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Final Report

TNW2010-09

Research Project Agreement No. 61-7320

School-Based Travel: A Mobility Assessment

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A report prepared for

Transportation Northwest (TransNow)
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February 2011

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. **TNW2010-09**	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE School-Based Travel: A Mobility Assessment		5.REPORT DATE 2/11 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Anne Vernez Moudon, Lin Lin		8. PERFORMING ORGANIZATION REPORT NO. **TNW2010-09**
9. PERFORMING ORGANIZATION NAME AND ADDRESS Transportation Northwest Regional Center X (TransNow) Box 352700, 112 More Hall University of Washington Seattle, WA 98195-2700		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. DTRT07-G-0010
12. SPONSORING AGENCY NAME AND ADDRESS United States Department of Transportation Office of the Secretary of Transportation 1200 New Jersey Ave, SE Washington, D.C. 20590		13. TYPE OF REPORT AND PERIOD COVERED Final Research Report 14. SPONSORING AGENCY CODE **61-7320**
15. SUPPLEMENTARY NOTES		

ABSTRACT

This project contributes to developing a technical infrastructure to support the Safe Routes to School (SRTS) Program, specifically to monitor its growth and to evaluate its effectiveness. Since its inception in 2005, the SRTS program mandated by SAFETEA-LU has benefited about 6,489 schools The National Center for Safe Routes to School keeps track of these schools by compiling tallies of children walking or biking to school and by collecting parent surveys. Each state works to have a fair and effective distribution of resources to the neediest schools.

This proposal adds to an on-going Pooled Fund project spearheaded by the Washington State Department of Transportation to support information exchanges and research between several participating states, including Florida, Texas, Mississippi, and Wisconsin. Over the past two years, the PI and her team have been working with WSDOT to provide technical support to members of the Pooled Fund. This proposal is to fill a relatively small but very important gap in the current knowledge about SRTS: that is the lack of data on the schools specific locations. Having spatial data on the location of schools will facilitate the selection of SRTS projects and the monitoring the SRTS programs over time. We propose to geocode schools nationwide in relation to existing transportation facilities. This would enable state SRTS coordinators to quickly evaluate the schools proximity to different types of transportation facilities and to establish their related level of exposure to traffic. Geocoded schools would also allow coordinators to analyze the characteristics of the neighborhoods around the schools based on spatial data that are readily available from the US Census.

17. KEY WORDS Safe Routes to School, children active travel, children safe travel, school neighborhoods, school transportation infrastructure		18. DISTRIBUTION STATEMENT	
19. SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF. (of this page) None	21. NO. OF PAGES 115	22. PRICE

DISCLAIMER

EXECUTIVE SUMMARY

Introduction

The research described in this report was submitted as the dissertation part of the Doctorate of Philosophy degree (Urban Design and Planning) that Research Assistant Lin Lin obtained in August 2010. Entitled “An Ecological Study of Children Commuting to School,” the dissertation was filed with the University of Washington Graduate School.

The dissertation Supervisory Committee consisted of Drs. Anne Vernez Moudon (chair), Professor, Department of Urban Design and Planning; Scott Rutherford, Professor of Civil and Environmental Engineering; Hendrika Meischke, Professor, Department of Health Services; Qing Shen, Professor, Department of Urban Design and Planning; and Marieka Klawitter (GSR), Associate Professor, Evans School of Public Affairs, all at the University of Washington. Dr. David Levinger, now Director of Research at Rails-To-Trails Conservancy, in Washington, DC, was also part of the Supervisory Committee.

Background and Problem

Active commuting to school had been an overlooked source of s physical activity for children. This study aimed to provide insights on how the individual activity-travel patterns of adults in the Puget Sound Region of Washington State were impacted by the presence of children in the household. It also investigated if and how the characteristics of both home and school neighborhood environments influenced mode choice for school-based trips, and explored the reciprocal relationships between children and adults’ travel patterns.

Research Objectives

The research sought to address two questions:

- How did having children aged 18 and younger affect activity-travel patterns of individual adults?
- How were children and household characteristics, parents’ travel patterns, and environments around home and school associated with children’s mode of commuting to school?

Method of Analysis

Travel data came from the 2006 Puget Sound Regional Council (PSRC) Household Activity and Travel Survey, which included data on basic demographics, activities, trip and tour characteristics for every member (including children) of 4,746 households (10,510 individuals) in King, Kitsap, Pierce, and Snohomish counties during a consecutive 48-hour travel period. The survey was conducted during weekdays from April to June of 2006. Data on the built environment came from tax-lots pr parcels supplied by county assessors’ offices. Data on transportation infrastructure and traffic conditions came from PSRC and the Washington State Department of Transportation. Park and travel destination data came from the Urban Form Lab (UFL) at the University of Washington.

Research addressing the first question included 7709 individuals aged 19, and 4469 households in the 4 counties of the Puget Sound region. The dependent variables were individual adult's trip frequency, travel time, and activity realm (the polygon enclosing all the destinations reached by an individual during the survey period). Multilevel models included individual and household demographic and socioeconomic characteristics, and residential density in the home neighborhood. The analyses considered interactions between gender, work status, and whether adults lived with children or not.

Research addressing the second question included 749 school age children (5-18) in King County: 396 in elementary school (age 5-11), 200 in middle school (age 12-15), and 153 in high school (age 16-18). The dependent variables were children's commute mode to school categorized as using a bus, using active transport, versus being driven to school. The independent variables were the child's demographic characteristics, those of the head of household, the household socioeconomic characteristics; and distance between home and school. Models examined the effects of home and school neighborhood characteristics—area characteristics, including transportation infrastructure and traffic conditions, presence of destinations—on a child's commute mode to school. Separate analyses were done for 211 elementary school children who lived within 1 mile of their school.

Results

Regarding the first question, there were significant differences in activity-travel patterns between individuals or households with and without children aged 18 or younger. People who lived with children generated more non-work related trips and spent more time on daily travel. Other differences in travel between parents and non-parents were explained by complex interactions between gender and work status. Women in general made more trips than men, but had a smaller daily activity realm. Interestingly, men who did not work but lived with children traveled the least. Yet men who worked part time and lived with children had the longest travel time and the largest daily activity realm. Individuals who lived in higher residential density had smaller size of individual activity realm, and were less likely to be automobile dependent. In all models, the number of cars in the household was strongly associated with mode choice.

