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Pathways to Active School Travel: The Influence of Individual, Sociodemographic, and the School Neighborhood Factors

Nathaniel C. Frisbee, *Western University*

Supervisor: Gilliland, Jason, *The University of Western Ontario*

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Abstract

This thesis evaluates the influence of school environment, sociodemographic, and household characteristics on the likelihood that a child will use active school travel (AST). Situated within Bronfenbrenner's ecological systems theory, the research examines intrapersonal, interpersonal, environmental, and policy factors impacting AST. Data is sourced from various publicly available sources and a province-wide survey. Two studies were conducted to address the key research questions. The first study employs spatial analysis within a geographic information system (GIS) to quantify built environment attributes such as sidewalks, road length, greenness, and dwelling density. Statistical techniques reveal that student age, length of sidewalks, and outdoor temperature are significant drivers of AST. The second study focuses on trip distance and the total length of local roads around a school (within 1600m) as critical factors influencing AST. The findings from both studies suggest that certain school environment characteristics significantly impact AST, with trip distance emerging as the most important factor. These insights contribute to the understanding of how various factors at different levels influence active school travel and provide a basis for policy and intervention strategies to promote AST.

Keywords: Active School Travel; GIS; Statistical Analysis; Built Environment; Sociodemographic Characteristics; Household Characteristics; Bronfenbrenner's Ecological Systems Theory

Summary for Lay Audience

This thesis investigates how built environment characteristics, sociodemographic, and household characteristics influence a student's choice to engage in AST. Using an ecological model as a framework, this thesis looks at multiple levels of influence, including individual, household, school, and environmental factors.

The research utilized survey data and techniques within geographic information systems (GIS) to analyze factors impacting students' transportation choices. A challenge of quantifying the built environment is the difference in measurements and variables across studies. This thesis improves upon prior research by using the same variables in each chapter to mitigate discrepancies in measurement. In Chapters 3 and 4, survey data combined with built environment features such as road lengths, sidewalks, and dwelling density. This approach tested statistical significance in factors associated with AST.

Key findings of Chapter 3 indicate older students are more likely to engage in AST. The study also identified the length of sidewalks within 1600m of the school was positively associated with AST. Additionally, outdoor temperature plays a significant role in AST, impacting both younger and older students. Survey data for this chapter was gleaned from BikeWalkRoll.org, which provides modal choice information of students based on a classroom.

Chapter 4 expanded the analysis in Chapter 3 by using the same built environment dataset, incorporating a provincial survey that provided new insights on sociodemographic and household characteristics. The analysis focused on students living 1600m or closer to their school. It revealed the distance from home to school is the most important factor influencing AST; the further a student lives from school the less likely they are to engage in AST.

This thesis emphasizes the importance of infrastructure such as sidewalks and road networks in promoting AST. Implications of this work can guide policy to improve the built environment and ensure students live within a walkable distance to school, increasing the likelihood of engaging in AST.

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List of Abbreviations

Abbreviations are listed in alphabetic order:

ASRTS: Active and Safe Routes to School

AST: Active school travel

AT: Active transportation

BWR: Bike-Walk-Roll

CF: Climactic Factors

DB: Dissemination Block

EQAO: Education Quality Assessment Office

GIS: Geographic Information Systems

KWC: Kitchener-Waterloo-Cambridge area in Ontario

MAUP: Modifiable areal unit problem

MOT: Mode of Travel

MT: Measurement theory

NHTS: National Household Travel Survey

OAST: Ontario Active School Travel

PA: Physical Activity

POI: Points of Interest

SES: Socioeconomic status

STP: School travel planning

UGCoP: Uncertain geographic context problem

VIF: Variance Inflation Factor

1.0. Chapter 1: Introduction

1.1 Introduction to the Current Research Problem

Active School Travel (AST) is any form of human-powered, non-motorized transportation to get to and from school (Buttazzoni et al., 2018; McDonald, 2007). AST has important health and environmental benefits. AST positively impacts child health through improving physical fitness, improving mental and social wellbeing, and creates a healthier environment around schools by reducing vehicular air pollution (Gilliland et al., 2019; Lambiase et al., 2010; Larouche et al., 2014; Medeiros, 2020; Ramanathan et al., 2013). Despite these benefits, AST in North America has been declining for several decades. In the United States, children engaging in AST has decrease from 48% in the 1960s to just 13% and, in Canada, there has been an increase in inactive forms of transportation from 51% to 62% between 2000 and 2010 (Builing et al., 2009; Canadian Fitness and Lifestyle Research Institute, 2010; Ham et al., 2008; Larsen et al., 2012).

AST, and any use of active transportation (AT), has positive environmental implications, particularly through the reduction of emissions from traditional gas vehicles. Hong (2018) identifies three key pathways linking AT to improved environmental quality: 1) small form factor, 2) clean transportation, and 3) less waste and fewer resources (Hong, 2018). First, AT modes require very little physical space when compared to the traditional automobile. When an individual parks a car, it requires approximately 3-times as much space as taking public transportation and 10-times more space than a parked bike (Nello-Deakin, 2019). Further, other studies have estimated that a driving a car takes up to 70% more space than a cyclist or pedestrian (Gossling, 2020). Second, AT is a cleaner form of transportation that does not negatively impact air quality, a well-established contributor to adverse human health outcomes. Globally, air pollution has been identified as the fifth-leading risk factor for premature mortality that, in 2015, caused and estimated 4.2 million deaths worldwide (Cohen et al., 2017; Glazener & Khreis, 2019; WHO, 2018). Additionally, emissions from automobiles contribute to poorer air quality that, subsequently, exacerbate cardiovascular and pulmonary disease risk factors (Gouldson et al., 2018; Patz et al., 2014). Third, AT uses less energy and resources, including financial resources, compared to private vehicles. Results from a study by Gossling et al. (2022), estimated that car ownership disproportionately costs low-income individuals more than high-income individuals and that lifetime costs of car ownership ranged from $870,310 to $1,389,941 depending upon the type of car driven. In comparison, AT modes have negligible lifetime costs.

Over the last several decades in North America, AST has declined, and motor vehicle use has become the preferred form of travel to school (McDonald, 2007; Builing et al., 2009; McDonald et al., 2011; Larsen et al., 2016). This shift from AST to motorized, non-active forms of transportation to school has, almost certainly, impacted the daily physical activity levels of children. Physical activity is important for overall child health and wellbeing. While the benefits of physical activity in children include better cholesterol levels, lower rates of obesity, cardiovascular fitness, increased bone mineral density, and improved mental health (Janssen & LeBlanc, 2010), lower physical activity is a well-established risk factor for increased obesity, cardiovascular disease, diabetes, musculoskeletal diseases, and other chronic diseases that persist into adulthood and, so, affect health over the life course (Trost et al., 2001; Janseen and LeBlanc, 2010: Fogelholm, 2010; Laitinen et al., 2001; Mamum et al., 2009; Must et al., 2005; Van Lenthe et al., 1996; Cleven et al., 2020; Sallis et al., 2020).

Globally, the observed increase in childhood obesity has been linked to a lack of physical activity and poor diet (Lobstein et al., 2005). In Canada, estimates are that 26%-29% of children are overweight or obese (Simen-Kapeu & Veugelers, 2010; Shields, 2005; Vander Ploeg et al., 2012), which has been attributed to fewer than half of Canadian children consuming a healthy diet, low levels of physical activity, and high levels of sedentary activities, estimated at an average of 8.4 hours/day (Rao et al., 2017). Recent Canadian guidelines recommend 60 minutes of moderate-to-vigorous physical activity every day for youth ages 5-11 years and 12-17 years (Tremblay et al., 2011), though only 29% of children between the ages of 5 and 17 years meet these recommended levels of physical activity (Roberts, 2019) and this has further declined in 7% of all Canadian youth between 2016 to 2021 (Canadian Fitness and Lifestyle Research Institute, 2023). Importantly, particularly within the context of this thesis, the most common setting for physical activity for children is school (Vander Ploeg et al., 2012). With youth – and students – becoming less physically active and increasingly more at risk for long-term chronic health issues, there is a population health policy need to increase physical activity. Thus, as students who use AT to get to school have higher levels of physical activity compared to students who do not (Delisle Nystrom et al., 2019; Larouche et al., 2014), transportation planning approaches to encourage AST may increasingly be regarded as a health promotion policy lever to encourage physical activity in school-aged youth.

Given this mounting need for the development of effective policy approaches to increase AST, understanding the factors associated with AST in youth is paramount. To date, substantial research has focused on the complex relationships between socio-economic status (SES) and factors within the built environment and AST. While previous studies have reported that students from lower SES households are more likely to engage in AST (Gray et al., 2014; Molina-Garcia & Queralt, 2017), a private family vehicle is a significant mediator in the relationship between SES and AST (Molina-Garcia & Queralt, 2017; Rothman et al., 2018). However, as reported by previous studies, there is likely a complex and interactive effect between SES and characteristics of the built environment, particularly walkability, which is related to neighborhood-level SES, age of the student, and AST (Molina-Garcia & Queralt, 2017; Molina-Garcia et al., 2017). Other contextual factors that may affect the direct association between AST and SES include higher crime rates and greater dangers from vehicular traffic (Sallis et al., 2011; Zhu & Lee, 2008) as well as more motor vehicle collisions, and with a higher mortality rate (Stoker et al., 2015), in lower SES neighborhoods. Additional factors that have been identified and discussed as further complicating AST decisions include age, gender, and the distance between home and school, though substantial inconsistencies between studies have been noted (Javadpoor et al., 2023).

Inconsistent findings from previous studies assessing factors affecting AST decisions are likely due to two interdependent analytic challenges facing all geographic researchers. The first issue is the Modifiable Areal Unit Problem (MAUP), which is the sensitivity of the geographical measurement and how the measurement relates to the scale in which they were taken (Fotheringham and Wong, 1991). Simply put, different measurements of the same variable at different geographic scales yield different results. The second issue is the Uncertain Geographic Context Problem (UGCoP), which acknowledges the limitations of areal aggregation to determine a single, area-based attribute and how the use of these attributes, specifically ascribing them to individuals, could impact the results from different statistical analyses or methodologic approaches (Kwan, 2012b). In particular, assigning a single, arbitrarily defined area-based attribute to an individual ignores the impact of the spatial and temporal context of that attribute, which is both dynamic and different across individuals in the same assigned area, thus creating uncertainty in the interpretation of analytic results (Kwan, 2012b). The UGCoP is further exacerbated with the use of variable approaches to measuring and / or quantifying (ostensibly) the same construct across different studies, with an unclear understanding of whether the metrics are comparable either within or between studies. For example, sidewalks around a school can variously be quantified as the total length of sidewalks, the density of sidewalks per unit area, or the proportion of streets (or street-distance) with sidewalks, without a clear understanding of the impact of these different metrics either between individuals in the same geographic unit or between individuals in different geographic units. This uncertainty contributes to the likelihood of different observations both across time and between studies and complicates our understanding of the effects of built and social environments on human behavior and phenomena (Kwan, 2012a).

1.2. Theoretical Framework

The foundational theoretical framework for the research presented in this thesis is Bronfenbrenner's Ecological Systems Theory (Bronfenbrenner, 1977). As depicted in Figure 1.1, this theory emphasizes a hierarchy of contextual factors related to a particular outcome and, thus, provides an excellent organizing framework for studying and understanding factors related to AST decisions. Specifically, this framework will assist in identifying factors at the individual and family level, neighborhood level, SES factors, and characteristics of the built and school neighborhood environment that influence AST. Further, Bronfenbrenner's Ecological Systems Theory is consistent with Tobler's First Law of Geography, which states, "*…everything is related to everything else; but near things are more related than distant things…"* (Tobler, 1970, pp. 236). Previous research on AST suggests that the most influential factor in AST is the distance between home and school (Ikeda et al., 2018; Mammen et al., 2014). Thus, Tobler's First Law of Geography and Bronfenbrenner's Ecological Systems Theory will guide the studies described in this thesis interrogating factors affecting AST decisions.

Figure 1.1. Graphical Depiction of Bronfenbrenner's Ecological Systems Theory (Wilson, 2017, pp. 4)

1.3. Research Question and Objectives

Guided by both Tobler's First Law of Geography and Bronfenbrenner's Ecological Systems Theory, the overall goal for this thesis is to understand the individual and contextual factors that influence a student's modal decision to engage in active school transportation. Specifically, the principal research question for this thesis is, "What are the individual and school neighborhood environment factors that impact a student's decision to engage in AST?", where, for the purposes of this thesis, school neighborhood environment factors encompass a range of physical and built environmental characteristics such as the length of sidewalks, road length, greenness, parks, cycling infrastructure, and intersection density (refer to Appendix 1A for further clarification of school neighborhood environment variables).

To explore the overarching goal of this thesis and investigate the principal research question, the following research objectives will be addressed:

1. Conduct a comprehensive literature review to summarize the individual and school neighborhood environment factors previously identified as affecting AST decisions, as well as the methodologic and analytic challenges, and strategies to address these challenges, in investigating the relationships between individual and school neighborhood environment factors and AST decisions;
2. To investigate, using multi-level statistical modeling and a GIS-created buffer approach, the individual and school neighborhood environment factors that influence AST and transportation modal choice in elementary school students in the Kitchener-Waterloo-Cambridge region of Ontario, Canada;
3. Using different accessibility methodologies and a transportation-route analysis, assess the the individual and school neighborhood environment factors that influence AST decisions in elementary school students in Ontario, Canada.

1.4. Thesis Format: Integrated Article

This thesis is presented in the integrated article format, with five specific chapters.

In **Chapter 1**, this chapter, an introduction to the thesis is provided, including an overview of the key scientific literature, the theoretical framework guiding the thesis research, the overall thesis research goal and principal question, the research objectives, and the thesis format.

In **Chapter 2**, a comprehensive literature review that addresses the first research objective (above) is provided. Specifically, this literature review summarizes the individual and school neighborhood environment factors previously identified as affecting AST decisions, as well as the methodologic and analytic challenges, and strategies to address these challenges, in investigating the relationships between individual and school neighborhood environment factors and AST decisions.

Chapter 3 and **Chapter 4** describe and present the results from two distinct quantitative studies, each employing distinct geographic and statistical methodologies, and in distinct data sets. Both

Chapters are presented in a format prepared for submission to peer reviewed academic journal and address the second and third research objectives, above. As previously described, the research design and operationalization for both studies was guided by both Tobler's First Law of Geography and Bronfenbrenner's Ecological Systems Theory. Further, the two studies presented in these Chapters employ both two unique data sets, both situated in Ontario, Canada (refer to Figure 1.2), that focused on children's travel behaviors to-and-from school.

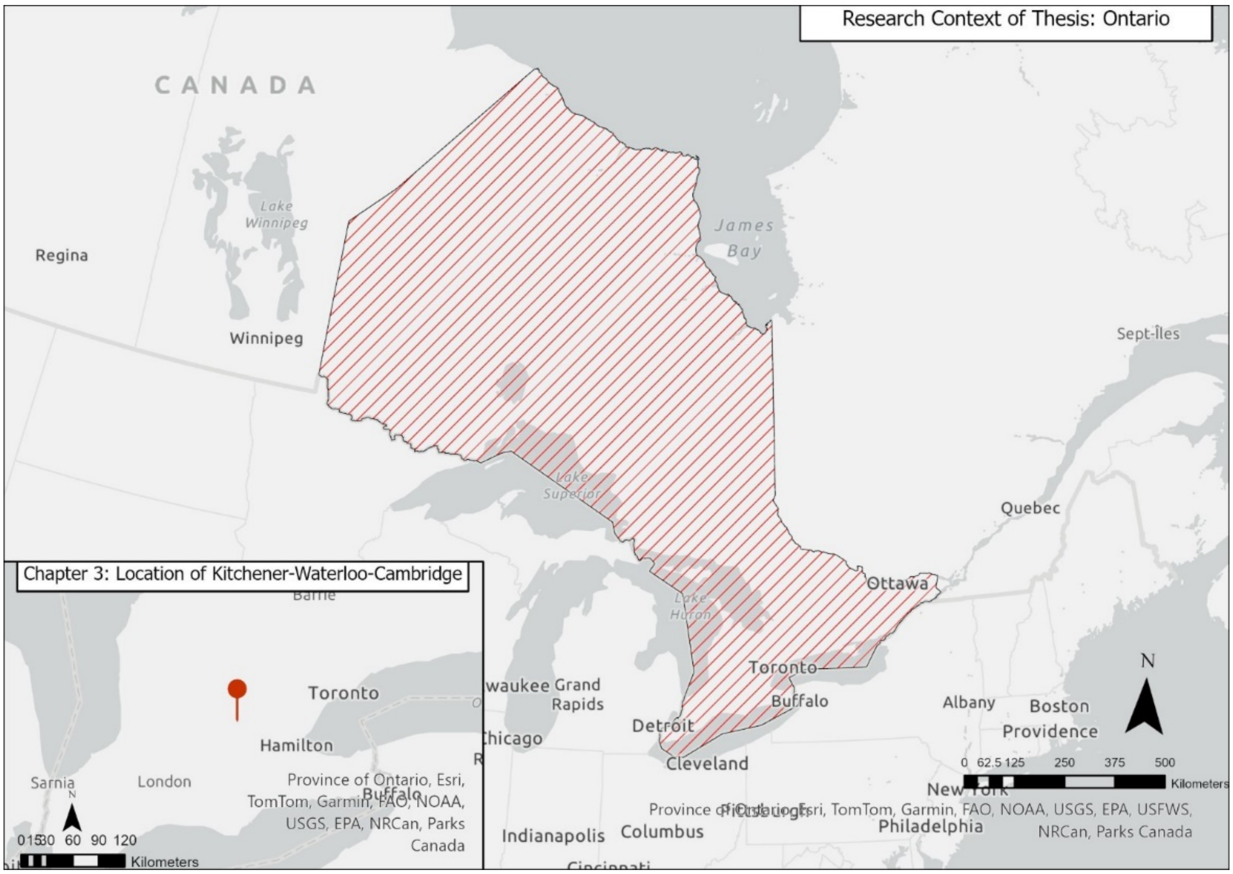

Figure 1.2. Study Areas (Source: ArcGIS Pro 3.2.2.)

