US and Canada (Basu, 2007; Schlossberg et al., 2006). Smaller neighborhood elementary schools are closing and certainly there has been an emerging conversation within school boards to consider closure of neighborhood schools in favor of larger "economically efficient" alternatives. These larger schools will accommodate more students, from a larger area, potentially leading to increased use of the automobile and other passive (or perhaps, less active) modes such as school buses. The effect of this economic rationalization of the supply of schools on school travel behavior should receive greater attention in research and policy.

Relating to traffic and pedestrian safety, the regression results suggest that signalized intersections (i.e., the proportion of street intersections that are signal-controlled) were associated with active travel to school, probably because of increased safety from motorized traffic. A neighborhood with smaller blocks (i.e., with a higher block density), which is largely representative of an inner-city, safe (from traffic), and walkable environment, was also associated with AST. This research also found a negative correlation between a high proportion of four-way intersections (i.e., representing a grid street network) and active travel. A grid-based street network may encourage adult walk trips by providing increased connectivity. But, this type of street network typically represents busy urban streets with potentially high traffic volumes, which may act as a barrier for active traveling to school.

In addition to the potential effects of street network design, walking school trips were more common in neighborhoods where other people walked for work or school travel purposes. A high walking rate could be facilitated by neighborhood built environment characteristics (Ewing and Cervero, 2010; Transportation Research Board, 2005). The WALK_DSTY variable was not correlated with the other environmental measures that were examined, but it may potentially capture the effects of some built environment variations that remain unexplored in this study. With regard to children's school travel, a neighborhood with high prevalence of walking can also produce a sense of pedestrian safety, and provide opportunities to produce and maintain social capital (Leyden, 2003; Mitra et al., 2010). Previous research has found that parents who valued the importance of a child's interaction with others (particularly, with other children) on the way to school were more likely to let their children actively travel to school (McMillan, 2007; Timperio et al., 2006). In contrast, objectively measured safety outcomes (i.e., the prevalence of collisions involving pedestrians/ cyclists near home or school) were not correlated with the mode choice decision; similar findings have also been reported elsewhere (Panter et al., 2010).

These results can be encouraging to the planning of a design based intervention to enable AST among children, such as the ones undertaken by the Federally funded Safe Routes to School (SRTS) programs in the US and the community/grass-roots Active and Safe Routes to School (ASRTS) campaign in Canada (Active and Safe Routes to School, 2010; National Center for Safe Routes to School, 2007). Particularly in the US, the SAFETEA-LU federal transportation legislation in 2005 devoted $612 million to implement the SRTS programs across the country. The individual SRTS programs were undertaken between then and 2009, and much of the spending was focused on an improvement in the built environment along school travel routes. Results from this study suggested that the design characteristics of a neighborhood that potentially create walkable and safe streets, particularly close to home locations, may increase the odds of active travel among children.

This study has several strengths and limitations. The travel data were drawn from a large population-based survey of travel behavior. Residential and school locations of this large sample were situated across a diversely developed urban landscape within the City of Toronto, which generated significant variation in the built environment measures. But, and similar to some other studies (e.g., Kerr et al., 2006; Larsen et al., 2009; Panter et al., 2010), travel modes were generalized into broader "active" and "passive" categories. Recent empirical research has emphasized differences in behavioral processes across individual travel modes, such as between driving, using transit, cycling and walking (Ewing et al., 2004; Lin and Chang, 2010; Yarlagadda and Srinivasan, 2008). While these potential differences are acknowledged, the purpose of this research was to examine the use of active modes compared to all other potential options, a topic that is relevant to the understanding of the geography of school transportation, and also to urban planning interventions.

Moreover, this paper purposefully explored AST behavior of 11–12 year old children only. The adoption of this approach limits the generalizability of findings to children and youth of other age groups. The school travel mode choice process may indeed be moderated by age (Mitra, 2011; Panter et al., 2008). The interaction between a child's cognitive development with age, and a household's sense of place, could produce more autonomous travel as a child ages, and also increase the use of different modes that are eventually matched to the growing spatial and social capabilities of aging children (e.g., taking transit). These "age effects" are not well understood, and remain an important area for empirical, policy-based research.

Despite these limitations, this study makes an important contribution by advancing the current approach to understanding school travel behavior through quantitative analysis. Importantly, this paper attempts to inform the emerging AST literature of the role of geography, or arbitrary geographies, on the modeling and understanding of children's school travel behavior, an issue that has not received adequate attention in the literature. This study addressed the potential measurement errors due to MAUP, and reported the BE–AST associations for six neighborhood representations. The results are suggestive of the presence of some scale and zoning effects, evidence that supports the primary hypothesis of this article that the MAUP may partly explain the inconsistency in empirical findings of the existing AST literature. Having not addressed the MAUP issue adequately, studies that use a single geographical representation of the neighborhood construct may produce misleading results. Future research can benefit from following a similar procedure applied in this study for assessing potential ecological uncertainty, and may report estimation results at different levels of geographical aggregation. As suggested by others (Zhang and Kukadia, 2005), a strong behavioral justification for the selection of spatial units, which takes into account the interaction between human behavior and the surrounding physical environment, may also be a useful approach to consider.

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