Regarding the second question, the study found a strong inverse association between network distance between home and school and active commuting to school for all school age groups, as well as for elementary school children who lived near to their school. Age was positively associated with active commuting in elementary school children only. Gender was consistently not associated with travel mode to school for all school age groups. Elementary and middle school children whose household heads worked part-time were more likely to be driven to school, whereas for youth in high school, this was the case when the head of household did not work. Different environmental attributes were associated with different travel modes by different age groups. The presence of parks in the neighborhood was positively associated with elementary children walking or biking to school rather than being driven there. For middle school children, having direct route to school has a positive effect on active travel to school, but traffic volumes in the neighborhood had a negative effect. For high school students, higher bus ridership in the neighborhood was associated with higher probability of their taking the bus to school.

Conclusions and Recommendations

It was not surprising to find that having school-aged children affected the travel patterns of adults. Specifically, the individual parent's gender and work status were strongly associated with travel frequency and mode choice. Future research and programs will need to consider the parent's socioeconomic characteristics in order to (1) better manage the general impact of family travel pattern on transportation systems; and (2) to effectively encourage children to use active travel to school. Increasing the number of children using active travel to school can potentially two benefits: to reduce traffic conditions in neighborhoods and to improve children's health.

The strong inverse association between network distance from home to school and active commuting to school found in all school age groups, even for those who lived near to their school, suggested that urban and transportation planners should work with school districts to change school siting and allocation policies, especially for elementary and middle schools. Route directness from home to school and traffic volume were additional characteristics of home and school neighborhoods that could be modified to encourage active travel to school.

Acknowledgments

Matching funds for this research were provided in part by the Washington State Department of Transportation. We wish to thank Charlotte Claybrooke (WSDOT) and Orion Stewart (UFL) for their help.

An Ecological Study of Children Commuting to School

Lin Lin

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

2010

Program Authorized to Offer Degree:
Interdisciplinary Program in Urban Design and Planning

University of Washington
Graduate School

This is to certify that I have examined this copy of a doctoral dissertation by

Lin Lin

and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

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Abstract

An Ecological Study of Children Commuting to School

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Chair of the Supervisory Committee:
Professor Anne Vernez Moudon
Urban Design & Planning

Active commuting to school had been an overlooked source of s physical activity for children. This study first aimed to provide insights on how the individual activity-travel patterns of adults in the Puget Sound Region of Washington State were impacted by the presence of children in the household. Secondly, this dissertation investigated environmental characteristics for school base trips and explored the reciprocal relationships between children and adult's travel patterns.

This study highlighted differences in activity-travel patterns between individuals or households with and without children aged 18 or younger. People who lived with children generated more non-work related trips and spent more time on daily travel. Other differences in travel between parents and non-parents were explained by complex interactions between gender and work status. Women in general made more trips than men, but had a smaller daily activity realm. Interestingly, men who did not work but lived with children traveled the least. On the other hand, men who worked part time and lived with children had the longest travel time and the largest daily activity realm. Individuals who lived in higher residential density had smaller size of individual activity realm, and were less likely to be automobile dependent.

A strong inverse association between network distance from home to school and active commuting to school was found in all school age groups, even for those who lived near to their school. Age was positively associated with active commuting in elementary school children only. Gender has been consistently shown to be a non-significant association with travel modes to school for all school age groups. Elementary and middle school children whose household heads worked part time were more likely to be driven to school, whereas it was more likely for high school children whose household heads did not work. Different environmental attributes were associated with different travel modes by different age groups.

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ACKNOWLEDGEMENTS

The author wishes to express sincere appreciation to her committee members – Professors Scott Rutherford, Hendrika W Meischke, Qing Shen, David Levinger, and Marieka Klawitter for their extended long-term support and especially to her chair, Professor Anne Vernez Moudon, for her vast reserve of patience and knowledge. This dissertation would never have been completed without the encouragement and devotion of my family and friends.

DEDICATION

To my parents.

Chapter 1 Introduction

Background

Active commuting to school had been an overlooked source of s physical activity for children (Tudor-Locke et al. 2001). Reviews of studies on active commuting to school and children's physical activity concluded a positive association between active commuting and overall physical activity level (Lee et al. 2008; Faulkner et al. 2009). A longitudinal study showed that sedentary children were more likely to become sedentary adults (Kelder et al. 1994). Active school transportation may also encourage healthy behavior into adulthood (Black et al. 2001). A systematic review of literature between 1970 and 2002 to identify research that evaluated the effectiveness of non-curricular interventions on the physical activity of children concluded that physical activity can be possibly increased through active transportation to school (Jago and Baranowski 2004). However the prevalence of children actively commuting to school in the U.S. decreased from 41% in 1969 to only 13% by 2001 (McDonald 2007).

Obesity is a leading public health concern in the United States and has become a rapid rise epidemic (Flegal et al. 2005; Ogden et al. 2007; Catenacci et al. 2009). Between 1980 and 2004, obesity prevalence doubled in adults aged 20 years or older from 15% to 33% and overweight prevalence tripled in children and adolescents from 5.5% to 17% (Flegal et al. 2002; Ogden et al. 2002; Hedley et al. 2004; Ogden et al. 2006). Obesity has many health, social, psychological, and economic consequences for individuals and society (Bray and Bouchard 2008). The economic impact of obesity is especially evident in health-care costs (Wolf and Colditz 1998; Colditz 1999; Wang and Dietz 2002). A study estimated that medical expenditures attributed to overweight and obesity accounted for 9.1% of total US medical expenditures in 1998 and may have reached 78.5 billion US dollars (Finkelstein et al. 2003). Expenditures will continue to rise particularly due to increases in obesity prevalence and in the cost of related health care (Thorpe et al. 2004). For adults, obesity increases the risk for many other chronic diseases, including diabetes mellitus, cardiovascular disease, and nonalcoholic fatty liver disease, and decreases overall quality of life (Catenacci et al. 2009). Awareness of the gravity of the risk that obesity poses to the health of children is gradually dawning on researchers. Obese children can become obese adults and suffer health problems as a result. Many obesity-related health conditions once thought applicable only to adults are now being seen in children and with increasing frequency. Furthermore, obesity in childhood, adolescence, and young adulthood may accelerate the development of heart diseases, and other obesity-related disorders (Daniels 2006). If current trends continue, a recent study has projected that the prevalence of overweight in children would reach 30% by 2030 (Wang et al. 2008). The public health profession considers childhood obesity to be an issue of utmost public health concern. The lack of evidence that basal metabolic rate (the amount of energy expended while at rest in a neutrally temperate environment in which the digestive system is inactive), affects childhood obesity argues for a research focus on physical activity – or the lack of physical activity (Anderson and Butcher 2006).