The specific research questions addressed in the study presented in **Chapter 3** include:

1. What are the travel behaviors of students between kindergarten – 8th grade?
2. What school neighborhood environment factors are significant in AST?

This study analyzes publicly available data from the Bike Walk Roll organization (bikewalkroll.org) (BWR), combined with additional spatial and SES data to create a bespoke dataset that provides school transportation information on a per-grade level for students in the Kitchener-Waterloo-Cambridge (KWC) region. The analytic methodology for this study includes a traditional Euclidean buffer-based form of analysis for accessibility around a school and determines the proportion of students engaging in AST to schools as well as the school neighborhood environment factors associated with AST.

The specific research questions addressed in the study presented in **Chapter 4** include:

1. What are the school neighborhood environment factors that are significant in AST?
2. What are the sociodemographic and household characteristics that are significant in AST?

This study analyzes data collected by Leger on behalf of the Human Environment Analysis Laboratory (HEAL) at the University of Western Ontario, combined with additional spatial and SES data. The analytic methodology for this study includes the shortest network paths along the street network to model accessibility to a school and a combined approach for testing the significance of school neighborhood environment factors by comparing school neighborhood environment, home environment, and the environment along the route to and from school.

Finally, **Chapter 5** will summarize and synthesized the findings from the studies presented in Chapters 3 and 4, present a discussion of the results, and provide suggestions for future research.

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2.0. Chapter 2: Literature Review

In this Chapter, a comprehensive literature review that addresses the first thesis research objective is provided. Specifically, this literature review summarizes the individual and school neighborhood environment factors previously identified as affecting AST decisions, as well as the methodologic and analytic challenges, and strategies to address these challenges, in investigating the relationships between individual and school neighborhood environment factors and AST decisions.

2.1. The Policy Context for the Current Research

As presented in the Introduction in Chapter 1, active school travel (AST) has declined globally as society has shifted towards automobile transport (Fyhri et al., 2011; Tremblay et al., 2014). Lu et al. (2014) and Aranda-Balboa et al. (2020) both identified that, in North America, the distances between home and school have increased, while parental perceptions about the safety of the built and social environment for AST have substantially declined. Further, as also described in the Introduction in Chapter 1, the decline in AST has been accompanied by a concomitant decline in physical activity and increase in obesity in children, while understanding that AST can improve physical health through increased cardiovascular fitness and better body composition (Larouche et al., 2014; Lubans et al., 2011). That is, transportation planning approaches to encourage AST are increasingly regarded as a health promotion policy lever to encourage physical activity in school-aged youth. Given this mounting need for the development of effective policy approaches to increase AST, understanding the factors associated with AST in youth is paramount.

In Canada, the Active and Safe Routes to School (ASRTS) program is a national health initiative developed by Green Communities Canada. ASRTS implements school travel planning (STP) models from other North American active school travel (AST) programs (Active and Safe Routes to School, 2018a) with the goal to increase AST knowledge and participation rates among school children and their families (Buttazzoni et al., 2018). As ASRTS works with school boards and governmental organizations to improve AST engagement, a key policy objective to support population health objectives, it will appear in multiple sections in the review of literature, below.

2.2. Qualitative and Quantitative Studies Active School Transport Research

AST research can be organized into three methodological approaches: qualitative, quantitative, and interventions, such as STP programs including ASRTS.

2.2.1. Qualitative Research in Active School Transport Research

Qualitative AST research provides insight into parental, students, and educators perceptions regarding facilitators and barriers to AST, which are important for informing research and policy about AST interventions (Buttazzoni et al., 2018).

2.2.1.1. Parental Perceptions

Parental perceptions are a substantial determinant of child AST, as parents typically make travel modal decisions based on perceived safety risks to their children (Ahern et al., 2017; Chillion et al., 2014; Wilson et al., 2018; Zuniga, 2012). Mah et al. (2017) identified parents as the "gatekeepers" of their children's travel choices. Parental support for AST can be influenced by factors including traffic volume, child safety, and the ability of the student to learn the route to school (Faulkner et al., 2010; Mah et al., 2017), as well as parental confidence in their child's ability to independently navigate to and from school and successfully manage different traffic conflict scenarios (Shliselberg and Givoni, 2016). Dangerous intersections, traffic volume, travel distance, speed of traffic, crime, no trusted adults to supervise the trip, weather, and the child's ability are all perceived, by parents, as barriers to AST (Chillon et al., 2014; Huertas-Delgado et al., 2018; Lu et al., 2015; Martins et al., 2016; Pfledderer et al., 2021). The social environment in the home and school neighborhood environment are also important parental perceptions that influences AST (Nystrom et al., 2023), with children in low-income neighborhoods and households are more likely to have less adult supervision than those in high-income neighborhoods and households (Dodd et al., 2021; Mitra et al., 2014). For example, children from disadvantaged neighborhoods in Quebec engaged in AST more, even though they are exposed to more dangerous transportation environments (Pabayo et al., 2012). Furthermore, a study in Sweden showed that parents engage in 'risk management' when it comes to their children engaging in AST, as they wish to support independent mobility but ensure their safety (Joelsson, 2019). Finally, prior research on parental perception of AST suggests that children are more likely to engage in AST if their parents do (Carlson et al., 2014; Henne et al., 2014).

2.2.1.2 Student Perceptions

Qualitative approaches to better understand child perspectives on AST is critical, as objective measurements of these factors might not encapsulate their true impact on transportation behavior decision-making (Wilson et al., 2018). Previous studies have established that children who engage in AST tend to be more physically active throughout the day compared to children who do not use AST (Larouche et al., 2014; Tremblay et al., 2015) and AST can improve student mental health, academic performance, overall fitness, spatial awareness, and cognitive development (Mendoza et al., 2011; Oliver et al., 2011; Ramanathan et al., 2014; Singh et al., 2012). Unfortunately, only 24% of Canadian children engage in AST (ParticipACTION., 2016; Wilson et al., 2019).

An informative study by Wilson et al. (2019) surveyed students regarding barriers and enablers of AST in the surrounding environment of their school who identified pedestrian friendly infrastructure, including sidewalks, stop signs, short cuts, and a short travel distance as enablers of AST. These children also identified that AST was influenced by their moods, feelings, and positive interactions with the social environment around them, such as interpersonal interactions with crossing guards (Wilson et al., 2019). The findings of Wilson et al. (2019) are consistent with previous studies of children's perceptions of barriers and facilitators of physical activity behaviors (Ahlport et al., 2008; Kirby & Inchley, 2009; Mulvihill et al., 2000; O'Dea, 2003; Romero, 2010).

To date, there has been little research investigating how AST is affected by the overall attractiveness and aesthetics of a trip to school (Van Kann et al., 2015). There are inconsistent findings regarding the importance of the perceived attractiveness of a trip, with only some studies reporting that the attractiveness of a trip to school can increase rates of AST (Mitra, 2013). Diversity in land-use mix, and subsequent perceptions about features in the built environment that may or may not be attractive, may also impact AST (Ikeda et al., 2018; Mitra & Buliung, 2015). Several previous studies have reported that neighborhood is a predictor for AST (Ding et al., 2011; Lobstein et al., 2004; Rybarczyk, 2018), and perceptions about whether the built environment in the neighborhood is supportive of AST (Wilson et al., 2018). Even with a differing land-use mix in neighborhood environment, the results on its impact on AST are inconsistent (Larsen et al., 2009; Wong et al., 2011) and further research is needed to fully understand and determine the impact of land-use mix on AST rates amongst children.

2.2.1.3. Educator Perceptions

Educators play an important role in guiding AST by either adopting policies that supports AST or promoting and modeling it in the classroom. However, while AST can be greatly influenced by educators (Ontario Active School Travel, 2020), there are significant challenges facing educators when promoting AST.

2.2.1.3.1. Liability

A key contributor to successfully expanding AST at a school are initiatives supported by partnerships between community groups and parent council groups (Price et al., 2011) as well as community stakeholders, parents, public safety officials, municipal governments, and schoolteachers and administrators (Eyler et al., 2008a; Eyler et al., 2008b; National Center for Safe Route to School, 2010). Considered a non-curriculum item in Ontario, a decision to adopt – or not – a program to support AST is greatly influenced by and under the discretion of the local school board, superintendent, and / or schoolteachers and administrators in individual school (Office of the Auditor General of Ontario, 2021; Flessa, 2012; Sturm, 2005). In considering factors that influence perceptions and, so, decisions regarding AST programs in schools, Price et al. (2011) conducted a survey to evaluate school leader perceptions of AST and identified liability and safety as the two biggest concerns and barriers to adopting and promoting AST at the school level. Put simply, the question, "*What happens if a student who is walking to school gets hurt, are we held liable for that injury?"* was repeatedly raised regarding the school's role in AST and a reason that schools do not adopt programs to promote AST (Price et al., 2011).

2.2.1.4. School Travel Planning

School Travel Planning (STP) is an approach that may address perceived liability risks and improve school support for AST. As defined by Green Communities Canada, *"STP is a multi-disciplinary, multi-sectoral, school-specific, intervention that engages key stakeholders, such as public health officers, police, planners, school boards, parents, children, and school administrators/teachers, in the survey and evaluation of school travel issues"* (Green

Communities Canada, 2007, pp. 1). That is, individuals and stakeholders from the public, private, and non-profit sectors partner to develop and implement a plan of action to increase AST at a specific school (Mammen et al., 2014).

STP has been reported as an effective strategy to increase AST by decreasing car trips to a school (Deligianni et al., 2021). For example, Cairns et al. (2005) reported that STPs reduced car traffic around schools from 8%-15% in the United Kingdom (Cairns et al., 2005). Another study, in New Zealand, estimated that STP interventions increased AST by 2.5% country wide (Hinckson et al., 2009). In Canada, a study of 12 STPs reported that AST increased by 2.1% and that 13.3% of participating households reduced car-based trips to school (Buliung et al., 2011). Additionally, STPs improve perceived safety surrounding schools, which further supports AST (Buliung et al., 2011; Deligianni et al., 2021).

However, research findings on the effectiveness of STP to increase AST has not been consistent. Baslington (2008) reported that STP programs can be limited in their effectiveness by support from parents. Additionally, Mammen et al. (2014) and Teixeira et al. (2019) demonstrated that the context of the built environment around a school is an important predictor of STP success: if the built environment around a school is not already conducive to active travel, then STP does not have a meaningful impact. Other studies have identified household income and cultural associations as influencing STP efficacy (Deligianni et al., 2021) and that older children, parental engagement in active travel, and parents without a driver’s license were predictive of more AST after the introduction of an STP intervention (Hennec et al., 2014). However, STP interventions do not appear to increase AST in lower income communities (Molina-Garcia and Queralt, 2017; Rothman et al., 2018).

2.2.2. Quantitative Research in Active School Transport Research

Quantitative research studies have identified a wide range of factors related to both individual and family as well as environmental characteristics that are associated with AST, including demographic and SES factors, characteristics of the household and home environment, the school neighborhood environment, route-based environmental factors, and other characteristics of the neighborhood and built environment (Larsen et al., 2012; Sirard et al., 2008).

2.2.2.1. Household Characteristics and Active School Travel

Individual and household characteristics may affect AST at multiple levels of the framework described by Bronfenbrenner's Ecological Systems Theory (Giles-Corti et al., 2005; Lu et al., 2014; Ikeda et al., 2018). Prior research has identified that parental education, household income, car ownership, and ethnicity are associated with AST (Pont et al., 2009; Rothman et al., 2018). The association between SES and AST is complex, as both the SES of the household and SES of the neighborhood are determining factors in school modal transportation decisions. SES of both the household (Pont et al., 2009; Rothman et al., 2018) and the neighborhood (Medeiros et al., 2021) are associated with AST, with lower SES generally associated with higher levels of AST, though this association may be influenced by lower accessibility to cars (Rothman et al., 2018). In lower SES neighborhoods, there may be inequities in the built environment that support AST. In particular, there may be poor infrastructure, traffic dangers, and higher crime rates (Medeiros et al., 2021; Sallis et al., 2011). Previous research has suggested that higher SES neighborhoods have better infrastructure to support AST, including sidewalks and cycling infrastructure (Sallis et al., 2011) and that this infrastructure is better maintained in higher SES communities (Zhu & Lee, 2008). For lower SES neighborhoods, challenges including higher crime rates and traffic congestion likely serve as to AST (Medieros et al., 2018; Sallis et al., 2011; Zhu & Lee, 2008).

A child's ethnicity and cultural background may also affect their willingness to engage in AST (Medeiros et al., 2018). In the United States, minority ethnic groups are more likely to engage in AST compared to white children (Davison et al., 2008; Pont et al., 2009; Rothman et al., 2018) whereas, in North America, Asian children are the least likely to engage in AST (Rothman et al., 2018). In New Zealand, being a recent immigrant was associated with higher AST engagement (Pont et al., 2009). Results from studies in the United Kingdom have reported similar results to those in North America, indicating that South Asian children are more likely to be driven to school when compared to white students and Afro-Caribbean students (Owen et al., 2012). It has been theorized that the differences in AST participation across ethnicities stem from parenting styles (Medeiros et al., 2021). Karsten et al. (2015) state that Chinese parents in North American are less likely to grant their children independent mobility, meaning they are supervised more by their parents and less likely to engage in AST.

Finally, many studies investigating predictors of AST have reported that the most important factor in AST is where the student lives. In particular, the distance from home to school is considered to be the strongest predictor of AST (Easton & Ferrari, 2015; Lobstein et al., 2004; Rojas Lopez & Wong, 2017; Rybarczyk, 2018). These findings place an emphasis on the role of the built environment in AST, which is discussed in the next section.

2.2.2.2. The Built Environment and Active School Transport

As previously highlighted, AST has decreased in North America while motor vehicle use has become the more common form of travel to and from school (McDonald, 2007: Buliung et al., 2009; McDonald et al., 2011, Larsen et al., 2016). The change from more active forms of transportation to motorized non-active forms has reduced the daily physical activity levels of children, with subsequent deleterious impacts on overall child health and wellbeing (Trost et al. 2001; Janseen and LeBlanc, 2010: Fogelholm, 2010). Transportation planning and health promotion praxis could be better informed by understanding the environmental factors that affect AST behavior.

2.2.2.1.1 Approaches in Built Environment Research

Previous studies investigating the association between the built environment and AST, particularly in elementary school children, have reported various, and often inconsistent, findings (Larsen et al., 2016). Larsen et al. (2016) identifies three common methodological approaches to measuring the built environment in AST research: neighborhood buffers, shortest path networks, or participant mapped routes. A common issue with these approaches is both Type 1 and Type 2 errors, that is the chance false positive or false negative results, as reported by other studies (Ewing et al., 2004; Timperio et al., 2006; Merom et al., 2006; Schlossberg et al., 2006), and these errors can lead to incorrect conclusions about the existence of statistical significance between factors and AST.

Using neighborhood buffers is a common practice in the studies examining associated between elements in the built environment and AST (Braza et al., 2004; Kerr et al., 2006; Frank et al., 2007; McMillan et al., 2007; Larsen et al., 2009). The most common approach to measuring features in the built environment is using the school as the origin point and identifying a radial distance from that point to represent the surrounding neighborhood area. The most widely accepted distance cut-off used is 800m (10-minute walk) or 1600m (20-minute walk) for the radial buffer (Pinna & Murrau, 2018). While this method may not identify specific built environment features an individual child will encounter on their specific journey to school, it creates an average value of the built environment features in that area which may be applicable to all students at the school. This method is most likely to be affected by an ecological fallacy.

Other studies examine linkages between AST and the built environment by finding the shortest path between a child's home and school (Schlossberg et al., 2006, Timperio et al., 2006, Panter et al., 2010; Panter et al., 2011; Larsen, Gilliland, and Hess, 2012). Theoretically, the shortest path might be a better way of finding that relationship between built environment factors and AST, but to accurately identify the shortest path an origin and destination point must be identified, which can be difficult to attain based on privacy concerns held by institutional research ethics boards, school boards, and parents. Proxies like the centroid of the surrounding dissemination area or six-digit postal code for the home could be used, but this would not be applicable for all students in that area. Shortest path analysis also selects shortest path between two points by distance which is not always the actual route a child might take to and from school (Buliung et al., 2013). Children may take a longer path to get to school simply to walk with a friend or to avoid an uncomfortable area, or to avoid complicated or major traffic intersections. The third way to identify linkages between AST and the built environment is a mapped route analysis. Larsen et al. (2013), explored the use of this measurement, alongside traditional measures, in modelling AST travel behavior among elementary school students. Route-based analysis identifies what built environment factors students are interacting with daily while engaging in AST. A route-based analysis can potentially provide a better understanding of AST by creating a more comprehensive picture of the built environment that a student would encounter on a trip to school (Giles-Corti et al., 2011; Panter et al., 2016). However, route-based analysis has not been widely deployed as a methodology, limiting the conclusions that can be drawn about its effectiveness in modelling AST behavior.