Research on children's active commuting to school has grown in the past few years. A recent review identified the predictors of active commuting to school to be demographic factors, individual and family factors, school factors (including the immediate area surrounding schools), and social and physical environmental factors (Davison et al. 2008). However, previous studies demonstrated inconsistent results regarding the association of a child's age and their active commuting to school. . Also missing from the majority of studies are the environmental characteristics of schools, important in making decisions on travel modes for school-based trips (Panter et al. 2008). Furthermore, the activity-travel patterns of individuals often include interaction with other household members, and this is particularly so for children, since the final decision about travel to school is most often made for them by the caregiver in the household. Therefore, the travel decision is likely not limited to the schedule, constraints or preferences of the child, but rather that of their caregiver (McMillan 2007). Yet, limited studies have explored how the intra-household interaction and schedules of parents or guardians affect children's commuting to school. Few studies have focused on how children affect the individual travel patterns of adult household members in the U.S. context.

This study first aimed to provide insights on how the individual activity-travel patterns of adults in the Puget Sound Region of Washington State were impacted by the presence of children in the household. Secondly, this dissertation investigated school environmental characteristics for school base trips and explored the reciprocal relationships between children and adult's travel patterns. It will contribute to a better understanding of the travel patterns of school children, which is necessary for developing effective interventions. This study would not only identify environmental factors around homes, but also environmental factors around schools, and constraints and interactions of household members that have impact on how children travel to school.

Research Questions

This dissertation seeks to comprehensively investigate the environmental correlates of how children commute to school, as well as effects of household interactions and schedules of household members on children's mode of travel to school. Specific research questions are:

1. How does having children aged 18 and younger affect activity-travel patterns of individual adults?
2. How are children and household characteristics, parents' travel patterns, and environments around home and school associated with children commuting to school?

Structure of Dissertation

This dissertation includes three parts. Part one provides background information. Parts two and three correspond to each of the dissertation's two research questions. Within each part, related literature specific to each research question is reviewed, methods are explained, findings are reported, and discussions with their implications for researchers and practitioners in the fields of urban/transportation planning and public health are included.

Chapter 2 The Impacts of Children on the Activity-Travel Patterns of Individual Adults

Introduction

The activity-travel patterns of individuals often include interactions with other household members (Bhat and Pendyala 2005; Bradley and Vovsha 2005; Srinivasan and Bhat 2005; Vovsha and Petersen 2005; McDonald 2008; Yarlagadda and Srinivasan 2008; Timmermans and Zhang 2009; Zhang et al. 2009). This is particularly true for children, since the final decision about travel is most often made by their parent(s) or guardians. Therefore, travel decisions are likely not limited to the schedules, constraints, or preferences of the child, but rather that of the parents (McMillan 2007). At the same time, the daily activities of children impact the travel patterns of adults. A study using 1968 travel survey data from Washington, D.C. found that households with children have higher total trip rates and non-work-trip rates (McGinnis 1980). Another study using 1977 Baltimore Travel Demand Data Set and investigating the relationship between the life-cycle stage of a household and the travel behavior of its members found that employed women who have young children spent less time in pleasure travel and more time shopping (Allaman et al. 1982). Changes of household size and structure, increases in labor-force participation by women, and changes in travel environment (such as land use patterns, housing supply, retail distribution systems, forms of employment and ways of performing work, etc.), inevitably influence and transform the life-styles of residents and their associated activity-travel behaviors (Kitamura 1988).

Few studies have focused on how children affect the individual travel patterns of adult household members in the US context. A study using travel diary data in Austria found that the number of small children and the number of current school pupils in a household have positive effects on the frequency of maintenance trips, such as shopping trips, for both females and males (Simma and

Axhausen 2001). Even so, the findings in Austria might not directly transfer to the U.S. environment. A study using travel diary data from two U.S. urban regions found that households with children spent less time on mandatory activities such as work and work-related trips (Stopher and Metcalf 1999). Yet this US study investigated activity-travel patterns at the aggregated level. Contrarily, a recent study using an Atlanta, GA, travel survey found that at the household level the presence of children positively influences the durations of out-of-home work-related activities in trip chains (Lee et al. 2007). More empirical knowledge is needed to understand how children affect activity-travel patterns of individual adults.

This study aims to provide insights on how individual activity-travel patterns of adults in the Puget Sound Region, Washington State are impacted by whether they lived with children or not. A better understanding of travel behavior will improve travel demand forecasting and the assessment of emerging transport policies (Stern and Richardson 2005).

Conceptual Framework

The conceptual framework for this study integrated a travel activity based framework widely used in the transportation field with the social ecological framework. Activity-travel decision processes are intrinsically multidimensional and complex. Individuals make activity travel decisions on a daily basis, subject to household, spatial, and temporal constraints, and in the presence of a diverse urban landscape. Consequently, individual activity-travel patterns are associated with an individual's social or economic status, by their household and societal roles, or by their location vis-a-vis the transport system and activity site (Hanson and Hanson 1981). Many studies have applied this travel activity based framework to understand individual activity-travel patterns in the transportation field (Sun et al. 1998; Chatman 2003; Ettema et al. 2007; Fan and Khattak 2008; Lee et al. 2009).

The social ecological framework considers several levels of influence ranging from intrapersonal level factors, interpersonal level processes, and institutional, community, and environmental level factors, to public policy. The travel activity based framework used in the transportation field, which considers intrapersonal level factors (a person's social or economic status), interpersonal level processes (one's household and societal roles), and environmental level factors (one's location vis-a-vis the transport system and activity site), is consistent with the social ecological framework. In addition, the social ecological framework allows for the possible reciprocal interactions among different factors. Figure 1 illustrates the relationships of individual level factors and environmental level factors on activity-travel patterns of adults.

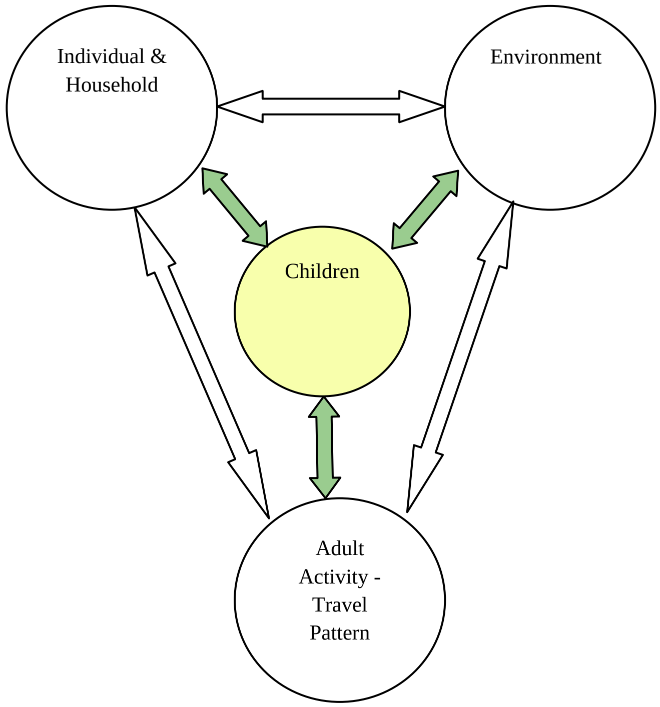

Figure 2-1 Conceptual Framework for Adult Activity-Travel Pattern

The conceptual framework for this study catered to individual travel patterns and accommodated interactions among different factors. Table 2-1 summarizes the elements of the conceptual framework.

Table 2-1 Constructs of the Conceptual Framework

Level	Element	Variables
Individual level factors	Socioeconomic status	Age
		Gender
		Education
		Employment status
	Attitudes	Attitude towards active transport
		Attitudes towards environment
	Perceptions	Perception of environment
Household	Characteristics of Household	Number of household members
		Availability of car
		Household income
	Children	Age
		Gender
		Ethnicity
		Independence
		Motivation for active transport
	Household Interactions	Joint decision making on travel
Built and social Environment	Physical Environment	Built environment, natural environment
	Social Environment	School influence
		Peer influence

Activity-travel patterns capture what people do in space on a regular basis, and how people use transport, which would be expressed as trip frequency, travel time, travel mode, and purposes of travel individually or in combination (Handy et al. 2002).

Individual level factors include individual socioeconomic status, their attitudes towards transportation and the environment, and their perceptions of the environment. Concerning the overestimation of the impact of the built environment on travel behavior, many recent empirical studies include attitudes towards the environment to address self-selection problems (Bohte et al. 2009).

Household factors– here referring to interpersonal level factors – might include household socioeconomic status and the interactions within the household, which could also be considered part of the social environment. For people who live with children, both social and built environments impact their travel considerations. At the same time, the daily activities of children impact the travel patterns of adults.

Built and Social Environment, or environmental level factors, refers to those factors physically external to the people, including physical environment and social environment. Physical environment might include the neighborhood built environment, natural environment, etc. Different neighborhoods and natural environments might support different activity-travel patterns. For example, if a person lives in a neighborhood where grocery stores, restaurants, coffee shops, and other retail services are close by, s/he would be likely to walk to these places. On the other hand, if a person lives in a residential only neighborhood without retail services within walking distance, s/he would be likely to use automobile to reach these places. Social environment refers to family members, friends, peers at work, and neighbors, and their associated social values and norms. Within a positive social environment that encourages active transportation, a person is more likely to walk or bike. If many of a person's family members, friends, and peers at work walk regularly, the person is also more likely to walk.

Literature Review

This review includes studies in which activity-travel patterns were measured at the individual or household level. In the early 1960s, behavior research in transportation began to study travel patterns with the aim of finding ways to represent spatially the movement of individuals and vehicles (Hensher 2001). When criticism of using aggregated data grew, a shift towards developing travel models based on disaggregated data began in the 1970s (Kutter 1973). In addition, a study (Steiner 1994) that reviewed literature on the relationship between residential density and travel patterns called for disaggregated studies to sort out the effects of socioeconomic status, mix of land use, density, and other location factors on travel patterns.

Several literature reviews already summarized studies conducted in the 1990s or before the early 2000s (Ewing and Cervero 2001; Saelens et al. 2003; Lee and Moudon 2004; Mokhtarian and Chen 2004; Buliung and Kanaroglou 2007; Saelens and Handy 2008). Thus more recent studies conducted since 2005 are the focus of this review. Studies were identified using the Transportation Research Information Services (TRIS) and the Science Citation Index with key words such as *travel behavior*, *travel pattern*, and *activity travel pattern*.

This review identified fourteen U.S. studies carried out between 2005 to 2009 (Bradley and Vovsha 2005; Gliebe and Koppelman 2005; Srinivasan and Athuru 2005; Srinivasan and Bhat 2005; Buliung and Kanaroglou 2006; Crane 2007; Lee et al. 2007; Chen et al. 2008; Fan and Khattak 2008; Frank et al. 2008; Lin and Long 2008; Chung et al. 2009; Lee et al. 2009; Pinjari et al. 2009). The study areas covered the San Francisco Bay Area, CA (Srinivasan and Athuru 2005; Srinivasan and Bhat 2005; Pinjari et al. 2009), the Puget Sound Region, WA (Gliebe and Koppelman 2005; Frank et al. 2008; Chung et al. 2009), Portland, OR (Buliung and Kanaroglou 2006), New York, NY (Chen et al. 2008), Tucson, AZ (Lee et al. 2007), Atlanta, GA (Bradley and Vovsha 2005; Lee et al. 2009), and the

Triangle Area of North Carolina (Fan and Khattak 2008), all of which used regional household travel activity surveys. One study used the American Housing Survey panel data from 1985 to 2005 (Crane 2007). Another study used the 2001 National Household Travel Survey (Lin and Long 2008). Table 2-2 lists the studies reviewed.