From this discussion, it is clear that studying associations between the built environment and AST faces several theoretical and methodological challenges, which are discussed in more detail in the next section.

2.3. Core Theoretical and Methodological Challenges

2.3.1. Theoretical Challenge: Measurement Theory

The built and social environment plays a substantial role in guiding the decision to engage in AST (Buttazzoni et al., 2018; Larsen et al., 2012). The quantification of factors in the built and social environment can be informed by measurement theory (Stevens, 1946). Measurement posits that measurements are not the same as the attribute being measured and thus, when making conclusions, one must factor in the nature of the relationship between the attributes and its measurement (Stevens, 1946; Sarle, 1995). Accounting for measurement theory within the design of AST studies will enable more meaningful and effective research.

2.3.1.1. Types of Data

In geography, there are four main types of data: nominal, ordinal, interval, and ratio (Christman, 1995). Nominal data points are assigned the same symbol/number if they have the same value (Christman, 1995). Ordinal data points are assigned numbers that reflect an order to a measurement (Sarle, 1995). Interval data points are assigned numbers that reflect differences between attributes (Sarle, 1995). Ratio data points are assigned numbers such that the differences and ratios between numbers reflect the ratio between attributes (Sarle, 1995). Measurement theory is important in geographic research, as geographic data are often arbitrary representations of observable conditions at specific points in time (Sarle, 1995). Pertaining to AST, consider a dataset that includes the date associated with active travel modality for students in elementary or middle schools. The researcher may incorporate temporal factors into the analysis of modal choice for AST, such as daily weather. How a researcher chooses to classify the effect of weather on travel behavior is arbitrary, but meaningful. However, these arbitrary decisions have implications during statistical analysis, where statistical models are used to “test” for an association between variables (Sarle, 1995). In making statements or conclusions about such statistical analyses based on arbitrary data points, caution is needed as these arbitrarily assigned data points used to represent “reality” may render the interpretation of results illogical (Sarle, 1995).

2.3.1.2. Measurement Theory in Active School Transport Research

The previously discussed decrease in AST and concomitant decrease in physical activity decreased by a third since the late 1970s (Hu & Reuscher, 2001). Coinciding with the decrease of physical activity and active travel, there has been a decline in active school travel (AST) with children (Buttazzoni et al., 2018). AST participation has been in decline for several decades and several external factors are causing this decline (Buttazzoni et al., 2018; Larsen et al., 2012). Some of these external factors are increased distances of travel to and from school, parental perceptions of safety, increased motor vehicle use, and a decrease in the quality of a built environment that is conducive to AST (Fotel & Thomsen, 2003; Larsen et al., 2012). My research will identify factors, both in the built and social environment, that influence the choice of engaging in AST. Measurement theory is important to consider in constructing representations about how sociodemographic characteristics affect AST behaviour. Certain sociodemographic characteristics are easier to define, such as gender, which can be self-reported by students, but characteristics such as parental influence on active travel, perceived safety from traffic, and pleasurability of the area of active travel are more difficult to accurately measure (Craig et al., 2002; Pikora et al., 2002).

As discussed by Velleman and Wilkinson, the decision on the scale of measurement should not be made randomly, as it could lead to inadequate data and bias the statistical analysis (Velleman & Wilkinson, 1993). This becomes even more challenging when looking to determine if specific sociodemographic characteristics are more predictive of AST than others, based on the established ranking system. An additional challenge that MT reveals in the sociodemographic characteristics of AST is how to measure when a parent says "no" to their child using active travel. This is something that cannot be easily measured, so predictive measurements are made to estimate the influence that a parent has in regard to their student engaging in AST. MT reveals that this area of geographic research is hindered by its reliance on arbitrary metrics that explain real-world phenomena, when the measurements may not truly represent what is happening.

2.3.1.3. Measurement Theory and Built Environment Research

Traditional built environment research looks at three main elements: density, diversity, and design (Cervero & Kockelman, 1997). These three elements have been associated with characteristics of the surrounding area such as the population density, land use, public spaces or park areas (Handy et al., 2002). MT is important in evaluating the built environment because the built environment is empirical data, other researchers can verify empirical data by checking your source, and this can satisfy MT by being grounded in reality. Additionally, when measuring the built environment, discrete variables are commonly measured. For example, for research on AST, when an investigator is examining built environment characteristics such as sidewalks, roads, bike lanes, and street trees. All these variables have been associated with AST, but these variables are discrete (Larsen et al., 2012). Sidewalks have a beginning and an end, the same goes for roads and bike lanes, and the presence of street trees can be clearly measured by just looking at the area for the presence of trees. MT does not have anything to do with what is a discrete or continuous variable, but it can help us determine what form of statistical analysis is most appropriate for the kind of data that is collected (Sarle, 1995). There is some flexibility within MT, as it has been shown by S.S Stevens (1946), that it is possible for the transformation of scale to occur within measurements (Stevens, 1946). This means data collected on the built environment can be transformed to make statistical analysis much more feasible. MT allows for the transformation of data to collect the mean, standard deviation, and the coefficient of variation (Sarle, 1995). In AST research, this makes running statistical analysis much easier. Being able to transform the data allows for a better statistical analysis of significance MT helps built environment measurements by allowing other researchers to validate the measurements that were collected, and it allows the transformation of data to make statistical analysis much more valid in their measurements.

2.3.1.4. Measurement Theory and Qualitative Research

Measurement tools for qualitative data collection that can help represent social and behavioral geographies have also come a long way in their effectiveness (Onwuegbuzie et al., 2010). One of the biggest criticisms that you can make when looking to apply MT to qualitative data is that the measurements one will make when collecting qualitative data is subject to bias. Much research has investigated ways to eliminate this bias, which has led to eight themes of questions that must be addressed when collecting this data (Onwuegbuzie et al., 2008). Elements like the researchers' background or their perception of the participant, the perception of non-verbal communication, and the professional impacts based on the findings based on the researcher are all things that need to be factored in when looking to critically evaluate qualitative measurements (Onwuegbuzie et al., 2008). MT is very critical of qualitative measurements as it is very hard to quantify these metrics because they are context dependent based on the dynamics between the researcher and the participant (Guba & Lincoln, 1989).

2.3.1.5. Tools to Address Measurement Theory in Academic Research

Geography researchers benefit from having a wide assortment of quantitative measurement tools. Tools such as GIS, RStudio, Python, and mobility trackers have given researchers access to immediate and reliable forms of data to measure (Goodchild, 2010). However, with the rise of tools such as GIS researchers began to find that measurements were not inaccurate when using these tools, but instead they were measurements that were not fully established (Burrough & Frank, 1996). Fundamentally, geographic researchers are faced with an impossible task; take real geographic world measurements which are in three dimensions, and then translate it to a platform that is only able to show data in two dimensions (Goodchild, 2010). This challenge has led to many discussions on how to solve this issue, which is why MT is important when taking geographic measurements.

It is important for geographic researchers to consider whether MT could be impacting in their analysis. Acknowledging its impact can help eliminate bias and it can show limitations of the research. There have been significant steps in quantitative research using MT. This can assist in validating measurements that can then enable researchers to establish a specific set of parameters designed to yield optimal results using contemporary measurement tools. Even with the advancements in quantitative measurements there is still room for improvement with qualitative measurements. Continual research is needed on how to remove measurement bias when conducted qualitative measurements as it still is an arbitrary metrics, which according to MT makes these measurements illogical (Sarle, 1995). However, MT has allowed the field of geography to enhance its data collection strategies, providing a more accurate representation of real-world phenomena.

MT has been shown to play a pivotal role in AST research methodologies, especially when looking to quantify built environment measurements to mitigate discrepancies. As these methodologies evolve beyond traditional quantitative geographic research, it is important to incorporate MT approaches into these measurements. This can help transportation planners and policymakers better understand and assess the safety around schools and then provide the opportunity for improvement. The remainder of this thesis will look to apply these MT strategies to identify better associations with AST and the built and sociodemographic environment.

2.3.2. Methodologic Challenge: The Modifiable Areal Unit Problem (MAUP)

Inconsistent results observed in AST and built environment research is likely caused by the modifiable areal unit problem (MAUP), the sensitivity in which geographical measurements are taken and how they relate to the scale in which they are taken (Fotheringham and Wong, 1991). The three main methods in AST research show how the built environment can influence travel behavior changes based on how researchers measure them. Each measurement strategy has a flaw in its analysis and assumptions, which limits accurate and precise quantification of the built environment. If a researcher is looking to identify if the length of sidewalks is significant in AST, the method of analysis could yield different results. Based on how you measure their presence you could get a different number, which is the MAUP. For example, if someone were to analyze the length of sidewalks at the neighborhood level compared to an analysis of sidewalks done at a block level. The difference in measurements could lead to inconsistent results about the relationship between sidewalk length and AST. This is important to consider when quantifying the built environment.

The MAUP, according to Heywood et al. (2006), occurs when "*arbitrarily defined boundaries are used for the measurement and reporting of spatial phenomena"* (Heywood et al., 2006, pp. 192). The MAUP is comprised of two effects: scale and zoning (Clark and Scott, 2014). The scale effect refers to the spatial resolution of data; where the zoning effect refers to the configuration of the spatial boundary delineation system (Clark and Scott, 2014). To this date, there has been very little research done on the impact of both the scale and zonal effect on built environment research. One study found that as the scale of the measure increases the coefficients of the associated results decrease (Zhang and Kukadia, 2005). The zoning effect is more challenging to compute. The example of a dissemination area (DA) is an example of how the zoning effect can impact results. While DAs are, generally speaking, similar in size and population they are not similar in general shape. Mitra and Buliung (2012) conducted a study intentionally investigating a home to traffic analysis (Mitra and Buliung, 2012). To attempt to mitigate the zonal effects impact on a measurement it is best practice to conduct analysis at uniform sizes. This way, even if areas are different sizes, like DAs, the measurement is consistent at all levels.

2.3.3. Methodologic Challenge: The Uncertain Geographic Context Problem (UGCoP)

The uncertain geographic context problem (UGCoP) looks to explore the effects of an area-based attribute and how measuring that attribute could impact different kinds of statistical analysis methods (Kwan, 2012). This is because arbitrary spatial units are being used to derive area-based variables in the pursuit of statistical significance (Kwan, 2012). The second issue, which Larsen et al. (2016) outlines that the UGCoP, in that how we are measuring Socioeconomic Status (SES) variables and how different SES can influence the perceptions of the built environment. Different SES groups perceive the built environment differently; families and students who are lower in SES do not percieve built environment features as much of a barrier as families and students in higher SES groups (Black et al., 2001; Lee et al., 2013; Panter et al., 2010). Another challenge of the UGCoP is that researchers are unable to precisely implement any kind of spatial and temporal analysis and apply it directly to the child who is choosing to engage in AST in their specific built environment and calculate any kind of influence that individual child will experience. Therefore, there are two substantial geographical measurement issues impacting the overall research on AST.

There is much geographic research on the effects of built and social environments on human behavior and phenomena (Kwan, 2012). AST research is challenged by inconsistent results caused by errors in how measures of the built environment are constructed by researchers (Wilks et al., 2010; Kwan, 2012). I tackle these problems by identifying how the form of measurement and choice of scale affects statistical significance in predicting AST behavior.

2.4. References

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3.0. Chapter 3: A Multi-Level Modelling Approach for Identifying Factors that Influence Active School Travel

3.1. Introduction

Only 29% of children in Canada between the ages of 5 and 17 years meet the recommended physical activity levels for their age (Roberts, 2019). Additionally, 7% of all youth in Canada saw a decrease in their physical activity levels from 2016 – 2021 (Canadian Fitness and Lifestyle Research Institute, 2023). These low levels of physical activity coincide with an observed decrease in active school travel (AST) among this age group in Canada since the 1960s (Buttazzoni et al., 2018). AST encompasses human powered forms of transportation, such as walking or wheeling to/from school (Buttazzoni et al., 2018; McDonald, 2007). Changes in the built form of neighborhoods surrounding schools, accompanied by the broad availability of private motor vehicles at all income levels, results in fewer children engaging in AST as part of their daily routine (Fotel et al., 2003). External factors, such as long-distance travel to school and parental perceptions of safety also limit the ability of students to engage in AST (Larsen et al., 2012).

Previous findings have consistently shown that distance to school is the primary factor determining whether children engage in AST (Lee et al., 2017; Martin and Carlson, 2005; Salmon et al., 2007). Research also indicates that the perceived safety of traveling to/from school can impact students' willingness to engage in AST (Zhu et al., 2011; Zhu and Lee, 2009). Elements such as fast-moving traffic, poor air quality, and poor pedestrian and cycling infrastructure may all be barriers to AST (Zhu et al., 2011). Concepts like 'walkability' and 'bikeability' are therefore important to AST engagement as they relate to the efficiency, safety, and comfort of the circulation networks which support active travel (Cohen et al., 2008; Lowry et al., 2012; Wang & Yang., 2019).

In recent decades, the siting of new schools in North America has tended to focus on development outwards from population centers and into remote areas where they are near high-speed arterials which becomes a substantial barrier to AST (United States Environmental Protection Agency, 2003). Research on the impact of personal and societal factors has shown inconsistent results pertaining to AST (Zhu and Lee, 2009). Some studies show that low-income households and children from ethnic minority groups walk to school more often; but they often do so in an environment that would be perceived as dangerous by others (Braza et al., 2004; Evenson et al., 2003; Ewing et al., 2004; Green et al., 2004; Zhu and Lee., 2008).

The purpose of this study is to identify neighbourhood-level predictors of AST rates in the Canadian context. This study makes use of a previously unanalyzed dataset that measured engagement in AST at a per class level over five years at elementary schools in Kitchener-Waterloo-Cambridge (KWC) Region, Ontario.

3.2. Challenges in Active School Transport Research

There has been extensive research in the transportation, urban planning, and public health fields around active travel behavior. Existing AST research mainly focuses on the factors that are influencing modal choice and the possible shift between non-active travel to active travel (Ermagun & Samini, 2015; Liu et al., 2024; Mehdizadeh et al., 2018). Generally, policymakers are trying to change students' travel behaviors to promote more physical activity and a healthier lifestyle by promoting AST (Liu et al., 2018; Liu et al., 2024). Prior research has shown that there are three main factors that influence AST; household characteristics, personal attributes, and travel characteristics (Li and Zhao, 2015; Sing and Vasudevan, 2018). This inherently brings about a major challenge in AST research in that it is both a social and built-form issue that determines the mode of travel to school.

Recently, there has been an increase in the amount of research that investigates the role that street networks and street-connectivity can impact AST (Torun et al., 2020). Studies have found that the proportion of trips and the overall length of active travel trips are positively correlated with the connectivity of roads, sidewalks, and the density of streets (Kerr et al., 2007; Moudon et al., 2006; Voorhees et al., 2010). A challenge in AST research is that there is not a systematic way to calculate the impact of built environment factors that could impact modal choice. Torun (2020) proposes that this is a spatial structure issue where the spatial structure can be defined in multiple ways (Torun et al., 2020). A possible solution to this for AST research could be using and creating consistent spatial structures, as Torun (2020) defines them, and testing them against AST rates around schools. Given that other researchers such as Ozbil and Peponis (2012) do find that street configurations play a role in walking behavior (Ozbil and Peponis, 2012). This can help guide quantitative AST research further, by consistently defining the spatial structures around schools and the environments that students may face.

The household in which a student lives can potentially be the most meaningful determining factor of AST, as the parent/caregiver of that student is the gatekeeper in modal choice (Mitra, 2013). There are two areas where the household can impact a student's modal choice. The first being social norms and socio-economic status of a household. Household values vary depending on cultural values and those may or may not be supportive of AST (McAlister et al., 2008; Mitra et al., 2010). This can also relate to whether a household can use a private vehicle to drive the student to school (Panter et al., 2008). The second issue presented by the household for AST is the presence of time restricting events; like fixed start/end times, where the job of the car owner might drop the student off on their way to work, or if a family has multiple children, it could be convenient to drive (Faulkner et al., 2010; Mitra and Buliung, 2012). A student's travel behavior can also be easily influenced by their parents/caregivers travel behavior (Mitra, 2013). For AST researchers, it is challenging to identify these specific variables when looking to see what might impact modal choice. Instead, researchers come up with variables that are used as a proxy to these variables that could influence modal choice to school (Buttazzoni et al., 2018).

3.3. Methodology

3.3.1. BikeWalkRoll Survey Data

The BikeWalkRoll (BWR) survey is a publicly accessible and open-source data portal that displays the responses to a survey that is conducted in a classroom by the teacher in the form of a "Hands-up" survey where students raise their hand for how they travelled to school that day. There are six modes of transportation a student can respond to about how they get to school: walk, bike, roll, school bus, public transit, or car. In this case, 'roll' refers to scootering and skateboarding. The teacher records the responses aggregated by classroom and then inputs them, along with grade level, school name, and survey date, into the BWR portal, where they are then posted on a public website. In practice, these surveys are voluntary and therefore not systematically collected across all schools in Ontario but still represent the best known publicly accessible datasets on AST within Ontario. In total, 45,819 survey responses were completed across 25 schools between November 2018 and October 2022 in the KWC region.

Utilizing this open dataset, the proportion of students who engaged in AST was calculated for each day, across each grade, and in each school. Our analysis focused on non-bus eligible students within the KWC region by removing all students who took the school bus to school from the calculation to account for the fact that these students would all live beyond 1.6 km from the school and therefore are unlikely to use AST (STSWR, 2024).

$$AST_{igt} = (W + B + R)/(N - SB)$$

Where AST_{igt} is the active school travel ratio (proportion) for students at school i in grade g on day t and W is the number of students that walked, B is the number of students that biked, R is the number of students who rolled, and N is the total number of students surveyed, and SB is the number of students who took a school bus.