Table 2-2 List of Studies Reviewed

Reference	Study Area	Data	Sample Size
Srinivasan & Bhat 2005	San Francisco Bay Area	2000 San Francisco Bay Area Travel Survey	?
Bradley & Vovsha 2005	Atlanta region	2001 Atlanta activity-travel household survey	13760 households
Gliebe & Koppelman 2005	Puget Sound region	1989–1997 Puget Sound Transportation Panel household survey	11443 one-day activity records
Srinivasan & Athuru 2005	San Francisco Bay Area	1996 San Francisco Bay Area Travel Survey	2518 maintenance trips with 2692 individuals in 1174 households
Buliung & Kanaroglou 2006	Portland metropolitan	1994/5 Portland metropolitan activity-travel survey	1596 households
Lee et al. 2007	Tucson	2000 Tucson Household Travel Survey	2070 households
Crane 2007	US	1985-2005 The American Housing Panel Survey	a sum of 100,000 individuals in 40,000 households from 1985-2005
Chen et al. 2008	New York Metropolitan Region	1997/8 New York Household Interview Survey	2,089 home-based work tours
Fan & Khattak 2008	the Triangle area of North Carolina	the 2006 Greater Triangle Travel Study	7422 individuals
Frank et al. 2008	Puget Sound region	1999 Puget Sound Household Travel Survey	10475 tours
Lin & Long 2008	US	the 2001 National Household Travel Survey	54463 households
Lee et al. 2009	Atlanta region	2001–2002 Atlanta household activity-based travel survey	13808 weekday tours, and 2990 weekend tours
Chung et al. 2009	Puget Sound region	Waves 3 and 4 Puget Sound Transportation Panel household survey	1621 individuals
Pinjari et al. 2009	Alameda County in San Francisco Bay Area	2000 San Francisco Bay Area Travel Survey	2793 individuals

The findings from the literature are organized according to the constructs of the conceptual framework, namely individual level factors, household factors, and environmental factors. Most of the studies reviewed used life-style as a guideline to construct individual and household level variables. Life-style was measured to include life-cycle stage, income, and residential location, was associated with behavioral patterns (Kitamura 1988). Life-cycle stage was viewed as an indicator of the social roles present in different households, as well as the size of the household and the age of its members.

Individual Level Factors and Activity-Travel Patterns

Eleven of the 14 studies included individual-level variables (Bradley and Vovsha 2005; Gliebe and Koppelman 2005; Srinivasan and Athuru 2005; Srinivasan and Bhat 2005; Crane 2007; Chen et al. 2008; Fan and Khattak 2008; Frank et al. 2008; Chung et al. 2009; Lee et al. 2009; Pinjari et al. 2009). The most common variables included were gender and age. Gender differences in commuting patterns have been a focal point of studies in geography. A review on gender difference in commuting patterns concluded that commuting by males is longer both in terms of time and distance; men commute in more directions than women; men usually have single-purpose commuting (to work) whereas women tend to exhibit multi-purpose commuting that combines work and diverse household needs (Blumen 1994). Schintler and colleagues concluded that women's travel patterns differed from those of men in terms of the distance traveled, the mode of travel, and the complexity and purpose of trip making (Schintler et al. 2000). A study analyzing a 2000 San Francisco Bay Area Travel Survey found that non-working women are more likely to shoulder a larger share of household maintenance tasks (Srinivasan and Bhat 2005). A more recent study that used panel data from the American 3Housing Survey from 1985 through 2005 found that the average woman's trip to work continually differed in many marked ways from the average man's (Crane 2007).

Short work trips may also reflect spatial entrapment in highly localized labor markets for women (MacDonald 1999). On the other hand, the proportion of women in white-collar professions since 1970 has doubled, and the gender gap in college enrollments reversed, with 1.3 female graduates for each male in recent years (Goldin et al. 2006). A recent study showed that in San Francisco the travel time of journey to work in 2000 were the same for women and men in all age groups except those in their fifties (Gossen and Purvis 2005). This suggested that women's travel may have caught up with that of men. While previous studies have explored the travel pattern differences between the genders, few have examined the interactions between genders, work, and children in the household.

It is known that the mobility of individuals peaks when they are in their 30s and 40s, and that the elderly are the least mobile (Kitamura 1988). Many studies included age measures, but, there was a lack of consensus on measurement. Of 11 studies including age, two measured age as an interval variable (Crane 2007; Chen et al. 2008) and the others categorized age using different thresholds. For example, one study (Srinivasan and Athuru 2005) categorized age into young (14-30), middle age (31-50), upper middle age (51-70), and older (71 and above), while another study (Fan and Khattak 2008) used children (0-14), young (14-24), adult (25-64), and old (65 and above). Using different age measures not only made comparing results across studies difficult, but also led to inaccurate model results due to the loss or misclassification of information.

To account for self-selection problems, two studies (Chen et al. 2008; Pinjari et al. 2009) excluded non-motorized travel modes and incorporated individual time-preference measures, respectively. Other individual level variables included in these previous studies were work status, work hours, education level, commute time, and possession of a driver's license, many of which were for controlling proposes in the multivariate regression models. None of the studies reviewed here included environmental or transportation attitude measures.

Household Factors and Activity-Travel Patterns

Household income has been one of the prime variables in travel demand analysis (Kitamura 1988). All studies reviewed, excepting one, included household income measures. Individuals in low-income households were more likely to stay home (Gliebe and Koppelman 2005), have fewer vehicle miles traveled (VMT) (Lin and Long 2008), use transit (Frank et al. 2008), and go shopping jointly with other household members (Srinivasan and Bhat 2005). On the other hand, higher income households were associated with longer daily travel distance (Buliung and Kanaroglou 2006; Fan and Khattak 2008), longer commute distance (Crane 2007), more time spent on discretionary activities such as entertainment, fitness/exercising, etc., on weekdays (Lee et al. 2009; Pinjari et al. 2009), and less time on work related activities on the weekends (Lee et al. 2009). Higher-income households were also more likely to own automobiles, but did not have a higher propensity to use automobiles (Chen et al. 2008). Higher-income households also exhibited a more equal distribution of maintenance trips within the household (Srinivasan and Athuru 2005).