3.3.2. Study Area and School Selection

Schools were selected from the Kitchener-Waterloo-Cambridge Region (KWC) region in Ontario, Canada. This region was chosen as it had the greatest numbers of participating schools and surveys completed. Within the KWC region, 25 schools conducted a BWR survey for elementary children (grades ranging from kindergarten to grade 8, age range from 5 to 13 years) (Figure 3.1).

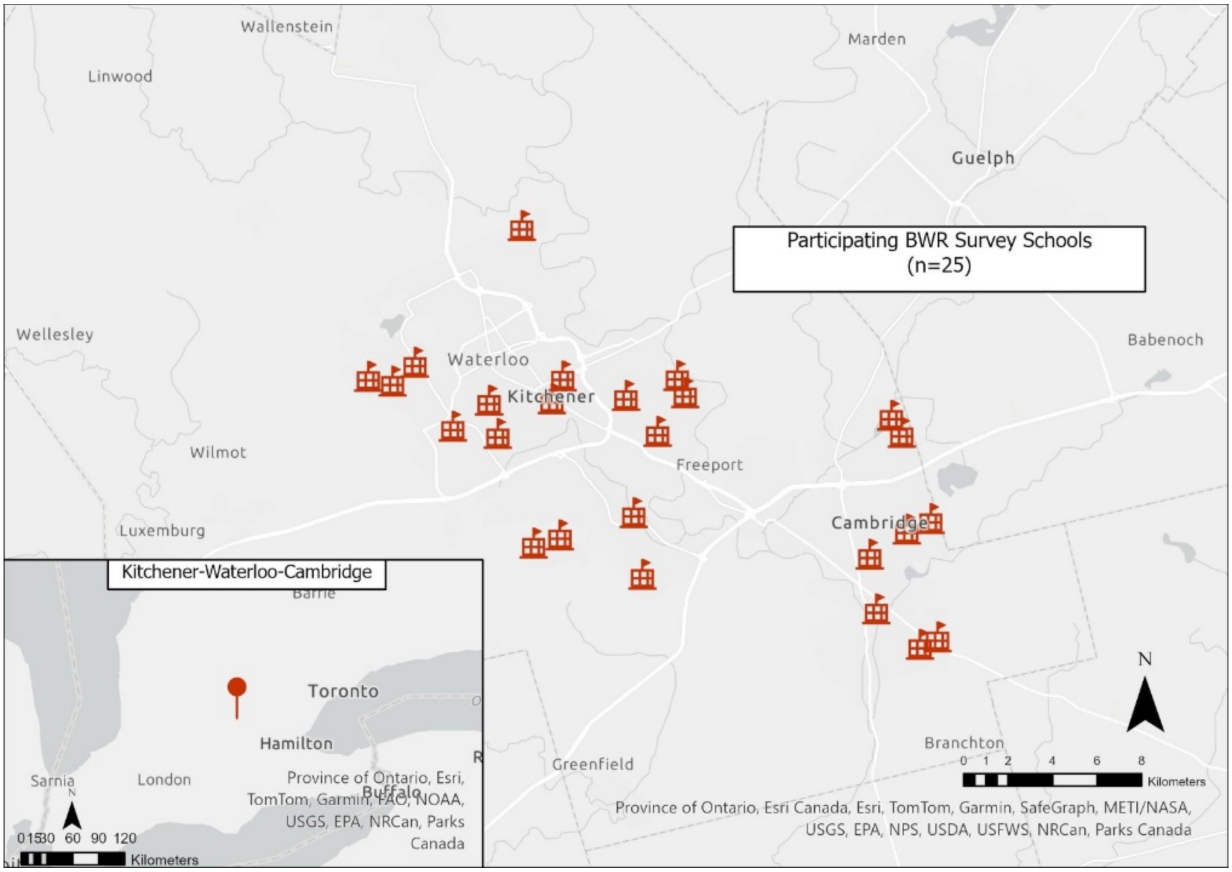

Figure 3.1. Location of the 25 schools in the KWC region that conducted a survey from November 2018-October 2022

3.3.3. Characterizing School Neighborhood Environments

A comprehensive analysis of the school surroundings was conducted using GIS software ArcGIS Pro 3.2.2, which compiled various built environment features within a 1600-meter road network buffer of participating schools. A buffer was then created to encompass and measure the identified features used in this analysis (refer to Figure 3.2). The school neighborhood environment comprises a composite of built environments, socioeconomic indicators, and climatic factors present within the 1600m buffer around the school. In this study, the school neighborhood environment was characterized using 11 unique built environment variables that were quantified using GIS (refer to Appendix 1A). The socioeconomic data used in this study was from the Education Quality and Accountability Office (EQAO) (EQAO, 2022). This dataset contains eight different measurements of socioeconomic and sociodemographic status: parental education level, percentage of low-income households, gifted student percentage, special education student percentage, non-English speaking percentage, non-French speaking percentage, moved from non-English speaking countries and moved from non-French speaking countries (refer to Appendix 2A). SES of individuals and neighborhoods has been shown to influence parental perceptions on (Ikeda et al., 2018). Based on the date the survey was conducted, climatic factor (CF) information was retrieved from a publicly available website, Time and Date, which holds historical weather data (Time and Date, 2024) (refer to Appendix 3A). This information was integral to our study as previous studies have rarely included temporally varying variables such as temperature into AST assessment. These school neighborhood environment features were measured and normalized using z-scores to account for differing units and scales of measurement.

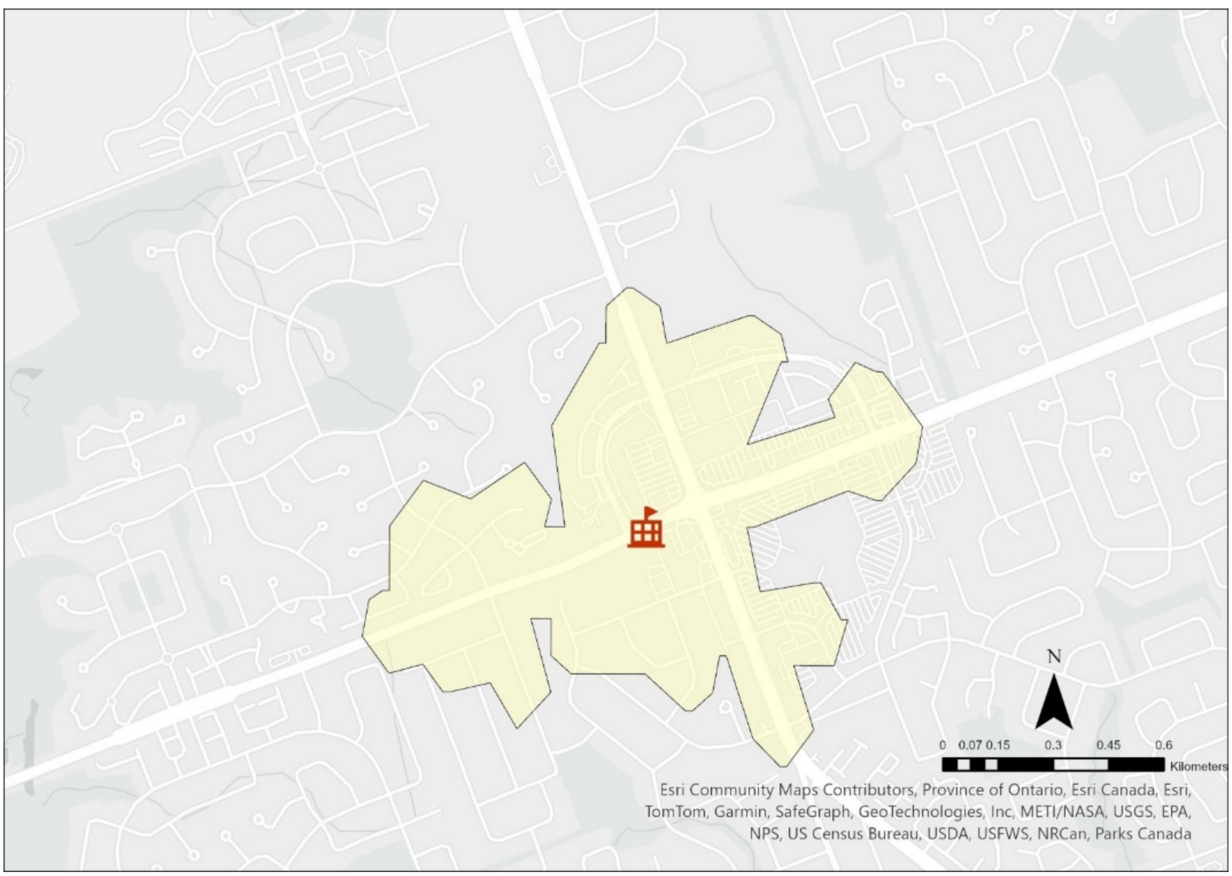

Figure 3.2. Characterization of the School neighborhood environment

3.3.4. Model Selection

A model selection process was employed where all variables were tested for significance and interaction effects. Multicollinearity was assessed using the variance inflation factor (VIF) score to identify predictors demonstrating high degrees of multicollinearity, i.e., those exceeding a VIF >= 5, were then removed from the analysis (James et al., 2013).

A dredge analysis was conducted by testing all combinations of variables to determine which combination resulted in the most parsimonious model for explaining AST, via the lowest AIC value, and then sub sequentially ranking all combinations. A dredge analysis consists of testing variables to determine a model that would best predict the outcome variable (Berry, 1987). This is done by calculating the combination of variables that would be the best fit for that model, ranking AICC values (Berry, 1987). The dredge analysis was repeated for each of the three age/grade groups.

3.3.5. Statistical Analysis

3.3.5.1. Global Model

In preliminary statistical testing of the data regarding school neighborhood environment factors that were significant in AST, it was found that only two variables had a significant impact on the results. The only factors that showed significance in predicting AST were Grade and Temperature in Degrees Celsius (refer to Appendix 4A for global model results). To improve the quality of the results it was found that, based on prior literature illustrating that children tend to overestimate their physical abilities in contrast to their parents, it was deemed appropriate to divide the data by age group (Plumert, 1995). This grouping of data provided the opportunity to undergo the same model selection process that yielded different results. The Intraclass Correlation Coefficient was 0.339, indicating that approximately 33.9% of the variance in AST scores is attributable to differences between schools, a multi-level model was employed to appropriately account for this hierarchical structure in the data.

3.3.5.2. Grade Groupings

The data was initially stratified by grade-level groups to account for age-related ability to engage in AST. Group 1 comprised of kindergarten, 1st, and 2nd grade, consisting of children typically 5-7 years old. Group 2 comprises 3rd, 4th, and 5th graders, which includes children usually aged 8-10 years. Group 3 consisted of 6th, 7th, and 8th graders, or those typically aged 11-13 years. A generalized linear mixed model was used to examine how school neighborhood environment variables were associated with AST, while controlling for the school as a random effect because schools had multiple surveys completed on different days. The school neighborhood environment variables were tested as fixed effects against the AST variable.

3.4. Survey Results

3.4.1. Descriptive Survey Results

The number of classes and total number of survey responses completed (i.e., # students) varied by grade (Table 3.1). The most surveys were completed by 6th grade classrooms, but the greatest total number of survey responses was in 5th grade classrooms; the lowest number of surveys and survey responses was observed in the oldest age category (8th grade) (refer to Table 3.1).

Table 3.1. Characteristics of Survey Data

Grade	Number of Classes	Survey Responses (# students)
Kindergarten	46	3,589
1st Grade	80	6,309
2nd Grade	65	5,111
3rd Grade	66	5,856
4th Grade	61	6,033
5th Grade	68	6,846
6th Grade	82	5,569
7th Grade	33	4,539
8th Grade	25	1,967
Total	526	45,819

3.4.2. AST Score Grade Patterns

The highest mean AST score was from Grade 6 at 57.9 with the overall mean AST score for all grades combined being 43.6 (refer Table 3.2). The lowest AST scores were observed in the youngest age categories, 29.8 (refer to Figure 3.3).

Table 3.2. Summary Statistics of AST Score of BWR Survey Participants

Grade	Minimum	Mean	Median	Maximum	Range	SD
Kindergarten	0	29.89	30	55	55	0.15
Grade 1	0	36.89	36	69	69	0.14
Grade 2	0	37.39	40	89.5	89.5	0.17
Grade 3	6	42.59	44	99	97	0.18
Grade 4	14	44.83	43	76	62	0.14
Grade 5	15	47.9	49	100	85	0.14
Grade 6	18	57.93	64	100	82	0.17
Grade 7	9	45	46	85	76	0.20
Grade 8	24	51.17	52	80	56	0.14

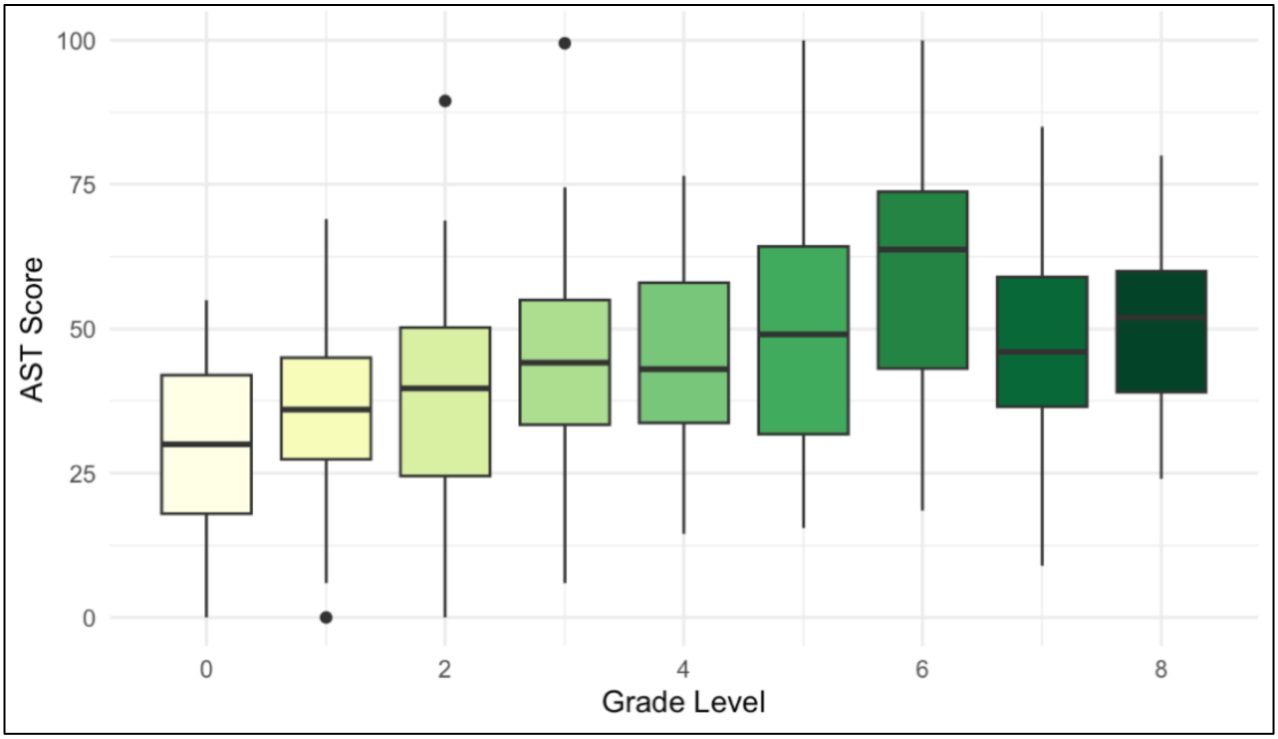

Figure 3.3. Relationship between AST Score and Grade Level

3.4.3. Students Modal Choice to School by Grade

The most common mode of transportation to school for students in kindergarten to Grade 3 was the car with walking being the second most common (refer to Figure 3.4). This situation flipped for students in Grade 4 to Grade 8 where walking was the most common with the car being the second most common. Overall, the most common form of active travel was walking and the most common non-active mode of travel was the car (refer to Figure 3.4). Taking the school bus to school remained the third most common form of transportation throughout the survey period. Biking to school saw an uptake in modal choice between Grade 5 and 7 (refer to Figure 3.4).

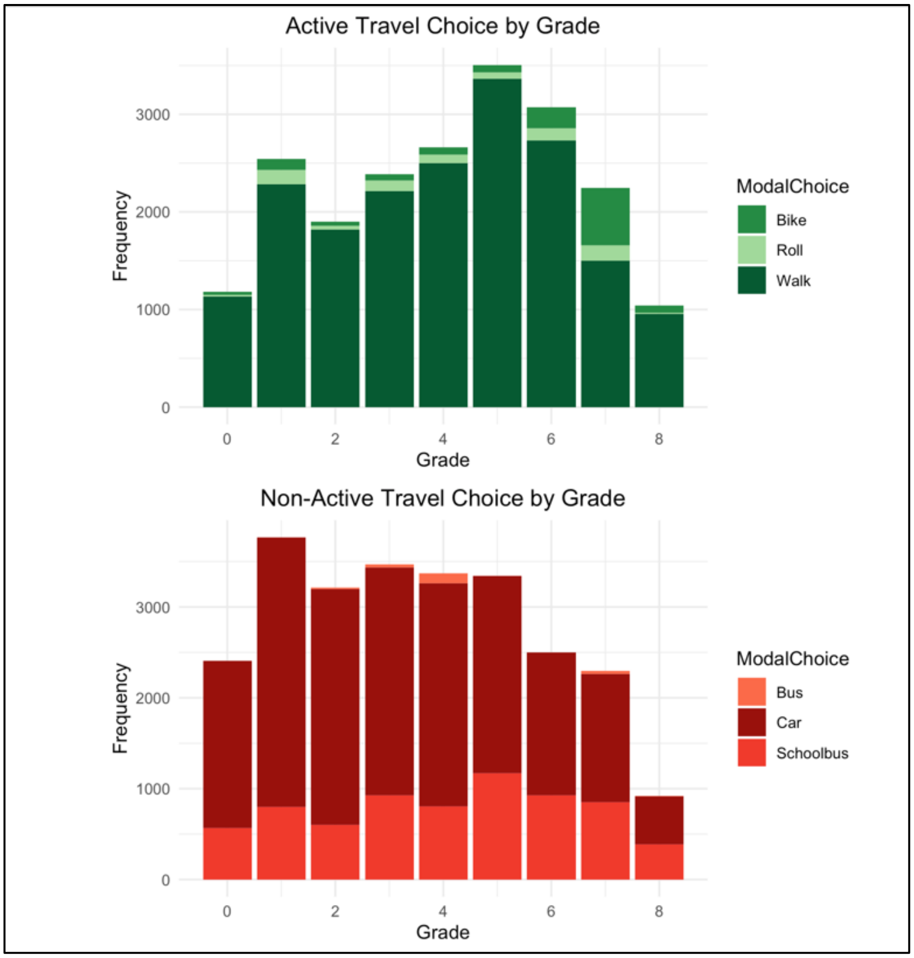

Figure 3.4. Active ad Non-Active Modal Choice by Grade

3.5. Statistical Analysis Results

Based on our model selection process, we found that the school neighborhood environment data had five variables that exhibited the best fit for all three of our data groupings: Green Roads, Sidewalk connectivity at 1600m, and the Ratio of Local to Major roads (refer to Table 3.3). The only social environment variable that proved to be significant and a best fit for our model was the Grade (serving as a proxy for age) at which a student was enrolled For CF data, it was found that the Temperature (degrees in Celsius) was the best fit for the model.

Table 3.3. Statistical Modeling Results

	Kindergarten – 2nd Grade			***3rd Grade – 5th Grade***			***6th Grade – 8th Grade***		
Social Environment	*Intercept*	*P-Value*	*Conf-Interval*	*Intercept*	*P-Value*	*Conf-Interval*	*Intercept*	*P-Value*	*Conf-Interval*
Grade	0.021	**<0.001**	0.005-0.037	0.042	**<0.001**	0.028-0.055	0.023	0.176	-0.004-0.051
Built Environments									
Local to Major Roads	-0.004	0.927	-0.088-0.079	0.004	0.925	-0.074-0.084	-0.005	0.917	-0.090-0.079
Green Roads	-0.043	0.173	-0.090-0.003	-0.032	0.287	-0.078-0.013	-0.008	0.799	-0.060-0.043
Sidewalk 1600m	0.043	**0.034**	0.012-0.073	0.037	**0.041**	0.010-0.064	0.008	0.639	-0.018-0.035
Climatic Factors									
Degrees	0.005	**0.030**	0.003-0.007	0.001	0.304	-0.0007-0.003	0.006	**0.001**	0.003-0.009

3.5.1. Multi-Level Model Group 1 Results

Upon further analysis of the results further it shows that a discernible pattern has emerged based on the results of the model. It shows that as students age, fewer variables remain significant in influencing their choice to engage in AST. For kindergarten – 2nd grade students, the analysis shows three factors that are positively associated with AST: the length of sidewalks within a 1600m radius, the grade they are in, and the outdoor temperature. The positive relationship between the length of sidewalks within a 1600m radius and the temperature suggests that warmer temperatures are associated with a higher likelihood of students engaging in AST. The R-squared value that is reported based on this model indicates that it is predictive of AST for this age group, with an adjusted R-squared (R-squaredc) of 0.65 and a marginal R-squared (R-squaredm) of 0.11. Furthermore, consistent VIF scores that support these results, with an AICc value of –238.65 which indicates that these variables fit extremely well in this model (refer to Table 3.4).

Table 3.4. Interaction Effects of Variables and Confidence Intervals for Group 1

	VIF scores	95% Confidence Intervals
Local To Major Roads	1.05	-0.089 - 0.079
Green Roads	1.10	-0.090 - 0.003
Sidewalk 1600m	1.05	0.012 - 0.073
Degrees	1.02	0.003 - 0.007
Grade	1.00	0.005 - 0.037

3.5.2. Multi-Level Model Group 2 Results

For students in grades 3rd – 5th grade, there are similar patterns, with one less factor remaining significant in influencing AST. This group saw that the length of sidewalks within a 1600m radius remained significant and that the grade level of the student became increasingly influential in AST. The model also shows a positive relationship between the length of sidewalks within a 1600m radius and the student's grade level. However, the outdoor temperature was no longer significant in influencing AST. Similar results are found with the R-squared values; the adjusted R-squared

(R-squaredc) being 0.64 and the marginal R-squared (R-squaredm) being 0.10, with supportive VIF scores showing no multicollinearity, and a supportive AICc value of –259.61 which indicates that for this grouping the variables from the model selection process fit extremely well with our model (refer to Table 3.5).

Table 3.5. Interaction Effects of Variables and Confidence Intervals for Group 2

	VIF scores	95% Confidence Intervals
Local To Major Roads	1.03	-0.074 - 0.084
Green Roads	1.07	-0.078 - 0.013
Sidewalk 1600m	1.05	0.010 - 0.064
Degrees	1.02	-0.0007 - 0.003
Grade	1.00	0.028 - 0.055

3.5.3. Multi-Level Model Group 3 Results

For students in the oldest age group, 6^{th} – 8^{th} grade, only the outdoor temperature remained significant in influencing AST. This indicates there are fewer factors required for students to engage in AST. The results for the R-squared values were slightly lower than the previous two groups, with the adjusted R-squared (R-squaredc) being 0.41 and the marginal R-squared (R-squaredm) being 0.07 and the AICc value for this grouping is –83.90. However, the VIF scores remain low, indicating minimal multicollinearity (refer to Table 3.6). This shows both VIF scores and 95% confidence intervals for the third grouping of data. This also indicates that in the model, none of the variables influence each other's significance within the analysis and that our confidence intervals show a high range of accuracy for our model as well.

Table 3.6. Interaction Effects of Variables and Confidence Intervals for Group 3

	VIF scores	95% Confidence Intervals
Local To Major Roads	1.07	-0.090 - 0.079
Green Roads	1.13	-0.060 - 0.043
Sidewalk 1600m	1.05	-0.018 - 0.035
Degrees	1.08	0.003 - 0.009
Grade	1.05	-0.004 - 0.051

3.6. Discussion

The findings of this research contribute valuable insights to the existing body of work that exists on AST; school neighborhood environment, and climatic factors that influence modal choice for students in Ontario. These results differ from the existing body of work in that these findings used variables that represented a more comprehensive built environment in the region. These findings show that based on the groupings of data there existed a diminishing level of significance as students age, suggesting that younger students require more facilitators to engage in AST than older students do (Chillion et al., 2014; Cooper et al., 2003). For Group 1, three significant factors were found: sidewalk lengthat 1600m, temperature, and the students' grade level. For Group 2, two significant factors were found: sidewalk lengthat 1600m and the students grade level (refer to Figure 3.5). For Group 3, only one significant factor was identified, temperature. These findings can have significant implications for school planning, school travel planning interventions, and overall urban planning practice around schools.

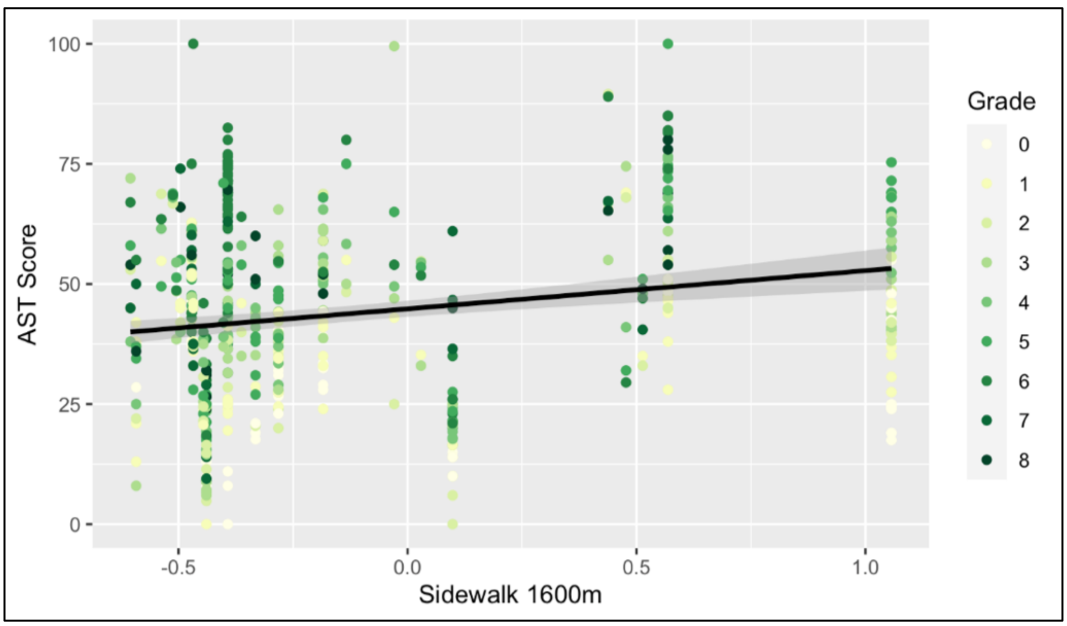

Figure 3.5. Relationship between AST Score and Length of sidewalks at 1600m

A significant component of the dataset that is being used in this analysis is its inclusion of both the date and location of the school (six-digit postal code). This provides a unique opportunity to identify the exact weather conditions were for each area and then quantify those conditions. This study found that the temperature played a significant role in whether a student engaged in AST on any given day (refer to Figure 3.6). Other studies have found differing results, such as Faulkner & Mitra, 2012, that found climate and weather do not impact modal choice to school (Faulkner & Mitra, 2012). This study looked at students in a similar age range, but only looked at students in Toronto, Ontario, and did not take into account-built environment features, and only looked at socio-economic and travel distance data (Faulkner & Mitra, 2012). However, other studies have also found comparable results in that daily weather and temperature do influence AST. For example, Blanchette et al., 2021, found that daily weather conditions impact AST and physical activity in children across Canada, more specifically Quebec City, Ottawa, and Vancouver (Blanchette et al., 2021).

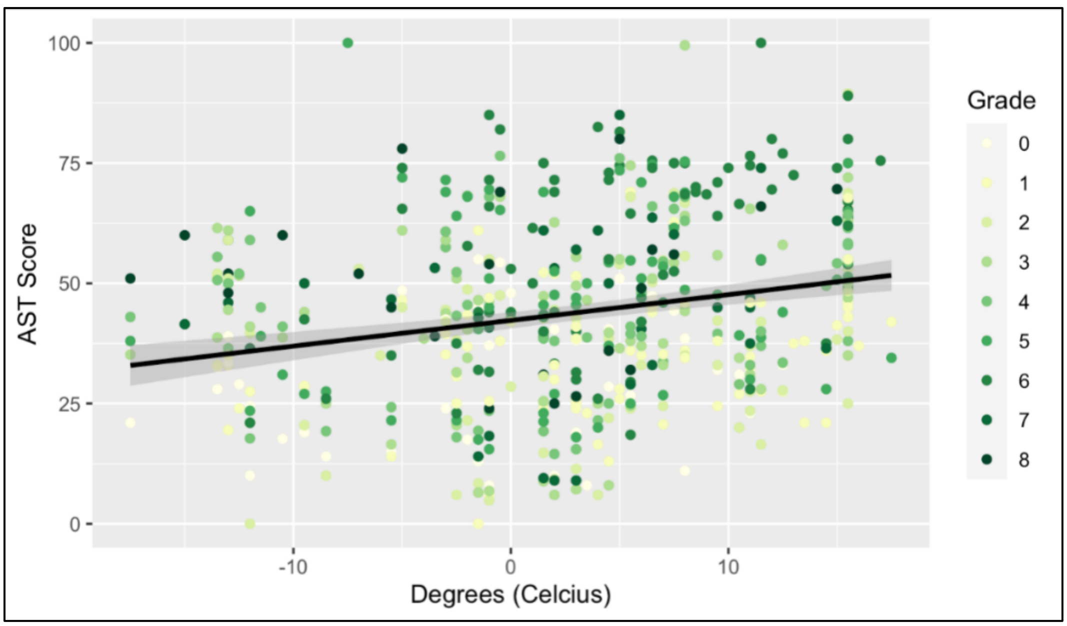

Figure 3.6. Relationship between AST Score and Degrees during a survey

As shown in Figure 5, another strong predictor of AST based on the results is the student's grade level. These results show that students in higher grades (older students) are more inclined to engage in AST. This could be attributed to the fact that the parental influence over a child in younger grades such as the students in Group 1 compared to those in Group 3 (Chillion et al., 2014). Parental influence on AST is well studied and has been shown to be one of the most significant factors in students engaging in AST (Mah et al., 2017; Wilson et al., 2018). Demonstrating that AST rates change based on age group is important for schools and planners to understand; as they can then educate children and parents on the importance of AST.

These results suggest that the conversation around AST needs to evolve. Instead of looking at AST as a choice made by students, researchers can choose to look at it as a physical activity ability level, and how different age groups interact with the built environment around them. It is common to overestimate a child's physical ability in general activities which can make them prone to accidents (Plumert, 1995). Educating on the importance of AST around the context of physical activity ability might be conducive to increasing AST. McKee et al., 2007, showed that with the distribution of educational materials around AST an increase in active transportation modes showed along with the distance of those travel distances post education on AST. However, understanding that the age of which a student is can have a significant impact on how that student engages in AST. This research is important for school travel planners, urban planners, community efforts/programs, and STP documents.

3.7. Limitations

Although this research is novel in its incorporating of different levels of analysis and its type of data there are several limitations in this study. One of these being that the EQAO data does not align with the exact years of which a BWR survey was conducted. The BWR surveys were conducted from late 2018 to the end of 2022, the EQAO data was from 2021. This discrepancy may result in some minor differences in specific SES percentages of the school. Another limitation of this study relates to the built environment network that was created, which has several minor flaws, including possible gaps in sidewalks and road networks. The data that was used for the built environment is from 2022. Because there may be a slight timing mismatch some of the survey data (collected 2018-2022), this may lead to an imprecise depiction of the neighborhood around a school that submitted a survey.

Another limitation in this research is that there is a key piece of information that is missing: the home location of a student who submitted a survey. Without this data it is difficult to assess the barriers these students are faced with on their trip to school. This research is generalizing the school neighborhood environment and uses proxy data for the SES environment. This research is also using the ‘walkability zone’ as the reference area around the school which is 1600m as defined by the Student Transportation Services of Waterloo Region (STSWR, 2024). This inevitably introduces the geographic measurement challenges like the MAUP and the UGCoP as this is not truly measuring what a student encounters on their journey to school. This analysis also generalizes an individual survey response to the entire school regarding its SES. This might not be an accurate representation of who is submitting each survey.

3.8. Conclusion

It is important to understand what factors are significant in AST. It was found that the length of sidewalks within a 1600m radius from school, the grade level of a student, and the temperature during travel are the most influential factors in AST. This is valuable information for urban planners and any school travel planning intervention that may be implemented. The presence of active transportation infrastructure is one of the most essential factors for AST. It is also important for schools and planners to know that as students get older, the likelihood for AST increases, and it is important to educate both students and parents on the benefits of AST.

This research contributes to the growing field of AST research by identifying what is significant in modal choice to school. It has also built upon other studies by incorporating different kinds of data with various levels of analysis that can be used to understand varying AST rates. What this research shows is that research around AST needs to progress to something more than measurement of environmental factors. There should be a better understanding of the individuals, families, and journeys of those who engage in AST. This research can be helpful for urban planners, public health professionals, and school travel planners.

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4.0. Chapter 4: Identifying Factors Associated with Active School Travel Among Elementary School Students in Ontario

4.1. Introduction

Physical activity (PA) levels among children have been declining since the early 2000's (Canadian Fitness and Lifestyle Research Institute, 2023; Mitra and Buliung, 2012; Stats Canada, 2015; World Health Organization, 2020). Recently, there have been significant decreases in PA, as before 2020 51% of children met their recommended levels of PA, where in 2022 only 37% of children met their recommended levels of PA (ParticipACTION, 2022). Active school travel (AST) has been suggested as a convenient way to increase children's overall physical activity levels (Buttazzonni et al., 2018; Fotel and Thomsen, 2002; Fyhri and Hjorthol, 2009). The most common form of PA for people of all ages is walking (Berrigan and Troiano, 2002). PA is important, especially in children, as physical inactivity has been shown to increase the risk of cardiovascular problems, poor bone health, high blood pressure, and obesity (Andersen et al., 2006; Biddle et al., 2004; Hedley et al., 2004; Leary et al., 2008; Mehdizadeh et al.; 2017; Sugiyama et al., 2007). The trip to school provides children with the opportunity to engage in AST and increase their overall PA by using forms of active transportation such as walking or cycling (Ikeda et al. 2018; Kontou et al., 2020).