Unlike household income, variables concerning children were not included in all of the studies reviewed. Of the nine studies that included measures of children in their analysis, six found significant associations with activity-travel patterns. Household heads who lived with children were associated with more joint shopping trips with other household members (Srinivasan and Bhat 2005), higher frequency of work related tours (Gliebe and Koppelman 2005), and more solo maintenance activities (Srinivasan and Athuru 2005). Men who lived with children were associated with longer commute distances (Crane 2007). Two studies investigating trip chaining behavior at the household levels found inconsistent results about children. One study using Tuscon, AZ, travel survey data found that the presence of children in households positively influenced the durations of out-of-home subsistence, maintenance, and discretionary activities in trip chains (Lee et al. 2007). On the other hand, another study using Atlanta, GA, travel survey data found that the presence of young children (less than 5 years old) tended to reduce the time spent on out-of-home subsistence (work and work related) and discretionary (social and recreational) activities (Lee et al. 2009). In addition to geographic differences, different methods might contribute to these contradictory outcomes. The former study did not include any built environment measures, while the latter included built environment measures within a kilometer of a residence.

Vehicle ownership or access to vehicles was another primal variable in travel demand analysis (Kitamura 1988). Some studies measured access to vehicles at the individual level, while others measured it at the household level. At the individual level, females who had access to their own vehicle were more likely to undertake grocery shopping for the household compared to women who did not have their own vehicle (Srinivasan and Bhat 2005); access to a car was also associated with longer commute distance (Crane 2007). At the household level, greater number of vehicles was associated with bigger household activity space (measured as the area size of the minimum Convex Polygons of all activity locations of a person) and a longer daily household travel distance (Buliung and Kanaroglou 2006), higher household VMT (Lin and Long 2008), and allowed members to allocate more time to out-of-home social and recreational activities (Lee et al. 2007). Higher motorized vehicle ownership in a household was also associated, at the individual level, with a lower preference for physically active out-of-home recreational activities (Pinjari et al. 2009).

Household members allocated and distributed tasks and activities among each other and jointly participated in them (Bhat and Pendyala 2005). Four studies reviewed focused on modeling interactions and group decision-making in terms of household activities and travels (Bradley and Vovsha 2005; Gliebe and Koppelman 2005; Srinivasan and Athuru 2005; Srinivasan and Bhat 2005).

Environmental Factors and Activity-Travel Patterns

A synthesis of more than 50 studies on travel behavior conducted in the 1990s concluded that the built environment influenced trip lengths, trip frequencies, travel mode choice, and VMT (Ewing and

Cervero 2001). Since 2000, researchers in public health, exercise science, psychology, and sociology have recognized the importance of physical activity for transportation purposes in health. Research on the correlates of walking and biking has proliferated (Sallis et al. 2006; Saelens and Handy 2008; Brownson et al. 2009; Pucher et al. 2009). A number of studies found that selected built environment attributes were related to levels of physical activity (Saelens et al. 2003; Lee and Moudon 2004; Buliung and Kanaroglou 2007; Saelens and Handy 2008). Nonetheless, not all studies reviewed here investigated the impacts of built environment on travel behaviors. Among 14 studies, five studies focused on individual and household level factors only (Bradley and Vovsha 2005; Gliebe and Koppelman 2005; Srinivasan and Bhat 2005; Lee et al. 2007; Chung et al. 2009).

One of the built environment attributes most frequently found to be related to walking was density, which was measured as residential density, employment density, population density, and building density. Density is a complex concept, influenced by such domains as urban form, settlement type, site design, street and transportation systems for both public transportation and private cars, urban sprawl, etc. (Churchman 1999). Numerous studies have found that density had significant impacts on travel behavior (Ewing and Cervero 2001). A literature review on the relationship between residential density and travel patterns called for disaggregated studies to sort out the effects of density on travel patterns (Steiner 1994). However, many studies measured density at the aggregated zonal level such as census tract level (Chen et al. 2008; Lin and Long 2008), or travel analysis zone (Pinjari et al. 2009). Only two studies measured density at the individual neighborhood level (Fan and Khattak 2008; Lee et al. 2009). One measured it using a 1 km (0.62 miles) buffer around each respondent's home (Lee et al. 2009), and the other used 0.40 km (0.25 miles) (Fan and Khattak 2008).

Other built environment attributes included in the studies reviewed here were land use types (retail floor area ratio, and retail accessibility and land use mixed measures) and transportation network measures (intersection density, neighborhood block size, distance to the nearest rail station/transit stop, and street connectivity measure). One study found that retail mix and street connectivity were key factors relating to individuals' travel space (Fan and Khattak 2008). Another study found that built environment measures such as land use mixed, retail floor area ratio, and intersection density were the strongest predictors of the number of stops within a tour (Frank et al. 2008). A study using Atlanta data found that the number of commercial parcels within a kilometer of a residence was associated with differences in weekday and weekend time-use allocations (Lee et al. 2009). And larger block sizes were associated with higher VMT (Lin and Long 2008).

Measurement of Activity-Travel Patterns

Travel patterns encompass trip frequency, travel time, travel mode, and purposes of travel individually or in combination (Handy et al. 2002). Recognizing that people made a series of trips on a daily basis such as stopping at a coffee shop on the way to work and at a day care center on the way home, quite a few studies included trip chaining or tour in their investigations of travel behavior (Gliebe and Koppelman 2005; Lee et al. 2007; Chen et al. 2008; Frank et al. 2008; Chung et al. 2009; Lee et al. 2009). Even though trip chaining has been widely recognized as important to understand travel behavior, the research literature revealed that no commonly accepted definition of a trip chain exists (Primerano et al. 2008). Furthermore, it is difficult to extract trip chaining from travel diary surveys and to analyze all the possible trip chain or tour types (Primerano et al. 2008). Table 2-3 lists the measures of activity-travel patterns used in the studies reviewed. Although travel frequency had been studied extensively in the transportation field, it was not the focus of the studies reviewed. This trend might be related to the recent focus on trip chaining.