Many studies on AST have identified a wide range of factors that can significantly influence participation in AST. Previous reviews of the AST literature have identified environmental factors (e.g., distance to school, sidewalk length, and road length) and socio-demographic characteristics (e.g., race, gender, and income) are the two general areas that influence AST (Buttazzonni et al., 2018; Chillion et al., 2014; Davison et al., 2008; Lorenc et al., 2008; Panter et al., 2008; Pont et al., 2009). Kontou et al. (2020) reports that based on the National Household Travel Survey (NHTS) of 2017, 9.6% of students in the United States between the ages of 5-17 years old walked and 1.1% of students biked to school (Kontou et al., 2020). The NHTS also reports for those who walk, that 77.5% of school trips are less than 1 mile (1600m) and that those students who did ride their bike to school, 82.8% of those trips were less than 2 miles (3200m) (Kontou et al., 2020). This is important contextually as the prevalence of AST for students in grades K-8 was nearly 48% in the 1970s but has since declined to less than 13% in 2017 (Kontou et al., 2020; McDonald et al., 2011). A recent study, conducted by Rothman et al. (2021) was done that evaluated AST rates across six Canadian cities: Calgary, Laval, Montreal, Surrey, Toronto, and Vancouver and one regional municipality – Peel region. A total of 552 schools were analyzed across these areas and it was found that the average number of children using AST was 54.3% (Rothman et al., 2021).

This paper will examine sociodemographic and built environment influences on a child's trip to school. Self-reported survey data on forms of travel will be used to determine what home environment, trip environment and school neighborhood environment factors are significant in AST in the province of Ontario, Canada.

4.2. Factors Influencing AST

4.2.1 Built Environment Influences on AST

AST can be beneficial for children due to its many health benefits; but it can also contribute towards a healthier environment by reducing traffic congestion and emissions around schools and increasing the greenness around a school such as street trees (Ikeda et al., 2019; Macedo et al., 2023). There has been a growing interest in AST over the last 15 years, as researchers are trying to identify the factors contributing to the significant drop in AST participation rates among students (Jing et al., 2021; Kontou et al., 2020; Stark et al., 2019). Even with this increased research interest however, AST remains a complex process that is not fully understood (Helbich, 2017). Parents and children are the two main decision makers in AST, but the built environment also plays an important role (Mitra, 2013; Pont et al., 2009).

There have been many studies on AST that investigate the correlations between the built environment and AST (Ewing & Cervero, 2010). Loon and Frank (2011) found that urban density can help stimulate walking and cycling by reducing the distance between the origin and destination point (Loon and Frank, 2011). This finding is supported by other studies that state the distance between home and school is an indicator for AST; that students who live closer to school are more likely to walk or bike (Fyhri and Hjorthol, 2009; Jural et al., 2021; Mitra and Buliung, 2012). A more disputed factor in the built environment literature is "land-use mix." There have been inconsistent findings related to this variable. Saelens and Handy (2008) argue that land-use mix can increase accessibility and therefore increase AST rates (Saelens and Handy, 2008). Other studies have found that increased diversity in land-use mix can cause more safety risks to vulnerable individuals and discourage AST (Broberg and Sarjala, 2015; Macedo et al. 2023; Mitra and Buliung, 2012). Another inconsistent finding is that a well-connected grid of streets can lead to an increase in AST, as suggested by Macedo et al., (2023). Studies have found that even though an increase in network connectivity can increase accessibility, it can also lead to more traffic and an increase in safety concerns and therefore discourage AST (Sirard and Slater, 2008). Reviews of existing literature reveal that there is a lack of consistency in the findings on the amount of influence that the built environment has on AST (Sirard & Slater, 2008; Mitra, 2013; Helbich, 2017; Macedo, 2023).

These inconsistent findings in prior research can be attributed to the context in which variables from the built environment are collected (Kwan, 2012). When generating numeric values for the built environment, these are often created through geographic information systems (GIS) as a static number that represents a geographic region around a school/home/trip (Badland et al., 2008; Duncan et al., 2009; Larsen et al., 2009; Su et al., 2013). Euclidean buffers are the traditional way of calculating built environment features in a geographic area (Owen et al., 2012); while shortest network path is traditionally used to look at the built environment features for a student's journey to school (Schlossberg et al., 2006).

Identifying what built environment factors are significant in modal choice to school can assist urban planners, policy makers and public health professionals in creating a healthier student and environment (Sallis et al., 2015).

4.2.2. Sociodemographic Factors Influence on AST

The decision to engage in AST includes many sociodemographic factors at the individual level (e.g., age, sex, gender, ethnicity), household level (e.g., household size, household structure, household income, parental education), and neighbourhood level (e.g., average income, density of children, unemployment rates) (Li et al., 2023). Studies have shown that older students are more likely to engage in AST than younger students (Curtis et al., 2015; Easton and Ferrari et al., 2015; McDonald, 2008; Yarlagadda and Srinivasan, 2008). Other researchers have found that boys are more likely to use AST than girls (Broberg and Sarjala, 2015; Easton and Ferrari, 2015; Hsu and Saphores, 2013). This finding can potentially be based on the idea that boys, generally speaking, are given more freedom by parents to move about more freely than girls (Curtis et al., 2015; Mitra and Buliung, 2015).

Li et al. (2023), believes that school commuting is an essential part of family dynamics because children are too young to have total autonomy (Li et al., 2023). This is supported by the fact that children are greatly influenced by their parents' decisions which can impact the child's ability to participate in AST (McDonald et al., 2010). Hsu and Saphores (2013) found that the likelihood of a child participating in AST is negatively correlated with age of parents (Hsu and Saphores, 2013). Studies have also found that higher parental educational attainment of parents is also associated with lower likelihood a child will participate in AST (Rodrigues et al., 2018; Yu and Zhu, 2016). These same studies also found that parents who are worried about safety are less likely to let their children use AST (Curtis et al., 2015; Hsu and Saphores, 2013; McDonald et al., 2010; Rodrigues et al., 2018).

Students from families that have a higher income, and more cars are more likely to be driven to school (Hsu and Saphores, 2013; Li and Zhao, 2015; McDonald, 2007; Mitra and Buliung, 2015). The size of the household is also an important factor for AST, as those with more school-age children are more likely to engage in AST, as it is believed to be safer if there is more than one child going together (Hsu and Saphores et al., 2013; McDonald, 2008).

4.3. Methods

4.3.1. Travel Behavior Survey

A comprehensive travel behavior survey was completed at home by students from kindergarten to grade 8 (aged 5 –13 years). A heterogeneous sample of elementary aged students, varying by income and built environment, was collected at the household level throughout Canada. There was a total of 1,196 surveys that were completed across the country, with a total of 428 coming from the province of Ontario, Canada. For this study's purposes, only surveys originating from this province will be analyzed. This survey was conducted from January 2023 – June 2023. A distance of 1.6km was used as the cutoff because school bussing policy among most, if not all, regional school boards in the province of Ontario mandates that students who live farther than 1.6km from their assigned school are to be provided school bus service, making them highly unlikely to choose to take an active mode of school travel. Of the 428 survey participants, 45.1% (n=193) were from participants who lived within 1.6km of their school (refer to Figure 4.1). Of these surveys, all provided their mode of travel (MOT) to school.

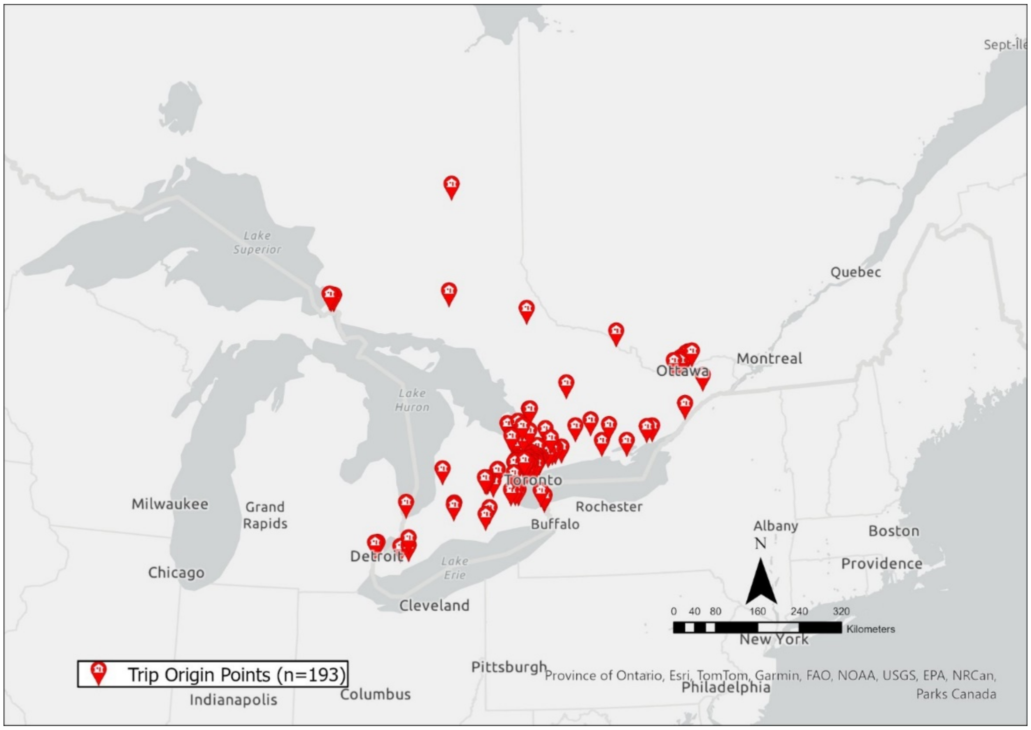

Figure 4.1. Distribution of Survey Participants in Ontario who lived within 1.6km of their school

The survey asked students about their mode of travel to and from school, household characteristics, perceived barriers/facilitators for using AST, and behavioral characteristics (such cellphone use and physical activity levels).

4.3.2. GIS Analysis of Home and School Neighborhood Environment and Routes

4.3.2.1. Characterizing the Home Neighborhood

The centroid (geographic center) of each home postal code provided by survey respondents was identified with ArcGIS Pro 3.2.2. (Environmental Systems Research Institute Inc, Redlands, CA). Canadian postal codes are much smaller geographic units than zip codes of the United States, and prior research shows that Canadian postal codes are sufficient representations of immediate home neighborhoods in urban environments (Bow et al., 2004). The median area of the home postal codes of our survey respondents is 105 m^2 and the mean area of a postal code is 320 m^2. The built environment features of the home postal code were calculated using geographic information systems (GIS). These features, including sidewalks, road lengths, greenness, and points of interest, were chosen based on prior AST research that used these features in their analysis (refer to Appendix 1A).

To validate the accuracy of the centroid in its relation to where a student would live within that postal code, each postal code was validated for its population in comparison to the corresponding Dissemination Block (DB) population. A 100m ring buffer was created around the centroid and then quantified the population based on DB population values. It was determined that based on the population value of the ring buffer, that 75.1% of the buffers had greater than or equal to 100% of the postal code population (more meaning that the postal code population is smaller than the corresponding DB and the 100m ring buffer extending outwards into other DBs). This indicates that of the identified centroids, 75.1% of survey participants live within 100m of that centroid.

4.3.2.2. School Neighborhood Environment

The school neighborhood environment and corresponding sociodemographic characteristics were measured utilizing well-used methods in GIS (Larsen et al., 2009). Neighborhoods were measured using a network buffer, which is an area around a school at a set distance calculated along the transportation network (in this instance the distance was set at 1.6km). This is in accordance with provincial policy that students who live within 1.6km are not eligible for the school bus (STSWS, 2024).

4.3.3. Data

A comprehensive transportation network was built for the province of Ontario, Canada. This included sidewalks, roads, green spaces, NDVI (normalized difference vegetation index) values, cycling routes, and dwelling density (Lai et al., 2023) (refer to Appendix 1A). This dataset was created using the most up-to-date data to accurately represent the built environment a student would encounter on their journey to/from school.

The sociodemographic characteristics of the school neighborhood environment were determined using the Educational Quality Assessment for Ontario (EQAO) Test dataset (EQAO, 2024). The

EQAO test contains a variety of sociodemographic characteristics for each publicly funded school, such as the number of non-English or French speaking students, educational attainment of the parents, and the percentage of low-income households (refer to Appendix 2B). This dataset is updated annually to assess each cohort of students that go through grades 3, 6 and 9. For this research, only data for grades 3 and 6 were used to generate a sociodemographic profile for each school.

The distance from home to school was calculated with ArcGIS Pro 3.2.2., using the shortest network path along the transportation network (this included the variables that are in Appendix A) between the centroid of each students' home postal code and the exact address of the school they attend. After the shortest network path was determined, a 50-meter buffer was created on each side of the pathway, totaling 100-meters, to quantify the built environment variables investigated in the study (refer to Figure 4.2).

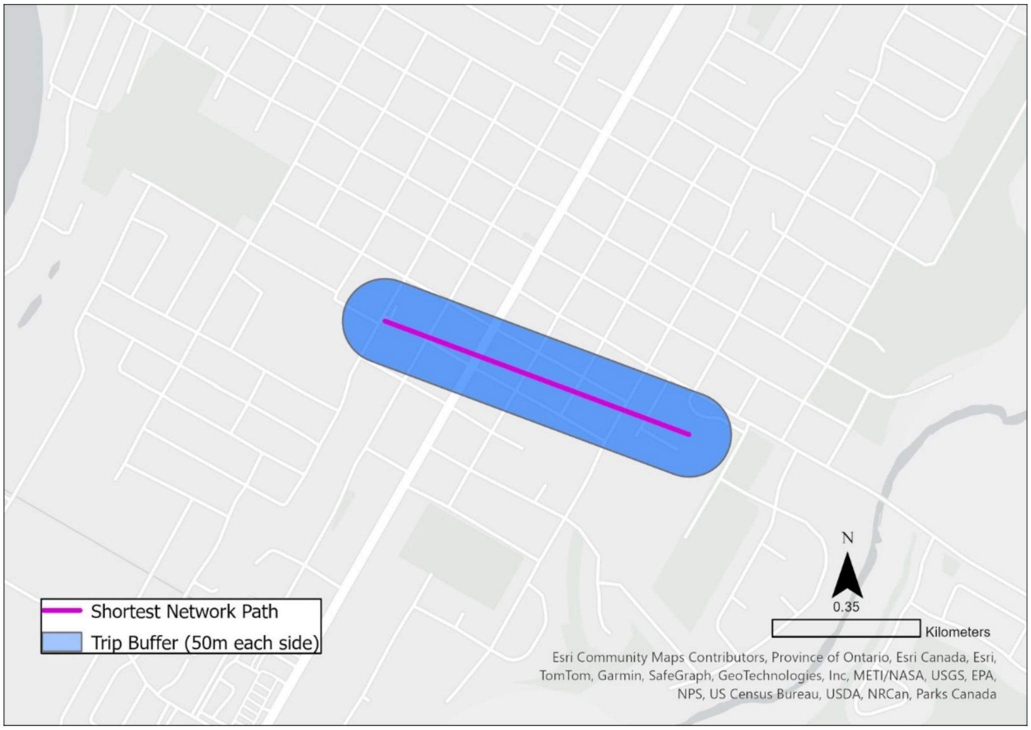

Figure 4.2. Example of how the built environment was quantified in this study; this is an example of a student who lives 1600m or less to their school

4.3.4. Statistical Analyses

All the variables that were investigated in this study were entered into a hierarchical linear and nonlinear model. Initial analysis showed that there was no significant interclass correlation between rates of active travel and the 193 surveys that were analyzed ($p=0.483$) which indicated that there was no need for a multilevel model. The survey data and the built environment data were entered into RStudio for statistical analysis. The P-values of the relationships between the built environment and AST were tested using a univariate logistic regression. All significant factors ($P<.05$) were used in a stepwise logistic regression.

4.4. Results

4.4.1. Survey Results

There was a total of 193 surveys that were analyzed; 55.4% of survey responses were boys (n=107), 43.5% were girls (n=84), and 1.03% of respondents did not provide a gender response (n=2). The average age of survey respondents was 10.9 years old. The average number of people in a household was 4.04 people per household. The average number of children in the household was 1.9 per household. The survey also inquired about student access to a cellphone; 43.5% did not have access to a cellphone (n=84), 7.7% had limited access to a cellphone (n=15), and 48.7% had full access to a cellphone (n=94). The amount of physical activity was asked of the students where it was scored on a scale of 0-7 with 0 being the least active and 7 being the most active. The average physical activity level of the survey responses was 3.8. Of the respondents who lived within 1.6km of their school, 60.1% indicated that they used active travel to school (n=116) and 39.9% indicated that they used a non-active form of travel to school (n=77) (refer to Table 4.1).

Table 4.1. Descriptive Statistics of Survey Questions based on Student Responses

Variable	No. (%)
Age	
8	8 (4.1)
9	32 (16.5)
10	37 (19.1)
11	39 (20.2)
12	42 (21.7)
13	32 (16.5)
14	1 (0.05)
NA	2 (1.03)
Gender	
Boys	107 (55.4)
Girls	84 (43.5)
NA	2 (1.03)
Number of People in the House	
2	12 (6.2)
3	57 (29.5)
4	66 (34.1)
5	35 (18.1)

Variable	No. (%)
6	18 (9.3)
7	2 (1.03)
8	3 (1.5)
Number of Children under 18 in the House	
1	64 (33.1)
2	88 (45.5)
3	29 (15)
4	10 (5.1)
5	0 (0)
6	1 (1.03)
NA	1 (1.03)
Access to Cellphone	
1. No Access	106 (24.2)
2. Limited Access	21 (4.7)
3. Full Access	149 (34)
Physical Activity Level (0-7 most active)	
0	8 (4.1)
1	16 (8.2)
2	25 (12.9)
3	33 (17.1)
4	27 (13.9)
5	48 (24.8)
6	15 (7.7)
7	21 (10.8)
Mode of Travel to School	
Active	116 (60.1)
Non-Active	77 (39.9)

4.4.2. Statistical Analyses Results

A result of this research was that the distance between home and school was found to be a significant factor for predicting AST (refer to Table 8). This finding is consistent with prior research that has identified that the distance between home and school is a significant factor. The local road length in the school neighborhood environment was found to be positively associated with AST (refer to Table 4.2). However, a result of the statistical analysis was that there were no sociodemographic or household characteristics that were associated with AST (refer to Table 4.2).