Table 2-3 Measures of Activity-Travel Patterns

Reference	Measure of Activity-Travel Patterns	
Srinivasan & Bhat 2005	Head of household's duration of in-home maintenance activity	Time, purpose of travel,
	Shopping trips (decision to shop and task allocation, shopping duration)	
Bradley & Vovsha 2005	Individual daily activity patterns (mandatory travel pattern, non-mandatory travel pattern, and at-home pattern)	Purposes of travel
Gliebe & Koppelman 2005	One all-joint discretionary tour (work and work related)	Time, purpose of travel, travel mode
	Two all-joint discretionary tours (work and work related)	
	Shared ride to non-joint activity	
	Shared ride home from non-joint activity	
Srinivasan & Athuru 2005	A person in a household allocated to joint or solo maintenance trip	Purposes of travel
Buliung & Kanaroglou 2006	Household daily space (the minimum convex polygon containing activity locations visited by a single household, during the course of a single day)	Travel time and space
	Household daily travel distance	
Lee et al. 2007	Household's duration of out-of-home subsistence activities during tour (work and work related)	Time, purposes of travel,
	Household's duration of out-of-home maintenance activities during tour (shopping, going to services, etc.)	
	Household's duration of out-of-home discretionary activities during tour (social and recreational)	
Crane 2007	Individual's one-way commute distance by automobile	Travel length, and Purposes of travel
Chen et al. 2008	propensity to use automobile in a home-based work tour	Travel mode, Purposes of travel
Fan & Khattak 2008	Individual activity space(the minimum convex polygon containing activity locations visited by a single person, during the course of a single day)	Travel time and space
	Individual daily travel distance	
Frank et al. 2008	Travel modes (drive alone, share ride, transit, bike, and walk) of a tour	Travel mode
Lin & Long 2008	Quadratic root of a household's VMT on a travel day	Travel length
Lee et al. 2009	Duration of out-of-home subsistence activities during tour (work and work related)	Time, purpose of travel,
	Duration of out-of-home maintenance activities during tour (shopping, going to services, etc.)	
	Duration of out-of-home discretionary activities during tour (social and recreational)	
	Duration of out-of-home total travel time during tour	
Chung et al. 2009	Individual's subsistence activities duration (work and work related)	Time, purpose of travel,
	Individual's maintenance activities duration (shopping, going to services, etc.)	
	Individual's leisure activities duration	
	Individual's total travel time	
	Individual's number of trip chains	
Pinjari et al. 2009	Individual activity time-use behavior	Time, purpose of travel,

In summary, a limited number of studies investigated the impacts of children on the travel patterns of individual adults or household. Studies explored the travel pattern differences between genders, however, with some examining interactions between gender, work status, and living with children at the individual level. Household income and the number of vehicles available in a household consistently exhibited significant associations with activity-travel patterns both at the individual and household levels. Many studies found residential density to be significantly associated with activity-travel patterns. However, density was not measured uniformly in all studies.

Hypotheses

Based on the literature reviewed, the following hypotheses were proposed.

1. Compared to their counterparts who did not live with children, adults with children would:

- have a higher frequency of non work trips,
- have longer travel time,
- have a larger size of daily activity realm,
- be more likely to be automobile dependent

2. Residential density would have less impact on the travel patterns of parents/guardians than non-parents.

Methodology

A cross-sectional research design was used to conduct this study. The 2006 Puget Sound Regional Council (PSRC) Household Activity and Travel Survey data was used to explore the activity-travel patterns. Multilevel regression models with individuals as the first level and household as a second level were developed to investigate how individual and household socio-demographic characteristics and the physical environment of home neighborhoods were associated with travel patterns of individual adult household members. This section also describes how activity-travel patterns were measured and provides arguments for why these measures were applied.

Data

The 2006 PSRC Household Activity and Travel Survey collected data on basic demographics, activities, and tour and travel characteristics for every member (including children) of 4,746 households (10,510 individuals) in King County, Kitsap, Pierce, and Snohomish counties during a consecutive 48-hour travel period. The survey was conducted during the weekdays from April to June of 2006. The detailed sampling and survey method were summarized elsewhere (International 2007). The built environmental data came from parcel data supplied by county assessor's offices. The data included not only the detailed information on travel activity of all surveyed household members, but also residential density around respondents' homes. Table 2-4 summarizes data sources.

Table 2-4 Data Sources

Information		Data Source
Socio-demographic characteristics	Individual's age, gender, education, and employment status	2006 PSRC Household Activity and Travel Survey
	household's income, size, and vehicle availability	
Individual travel-activity characteristics	Travel time, travel frequency, travel distance, etc.	
Residential density	Parcel data	King, Kitsap, Pierce, and Snohomish County assessor's offices

The 2006 PSRC Household Activity and Travel Survey recorded and geocoded the individual household members' 2-day travel activity locations. The method of geocoding was documented elsewhere (2006). Figure 2 displays the spatial distribution of households included in the survey.