Another result of the statistical testing was that there were no EQAO variables that showed a relationship with AST (refer to Appendix 5A).

Table 4.2. Correlations Between Student Modal Choice to School: School, Home, and Route Environment

School neighborhood environment	Coefficient	T-value	P-value
Age	-0.153	-0.851	0.4013
Gender	-0.038	-0.185	0.8546
Grade	0.197	1.029	0.3117
People in House	-0.067	-0.501	0.6202
Children Under 18 in House	0.029	0.191	0.8499
Cellphone	-0.027	-0.257	0.7986
Chronic Health Disability	0.030	0.095	0.9248
Oldest Only	0.078	0.320	0.7509
Physical Activity	0.002	0.053	0.9577
Local Road Length (meters)	0.003	2.249	**0.0320**
Major Road Length (meters)	0.3483	1.060	0.2974
Intersection Density	0.047	0.064	0.9494
Points of Interest	0.039	0.024	0.9809
Dwelling Density	-0.095	-0.492	0.6262
Park Area	-0.104	-0.249	0.8052
Can Bics	0.208	1.523	0.1382
Green Roads	0.035	0.400	0.6918
Sidewalk Length (meters)	<-0.001	0.132	0.8959
Trip Distance (meters)	-0.1174	-3.173	**0.0017**
Deviance from Network	<0.001	0.163	0.8717
R-Squared = 0.2712			
AIC = 127.9462			
Home Environment			
Age	0.255	0.993	0.3304
Gender	0.025	0.112	0.9114
Grade	-0.186	-0.634	0.5316
People in House	-0.080	-0.396	0.6957
Children U18 in House	0.071	0.379	0.7078
Cellphone	0.055	0.428	0.6721
Chronic Health Disability	0.033	0.092	0.9276
Oldest Only	0.087	0.271	0.7884
Physical Activity	-0.053	-0.934	0.3890

School neighborhood environment	Coefficient	T-value	P-value
Local Road Length (meters)	-0.003	-0.288	0.7757
Major Road Length (meters)	0.167	1.419	0.1683
Intersection Density	<0.001	0.048	0.9622
Points of Interest	-1.407	-1.207	0.2389
Green Roads	-0.160	-1.071	0.2942
Dwelling Density	0.226	1.011	0.3218
Park Area	-0.500	-0.956	0.3481
Can Bics	0.144	1.016	0.3193
Sidewalk Length (meters)	0.020	0.140	0.8897
Trip Distance (meters)	-0.216	-2.254	**0.0332**
Deviance from Network	<0.001	0.048	0.9622
R-Squared = 0.2648			
AIC = 131.4302			
Route Environment			
Age	0.018	0.047	0.9630
Gender	0.034	0.157	0.8764
Grade	0.023	0.056	0.9560
People in House	-0.142	-0.767	0.4516
Children U18 in House	0.156	0.873	0.3925
Cellphone	-0.013	-0.097	0.9234
Chronic Health Disability	0.193	0.567	0.5765
Oldest Only	0.029	0.098	0.9227
Physical Activity	-0.065	-1.278	0.2152
Local Road Length (meters)	<-0.001	-0.007	0.9943
Major Road Length (meters)	0.251	1.670	0.1097
Intersection Density	<0.001	-0.049	0.9612
Points of Interest	-0.2499	-1.702	0.1034
Green Roads	-0.253	-1.915	*0.0692*
Dwelling Density	0.249	1.228	0.2331
Park Area	-0.085	-0.137	0.8923
Can Bics	0.135	1.1013	0.3226
Sidewalk Length (meters)	-0.034	-0.292	0.7731
Trip Distance (meters)	-0.245	-2.394	**0.0261**
Deviance from Network	<0.001	-1.702	0.1034
R-Squared = 0.3384			
AIC = 127.5885			

The stepwise regression analysis showed similar results where the trip distance is the biggest predictor of AST with the number of children under 18 in the house being close to statistically significant. (refer to Table 4.3). These variables show that they have a negative relationship with AST.

Table 4.3. Results of Stepwise Logistic Regressions for Modal Choice to School a Combination of School, Home, and Route Environment

Variable	Coefficient	Std. Error	Wald Statistic	P-Value	Lower CI	Upper CI
Trip Distance	-0.1274	0.0375	11.5546	**<0.001**	-0.2014	-0.0534

4.5. Discussion

These findings contribute to the growing body of knowledge and understanding on how built environments and sociodemographic characteristics influence a child's mode of transport to school. One of the biggest contributions of this research, that is consistent with prior research, is that the distance away from school is the biggest determining factor in AST. The further away a student lives from school, the less likely they are to engage in AST (Ikeda et al., 2018; Kontou et al., 2020; Mehdizadeh et al., 2017). The trip distance to school was analyzed for the three built environment areas that a student would encounter on their route going to school (home, route, school) and it was negatively associated with AST for all three areas. The other built environment factor shown to be associated with AST in this analysis was the local road length in the school neighborhood environment; this factor was positively associated with AST. Local road length being positively associated with AST in the school neighborhood environment could be attributed to slower moving vehicles around a school, making it safer for students to engage in AST. Local road lengths are defined as a road with sidewalk on at least one side of the road and a maximum speed limit of 50km/h (City of Toronto, 2018). Perhaps this could mean that as traffic is moving slower in these areas around a school, students feel safer and more confident in using AST. This is consistent with other research that has found that students are less likely to engage in AST if the speed limit around the school is higher (Duncan et al., 2014; Jerrett et al., 2010; Jia et al., 2017; Luo et al., 2021; Rothman et al., 2014).

Another analysis finding was that there were no sociodemographic, household characteristics, or school-level factors (refer to Appendix A for results of school-level factors) associated with AST. There have been inconsistent findings on the relationship between AST and sociodemographic or household characteristics. Some studies have found that boys are more likely to engage in AST than girls (Easton et al., 2015; Larsen et al., 2009; Mitra and Buliung, 2015). Other studies have found that as a student ages, their perception of the environment changes, which could then impact their travel behaviors (Johansson, 2006; Mitra and Buliung, 2015; Prezza et al., 2001). Household characteristics like the number of school aged children has been found to be associated with AST in previous studies (Hsu and Saphores, 2014; McDonald, 2008). Other studies have found that household characteristics such as low-income households show a relationship with AST (Rind et al., 2015; Turrell et al., 2013). This study did not find these characteristics to be associated with AST.

The result of the stepwise regression, that took the significant variables from each environment, showed that the main predictor, which is consistent with prior research, is the total trip distance that a student would take to school (this variable did not change across the three environments) (Ikeda et al., 2018; Mammen et al., 2014; Murtagh et al., 2016; Rothman et al., 2018; Wong et al., 2011). Trip distance being the biggest predictor of AST shows that distance is the main driver of the decision to engage in AST; the further away a student lives from their school the less likely they are to engage in AST.

One of the biggest societal barriers to a student engaging in AST is parental consent (Wilson et al., 2018). As described by Nystrom et al. (2023), parents are the ‘gatekeepers’ of AST for children and it is their behaviors, knowledge, attitudes, and/or perceptions that drive the final decision as to whether a child walks or not. One of the biggest concerns around AST is the safety of the trip for their child, and this has only increased as the distance between home and school has increased (Huertas-Delgado et al., 2019; Pfledderer et al., 2021; Wang & Yang, 2019). Research has continued to identify that distance to school is the strongest predictor for AST and the findings in this research support that.

There have been many studies on AST and how the built environment can impact modal choice. However, there have been inconsistent findings as to what factors facilitate, or hinder, AST. Some studies have found that sidewalk density, greenness of the pathway to school, dwelling density, intersection density and land use mix is supportive of AST (Hinckson et al., 2014; Larsen et al., 2009; Mandic et al., 2016; Oliver et al., 2011; Schlossberg et al., 2006). This present study did not find that any of these built environment factors were associated with AST. This emphasizes that the distance between home and school is the most important factor in AST. Other variables might impact the AST slightly but the main factor in the decision to engage in AST is distance.

4.6. Limitations

Even though this research builds upon and improves on prior quantitative methods of identifying factors associated with AST, there are limitations in this research that must be noted. The actual route of which a student would take to school was not identified; only the shortest network path between home and school, which might not be the actual route taken. Another limitation of this research is that the trip was determined based on the centroid of the home postal code (serving as the origin point) going to the exact address of the school (destination point). With this address proxy, there is a potential for over/underestimating distances, is especially for students who are living in more rural/remote areas where postal code zones are larger, and the postal code centroid could be far from their actual place of residence (Healy and Gilliland, 2012). This limitation is not unique to this paper, however, as most AST papers in Canada use home postal code centroid as origins (Mitra and Buliung, 2012; Larsen et al., 2012), and therefore suffer the same potential for over/underestimation. Another limitation of this paper is the response rates to questions in the survey. Not all survey respondents filled in all sociodemographic data, which could lead to some sampling bias. Further data validation in future surveys could be beneficial for ensuring accuracy of the results.

4.7. Conclusions

This paper has contributed to the growing body of knowledge regarding AST, as it has found several new factors that are associated with AST and supported existing results. These results show that distance is the main predictor for AST and that other factors do not matter as much. This study also examines what factors are associated with AST for students who live less than 1600m from their school. This shows that for those students the built environment factor that matters the most is the distance from school. The other variable that influences AST was the local road length in the school neighborhood environment, which was positively associated with AST.

AST has been shown to improve the health outcomes of children and to carry those health outcomes into adulthood. It is important to improve the area of AST by looking to identify new factors that could support or prevent children from using active transportation to get to school. This paper supports the need for more collaboration between school travel planners and policy makers to provide and support AST interventions at schools in Ontario and beyond.

4.8. References

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5.0. Chapter 5: Discussion

5.1. Summary

The continued analysis of AST and the relationship it has with the built environment and sociodemographic characteristics has complicated our current understanding. These interactions require further study to fully grasp their relationship. Discrepancies in the definitions and variables that researchers have used for measuring the built environment and sociodemographic characteristics make it challenging for future AST researchers to repeat and interpret findings. Variables such as road length, sidewalk density, cycling infrastructure, and greenness, that have been shown to impact the results of statistical modelling as the measurements of the variables can change based on available data (MAUP, MT, and UGCoP) (Fotheringham and Wang, 1991; Kwan, 2012). In this thesis, consistent and established definitions of the same variables were used across two different kinds of analysis. This thesis has mitigated some of the discrepancies that have challenged past research on AST by identifying a more representative form of statistical significance in AST.

Bronfenbrenner's Ecological Systems Theory provided a theoretical framework that supported the multifaceted spatial, temporal, and social elements in the analysis of the built environment, sociodemographic characteristics, and AST relationship. Each level of the ecological model represents a form of data that was used in this analysis:

1. Intrapersonal (age and gender)
2. Interpersonal (household characteristics, parents, siblings)
3. Environmental (built environment factors)
4. Policy (walkability zone – less than 1600m from school)

Chapters 3 and 4 of this thesis used a combination of survey data that represented intrapersonal (i.e., age and gender) and interpersonal features (i.e., household size and number of parents, EQAO data). A conceptual built environment within ArcGIS Pro 3.2.2 was created to quantify built environment attributes, such as sidewalks, road length, and greenness, utilizing publicly available data. to represent the environment that a student would encounter on their way to school. Finally, to represent the policy level, this thesis focused on the 'walkability' zone around schools. Ontario

Ministry of Education policy dictates that students who live less than 1600 m from their assigned school are not eligible for bus service, except under special circumstances. The results of this thesis support existing work on AST, while also providing new insights to the growing body of work.

As argued by Kwan (2012) and Goodchild (2011), it is impossible to completely mitigate issues such as the MAUP and the UGCoP in these types of environment and health related studies. Recognizing these common problems in geographic literature, this thesis presents two different studies of AST that use different methodologies for assessing built environments and sociodemographic characteristics that have shown different sets of results. Chapter 3 used a more traditional approach by defining the school neighborhood environment boundary and then characterizing the built environment within that neighborhood (1600m as the school neighborhood boundary). Chapter 4 used a more sophisticated methodology for measuring a student's environment. This chapter delineated boundaries of a student's school travel environment in three ways: 1) the school neighborhood environment; 2) the home neighborhood; and 3) the shortest route between home and school.

The research presented in Chapter 3 used publicly available survey data from the BWR website that showed the modal choice of students from grades K-8. This region was chosen as it had the greatest numbers of participating schools and surveys completed. 25 schools in this region participated in the survey, with 526 distinct classrooms and 45,819 individual survey responses between November 2018 and October 2022. The responses were divided into three groups based on grade-level to account for age-related ability. Group 1 consisted of students from grades K-2, Group 2 from grades 3-5, and Group 3 from grades 6-8. It was observed that students in Grade 6 engaged in AST more than other the other grades (students engaged in AST 64% of the time). A built environment was created using ArcGIS Pro 3.2.2. that quantified factors that were commonly used in previous AST research (refer to Appendix A, Table 1A). A multi-level model was used to identify statistical significance in AST as the students were attending a school nested in a built environment. It was found that as students age, there are fewer factors associated with AST. However, the most important intrapersonal factor in this analysis was the grade level of the student who participated in the survey. As students age, they become more physically capable in engaging in AST. This research also found that the length of sidewalks at 1600m (total length of sidewalks) was also associated with AST, indicating that active transportation infrastructure can also impact modal choice to school. The final finding of Chapter 3 was that temperature plays a role in whether students engage in AST, particularly in younger and older students.

Chapter 4 built upon the analysis in Chapter 3 by incorporating different types of survey data and areas for analysis. This chapter incorporated data from a provincial wide survey (Ontario, Canada), that looked at intra and interpersonal characteristics of a student and their travel behavior. The survey looked at individual level characteristics like age, gender, physical activity levels, and chronic health issues; while also looking at household characteristics like number of children under 18 in the household, number of people in the house, and access to a cellphone. A total of 428 survey responses were recorded, with 193 of them living within 1600m of their school. The analysis of this chapter focused specifically on those students. The same built environment features were used in this chapter as the ones in Chapter 3. The home postal code based built environment features were quantified to represent the environment of where a student lives. Then the shortest network path was identified and a 50m buffer on either side of the path (100m total) was created to quantify the built environment that a student would encounter on their route to school. Lastly, the school neighborhood environment was quantified at 1600m (the walkability zone) to show the built environment around the school. To identify which factors were significant in AST a binomial logistic regression was used, active travel or non-active travel, to show statistical significance. Regressions were used at all three environments; the results of these regressions showed that the distance a student would travel to school is the biggest predictor of AST. The further away a student lives from school the less likely a student is to engage in AST. The other variable that showed statistical significance was the local road length in the school neighborhood environment. The results of the regressions were then put into a stepwise logistical regression, which resulted in showing that the most important predictor of AST is the distance that a student would travel to school. The further away a student lives from school the less likely that student is to engage in AST.

A fundamental area that this thesis builds on is the incorporation of survey data into its analysis. Survey data plays an important role in any research (Weisberg et al., 1996), and by incorporating survey data into both Chapter 3 & 4, it has provided valuable insight as to how the built environment and sociodemographic characteristics are associated with AST. Two different kinds of survey data were used in this thesis. Chapter 3 used ground truth travel behavior survey data from students who attended a specific school over a several year period. This provided a unique insight into how different age groups got to school at specific locations. Chapter 4 incorporated a higher-level survey that was able to acquire more detailed intra and interpersonal information about a student and the factors that could influence AST participation. Both surveys, while valuable, provided two unique understandings of the relationship between AST and the built/sociodemographic environments. This thesis builds upon and incorporates a mixed methods approach when investigating AST so that policy makers can make informed decisions. It is hoped that the work in this thesis will be used as an example as to how survey data can be used to support different methodologies in quantitative research.

The findings of Chapter 3 and 4 are supportive of existing work on AST; age and trip distance have been found by prior research to be the biggest predictors of AST (Ikeda et al., 2018; Larouche et al., 2014; Wong et al., 2011). Trip distance to school is incredibly important to AST as it has shown to be the driving force in whether students engage in AST. Other built environment factors can be shown to be significant based on where they are measured in relation to AST. For example, in Chapter 4 local road length was shown to be statistically significant in the school neighborhood environment but not in the home and route environment. In the same study, there were no sociodemographic and household characteristics that showed to be statistically significant across all three environments. However, trip distance showed to be significant across all three areas in Chapter 4, and showed to be significant in the stepwise regression, meaning that distance is the most important factor in AST.

5.2. Research Contributions

The findings of this thesis align with and expand on prior research on how the built environment and sociodemographic characteristics impact AST. More specifically, it has been shown that trip distance is the main driver of AST. Both studies in this thesis found factors from all levels of the ecological model can influence AST. The findings of this work confirm the importance of the ecological model within this research field to consider the many factors at the different levels of the model that can influence AST.

This research contributes to the broader field of geography by investigating statistical significance in the relationship that AST has with the built environment and sociodemographic characteristics.

The studies in this thesis improve the literature by incorporating survey data and established built-environment characteristics selected from a range of existing research that used similar variables (Ikeda et al., 2018; Larsen et al., 2012; Ozbil and Peponis, 2012; Torun et al., 2020). The research shows that the trip distance and grade (proxy for age) are driving factors in AST and the findings of this thesis support that finding.

In Chapter 3, the survey data used is longitudinal, spanning four years; however it is not possible to determine if the same student took the survey every single year at the same time. There have been several studies that investigate AST over a multi-year period, but none in Canada (Chen et al., 2018; Chillon et al., 2015; Saksvig et al., 2012; Smith et al., 2012). With a sample size of 526 distinct classrooms and 45,819 individual survey responses, this provides a large sample size of AST rates in comparison to other studies (Panter et al., 2013; Sakvig et al., 2012; Smith et al., 2012; van Slujis et al., 2009). This study fills a gap by undergoing a model selection process for which school neighborhood environment factors were associated with AST. The contribution of this model selection process was that it validated that variables that had previously shown to not be associated with AST were in this research, across different groupings of data. Prior research had found contradictory results where climatic factors were not associated with AST Mitra et al., 2012), while other research had found similar results to what this thesis showed (Blanchette et al., 2021). The other contribution this chapter makes is by showing that AST is more about a student's physical ability than prior research suggests. This chapter groups data into three distinct groups that are delineated by grade. It was found that as students age, fewer factors are associated with AST, showing that students become more independent and need fewer things to engage in AST.

The research contribution that Chapter 4 made was by incorporating the same built environment around the school but then including the shortest network path from the centroid of a student's self-identified home postal code. With a sample size of 193 students living within 1600m of their school, it provided the opportunity to understand what built environment and sociodemographic factors were associated with AST. This research fills a gap where multiple areas of a students environment were quantified and then evaluated for statistical significance in AST. Many studies have looked at the home environment and what factors influence AST (Carver et al., 2019; Ikeda et al., 2018). Some studies have investigated the route environment and how that impacts AST (Larsen et al., 2009d; Larsen et al., 2016; Panter et al., 2010). Lastly, other studies have looked at the broader school neighborhood environment and what factors facilitate AST around the school (Ikeda et al., 2018; Mehdizadeh et al., 2017). No studies have combined all three areas that a student would encounter on their trip to school and combined them to create a comprehensive picture of what the built environment would be like during their trip. This chapter makes that contribution to the literature by investigating these areas with the same built environment data from Chapter 3 and new sociodemographic information. This chapter contributes by supporting prior literature by showing that trip distance is the main determinant of AST; the further away a student lives from their school, the less likely they are to engage in AST.

5.3. Policy Implications

The results of this thesis will have potential policy implications for urban planners, transportation planners, and policy makers. Professionals in these areas of work can take the findings of this thesis and apply them to make meaningful policy to effectively increase AST. Ontario Active School Travel (OAST) has outlined a report that makes several policy recommendations that could effectively increase AST. This thesis' findings align with several policies that OAST has outlined that could support AST.

5.3.1. Policy Recommendations

Policy A.3.3. "*Establish a collaborative process for planning new schools before subdivision approval that involves developers, municipal planners, and school board planners that prioritizes sustainable mobility and active transportation as key factors in site selection criteria, and that sets minimum standards for connectivity and proximity of a new school to local active transportation networks*." (Green Communities Canada, 2022, pp. 13).

Developing a collaborative process for integrating new schools into emerging neighborhoods can be imperative for promoting AST. Involving various AST stakeholders, such as school travel planners and urban planners, in the design of neighborhood planning can ensure that these areas are built to facilitate AST. The findings of this research show that a driving factor of a student engaging AST is the distance to school. Policymakers can utilize this data and concentrate development and housing closer to schools. Additionally, shifting away from the current model of fewer, larger schools to a model that emphasizes more, smaller schools could enhance AST (Wang and Yang, 2019). By positioning schools closer to students' residences, this can significantly impact the number of students engaging in AST.

Policy B.6.2. "*Ensure all new developments have sidewalks on both sides of the street to ensure safe school travel*." (Green Communities Canada, 2022, pp. 19).

Policymakers can develop a standard for the sidewalk quantity, and quality that can be a crucial aspect when looking to increase AST. The findings of this thesis show that sidewalks around the school matter and ensuring that sidewalks are incorporated in the design of the neighborhood, especially around schools, can promote AST. Studies have found that sidewalks are an important feature to have around a school, and that the length of sidewalks on both sides of the street are associated with AST (Ewing and Handy, 2009; Carson et al., 2010; Ozbil et al., 2021; Santos et al., 2013). Through the development of a proper sidewalk infrastructure, schools can start to see an increase in AST with the proper design and development of sidewalks.

Policy C.1.1. "*Design or modify school sites to prioritize pedestrians, cyclists, and school bus services and to minimize conflict between pedestrians and vehicles*." (Green Communities Canada, 2022, pp. 23).

Previous literature on AST shows that predominant form of AST is walking, which is also the most common form of AT in general (Gordon-Larsen et al., 2005; Kontou et al., 2020; Siegel et al., 1995; Smith et al., 2015). Parents driving their children to school has become the, rising from 20% in the 1960s to more than 50% today (Ham et al., 2008; McDonald and Aalborg., 2009; Westman et al., 2017). The findings of the core research papers of this thesis suggest that age, sidewalks, and trip distance are the driving factors of AST. Policymakers can take these findings and relate them to the context in which a school sits. There is a need for decreased interaction between students and vehicles as that is a main area of concern for parents (Francis et al., 2017; Mah et al., 2017). Making changes to the traffic patterns around a school, with a combination of the two policies above, can modify the school site to prioritize AST and increase the safety of students through an abundance of high-quality infrastructure.

5.4. Limitations

There are a few limitations within this thesis that need to be acknowledged in the interpretation of the results. AST research reiterates that AST has many confounding variables, meaning it is unlikely to have a perfectly designed study that can precisely predict AST. Each research paper in this thesis is limited by the study's aim and scope. The aim of this thesis was to provide a methodological comparison of quantifying the relationship between AST and the built and sociodemographic environment. Survey data for this thesis was from the Kitchener-Waterloo-Cambridge region in Ontario, Canada for Chapter 3, and for Chapter 4 survey data was from across Ontario. The responses to the surveys might not be representative of AST in Canada.

In Chapter 3, the survey data used is quasi-longitudinal as it was collected over a 4-year period, with the possibility of the same student not completing the survey every year at the same time. This could lead to fallacies in the built environment created given that the network data used reflects the built environment in 2021 for that region; with the earliest survey being submitted in 2018. Perhaps the greatest limitation of this research is that the data does not include an origin point or trip distance that could be calculated. A measurement challenge that this chapter faces is that a student could live on the other side of the school where the built environment is more/less supportive of AST and therefore bias the results (Goodchild, 2004; Javanmard et al., 2023). Additionally, the school could reside on the edge of its catchment area and half of the buffer could not be relevant as students would never come from that direction. As stated previously, prior research suggests that trip distance is the driving force in AST. The other limitation of this paper is that the sociodemographic variables used in this study were from the Education Quality and Accountability Office (EQAO) test. The EQAO test only collects sociodemographic information on a school-wide level for students in grade 3 and 6. While this information is reflective for students in those grades, it might not be for the students in the other grades, which could change the results of this paper.

In Chapter 4, the survey data used provided the postal code but not the student's exact address; this was not asked due to the research's ethical implications. This means that the shortest network path is calculation is starting from a theoretical origin point to an exact address and this journey might not be reflective of the actual journey taken (Larsen et al., 2012; Timperio et al., 2006). Another limitation that this paper poses is that for the students who live in rural postal codes, which are much larger than postal codes in urban areas, the issue might be exacerbated by the fact that the shortest network path is not representative of their journey. Also, they might have been excluded from the analysis as they might live closer than 1600m to their school, but the centroid is greater than 1600m. This would have automatically removed them from the analysis as they did not meet the criteria.

5.5. Future Research Directions

This thesis was built upon the prior work of researchers that have investigated the relationship between AST and the built/sociodemographic environments. With the findings in this thesis, it allows policy makers and researchers to continue the work on AST by validating existing findings identifying new factors that are associated with AST. The findings also allow policymakers to develop and implement targeted programs to encourage AST among students who do not participate. There are many ways forward for researchers in this field, but the continuation of survey data can be vital for the success of meaningful AST research.

There are opportunities for methodological improvement in quantifying the built environment and the pathway taken to school by students. A way to do this would be through incorporating Global Positioning System (GPS) data. The shortest-network path might not be completely representative of the route a student takes to school (Buliung et al., 2013; Clark et al., 2016; Dessing et al., 2016). GPS data can provide the actual route a student would take to school which can then be used to quantify the built environment that the student actually encounters on their journey to school.

Another opportunity for a methodology would be by incorporating a more detailed survey of household characteristics and a participatory mapping exercise in combination with GPS data. Other studies have done participatory mapping exercises and through surveys and public participation, but none have incorporated it with GPS data (Alattar et al., 2021; Ikeda et al., 2019; Wilson et al., 2019). These activities can provide new insights into what students perceive as barriers in the built environment. The results of those activities can be compared to how the built environment was quantified and see if there are differences in a statistical analysis versus what a student perceives as a barrier.

A more thorough understanding of the built environment through more accurate route information with GPS and direct input from students as to what are facilitators/barriers to AST can be significant methodological advancements in AST research. AST research relies on data input from stakeholders involved in AST like students, parents, and educators. These stakeholders provide information on travel rates, perceptions, household characteristics, schools programs, and other limitations to AST. The results of the kind of work by combining the improvements in methodologies would provide policymakers with the opportunity to see real world implications of their transportation planning decisions and understand what components need to be improved to facilitate AST.

5.6. Conclusion

Over the different chapters of this thesis, the purpose was to compare different methodologies for identifying what built environment and sociodemographic characteristics are associated with AST. A literature review was conducted to identify common built environment features associated with AST; these factors were used for both the main research papers. This thesis builds on an extensive body of work on AST by validating previous findings but also providing new and insightful information on the factors associated with increased participation in AST. The results of this thesis show that the main drivers of AST are the distance to school and the age of the student. New variables such as temperature and the number of children under 18 in the household were shown to be predictors of AST as well. A deeper investigation of barriers for AST, perhaps using mixed methods, is needed to further strengthen AST research. The two main studies provide new and informative information on the relation AST and the built/sociodemographic environment in Ontario. These results can help guide meaningful policy that can increase the rates AST and increase the rates of PA among children in Ontario.

5.7. References

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Appendices

Appendix 1A: Variable & Definition of Every School Neighborhood Environment Measured

Variable	Definition	Use
Dwelling Density	Dwelling Density is the number of housing units divided by the residential site area (Alexander, 1993). High density development is something that policy makers do to accommodate population growth (Kotulla, 2019).	This variable is used as a measurement of the built environment. The greater the dwelling density the more built up the surrounding area is. We calculated the dwelling density to provide a value for each school catchment area
Intersection Density	Intersection density is the number of intersections per square kilometer at a local scale, where intersections are defined as the junctions of three or more road segment (Xue, 2020).	This variable is used as a measurement of connectivity of the street network. Intersection density has been shown to increase the walkability of destinations (Xue, 2020). This was calculated as the intersection density based on the school catchment area.
Major Road Length	Road length is a measurement tool to determine how much accessibility a road segment provides to the network.	This variable was used to see the level of accessibility a road segment provides to the entire buffer in our catchment area.

	Major roads are defined as roads with 4 or more lanes (City of Toronto, 2018).	
Local Road Length	Road length is a measurement tool to determine how much accessibility a road segment provides to the network. Local roads are defined as roads with 3 or fewer lanes (City of Toronto, 2018).	This variable was used to see the level of accessibility a road segment provides to the entire buffer in the catchment area
Deviance from Network	Before each network analysis was ran, each school needed to be snapped to the nearest network point. This measurement of 'Deviance from Network' shows how far that snapping feature was.	This variable was used as a measurement tool of how connected the school is to our network. It is a proxy variable to see if the distance from a road the school exists (parking lot or field) to see if that has any impact on AST.
DMTI POI	Points of Interest (POI) data is the location of destinations in Ontario. This is a comprehensive list of destinations ranging from schools, restaurants, hospitals, commercial areas, and parks.	This variable was used as a measurement of urbanicity. The number of POIs (Points of Interest) was calculated within each catchment area of the school.
Can-BICS	The Canadian Bikeway Comfort and Safety (Can-BICS) classification system is	This variable was used as a measurement of the bikeability of schools and the

	a three-tiered classification scheme that groups five bicycle facilities based on safety and comfort (P.HA. Of Canada, 2020). The Can-BICS system outlines its facilities as High-comfort, Medium-comfort, and Low-comfort (P.HA. Of Canada, 2020).	quality of cycling infrastructure around a school. The average of an entire segment of a bikeway was calculated within the catchment area of a school. If a school buffer had multiple levels of bike infrastructure within its boundaries the average was calculated to give it a score for the buffer.
Green road	Green road data is a network that finds the average normalized difference vegetation index (NDVI) from the Google Earth Engine (Sutton, 2020). It uses Open Street Maps as its guidance system for a road network (Sutton, 2020). The data calculates the NDVI value, and anything greater than a 0.3, the data generates a point, indicating a green road (Sutton, 2020).	This variable was used to show that the more greenness of a road the more walkable and bikeable an area becomes. This was calculated by the average greenness of the roads within the school catchment area.
Park Area	Park area data looks at the land classification of the area around the school. Research suggests that parks have no impact on the walkability of	This variable was used to see if the park area around a school had an impact on the walkability of the school.

	destinations (Shuvo et al., 2021).	
Sidewalk 1600m	Measurement of sidewalks in a 1600m buffer around a school.	This variable is a measurement of sidewalk density around a school in a 1600m buffer.
Trip Distance	The distance from to school.	The distance calculated from the centroid of the home postal code to the school a student attended.

Appendix 2A: Variable & Description of Socioeconomic Status Metric

Variable	Description	Use
Low-Income	The percentage of students who live in low-income households. This measurement is determined by the after-tax low-income threshold.	This variable is a measurement of low-income households on a grade level on a per school basis.

Parent with no Education	The percentage of parents who do not have a certificate, diploma, or degree.	This variable is a measurement of the average number of students who have parent(s) (dual parent or single parent household) that do not have any post-secondary certificate, diploma, or degree. It was used to help give a description of the grade 3 and 6 classrooms at a school.
Special Education	The percentage of students who receive or are in special education programs.	This variable was used to measure the number of special education students that exist on a grade level at a school.
Gifted Students	The percentage of students who have been identified as gifted, meaning a student with advanced intellectual ability.	This variable was used to measure the number of gifted students that exist on a grade level at a school.
English Not First Language	The percentage of students whose first language is not English.	Proxy immigrant variable.
Moved Non-English	The percentage of students who moved to Canada from a non-English speaking country in the last four years.	Proxy immigrant variable.

French Not Frist Language	The percentage of students whose first language is not French	Proxy immigrant variable.
Moved Non-French	The percentage of students who moved to Canada from a non-French speaking country in the last four years.	Proxy immigrant variable.
Grade	Grade level of the student who submitted a survey. This study looks specifically at grade 3 and 6 students.	This was used to identify a difference in AST rates between grade 3 and 6.

Appendix 3A: Variable & Description of Climatic Factors

Variable	Description	Use
Sunrise	If the sun was up or down at the location of the survey at 8am.	This was used as a proxy variable for student reflectivity. Could students see where they are going and could drivers see the students.
Temperature	What the official temperature, in Celsius, was of the community where the survey was conducted.	This was used to see if the temperature impacted AST rates at a school.

Precipitation	If there was any precipitation at the location of the school. This could then be determined if it were rain or snow based on the temperature.	This was used to determine if the rain or snow impacted AST rates at a school.

Appendix 4A: Global Model Statistical Results

	Intercept	*P-Value*	*Conf-Interval*
Grade	0.043	**<0.001**	0.039 - 0.047
Built Environments			
Local to Major Roads	0.005	0.900	-0.058 - 0.069
Green Roads	-0.035	0.143	-0.072 - 0.001
Sidewalk 1600m	0.024	0.057	0.004 - 0.044
Climatic Factors			
Degrees	0.004	**<0.001**	0.003 - 0.006

Appendix 5A: Results of statistical analysis testing of EQAO variables

Variable	Coefficient	T Value	P-Value
Low Income Percentage	0.0032272	0.616	0.53884
Parental Education Percentage	0.0028795	1.114	0.26674
Special Education Percentage	-0.0072603	-0.841	0.40155
Gifted Percentage	0.0011527	0.229	0.81936
Not English Percentage	-0.0007529	-0.328	0.74320
Not French Percentage	-0.0104235	-1.331	0.18519
Non-English Percentage	0.0350999	2.003	0.06480
Non-French Percentage	-0.0348342	-1.918	0.05685

Curriculum Vitae

Name:	Nathaniel Clark Frisbee
Post-Secondary Education and Degrees:	Huron University College London, Ontario, Canada 2018-2022. B.A. Hons. Governance, Leadership and Ethics & Environment and Health
Honours and Awards:	2024 Pleva Teaching Award
	2023 Pleva Academic Achievement Award
	2022 Canadian Association of Geographers Undergraduate Thesis Award
	2019 – 2022 Huron University College Dean's Honor List

Related Work Experience:	Teaching Assistant Western University 2022-2024 Research Assistant Human Environment Analysis Laboratory 2020-2023