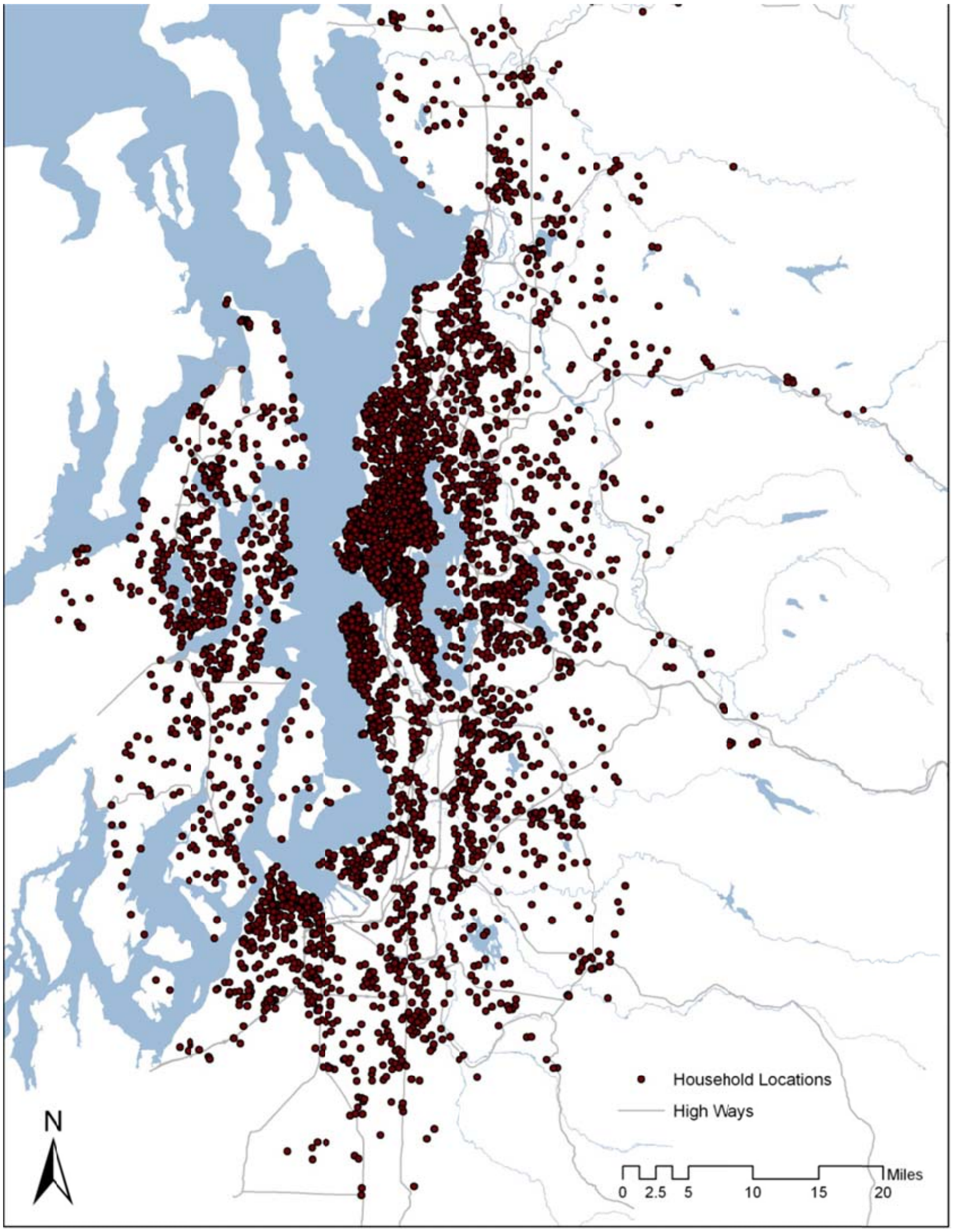

Figure 2-2 Household Location in the PSRC 2006 Household Activity and Travel Survey

Dependent Variables

Measures of Activity-Travel Patterns

Due to the lack of consistency in defining trip chains and the difficulties of using trip chaining to measure activity-travel patterns (Primerano et al. 2008), this study turned to the conventional measures of activity-travel patterns that had been consistently used in the previous studies. Table 2-5 lists how each travel pattern variable was measured.

Table 2-5 Measures of Activity-Travel Patterns

Travel Pattern	Measure	Description of Measurement
Trip Frequency	Average number of trips per survey day	The total trips of a participant made during the survey was divided by number of days of the participant recorded activities for the survey
Trip Frequency by Purpose	Average number of non work trips per survey day	All trips except for work related trips of a participant made during the survey was divided by number of days of the participant recorded activities for the survey
Travel Time	Average travel time per survey day	The total minutes reported by a participant spent on travel was divided by number of days of the participant recorded activities for the survey
Travel Space	Size of daily activity realm	The area of the minimum convex polygon of all activity locations of a participant during the survey
Travel Mode	Active transportation (walk and bike)	A binary variable indicating whether a participant had at least one walk or bike trip during the survey
	Transit user	A binary variable indicating whether a participant had at least one trip by transit during the survey
	Automobile dependent	A binary variable indicating whether a participant had done all his/her trips by driving or being a passenger during the survey

Activity-travel patterns were quantified using trip frequency (average trips per survey day), the frequency of trips and their purpose (average non-work trips per survey day), travel time (average travel time per survey day), the size of the daily activity realm, and travel modes (active transportation, transit users, and whether a participant had done all his/her trips by private automobile).

Trip frequencies have attracted considered academic interest (Ewing and Cervero 2001), which might be explained by the fact that trip frequency is the first step of the 4-step travel demand modeling that has been used by most regional transportation planning offices nationwide. In this study, trip frequency was measured in two ways: average total trips per survey day for each adult and average non-work trips per survey day. Non-work trips refer to all trips except for work related travels.

Time allocation has been seen as a means of studying how human activity affects and is affected by the environment and how they jointly influence the structure and functioning of the metropolitan community (Brail and Chapin 1973). Thanks to the increased recognition of the activity-based approach in travel behavior research, time is beginning to play a central role in travel demand analysis and modeling (Pas 1998). A frequently-studied time-related measure is the amount of the time allocated to travel (Mokhtarian and Chen 2004). Hence, average time spent on travel per survey day for each individual was used here.

The geographical dispersion of individual activity locations provided insight to the behavioral response of individuals to the spatial organization of cities (Buliung and Kanaroglou 2006). When policy encourages adjustments to the spatial organization and accessibility of places, people may choose to respond by modifying their daily activity patterns to reflect the latest distribution of activity locations. Two recent studies have used this approach to investigate activity-travel spatial distributes (Buliung and Kanaroglou 2006; Fan and Khattak 2008). The individual daily activity realm (space) that was used in these previous studies was applied here. How individual daily realm was measured is described in the following section.

Travel mode choice has been studied extensively (Ewing and Cervero 2001). The motivation for the transportation planning field has been a concern over the growing amount of automobile traffic and a desire to reduce traffic congestion by encouraging alternative travel modes. As mentioned above, recent public health research on walking and biking has highlighted how “active travel” might benefit personal health (Sallis et al. 2006; Saelens and Handy 2008; Brownson et al. 2009; Pucher et al.

2009). In this study, travel modes were put into three categories: using active transport (walking and biking), using public transportation, and automobile dependency (using private automobile alone for all daily activity travels).

Measuring Daily Activity Realm

The household survey recorded individual's 2-day travel activity locations, which were then geocoded. A geospacial modeling program, Hawth's Tools, was used to create minimum Convex Polygons of all activity locations used by an individual during the survey. These minimum Convex Polygons were the measure of a participant's activity realm during the survey.

For example, a 32-year-old woman with a graduate-level education lives in a two-person household with no children in the Ballard/Fremont area in Seattle and works part-time for the University of Washington. On the first day of the household survey, she took the bus to work, stopping first at the Post Office and walking to her office afterwards. After work, she took the bus directly home (Figure 3). On the second day of the household survey, she drove alone to go shopping at a Fred Meyer department store, and then returned home. She and her housemate then drove together to a restaurant in the Capitol Hill neighborhood of Seattle, for happy hour and an early dinner. After that, they drove back to her place of work for a social event, then walked to the nearby College Inn, a popular local bar. Before driving back home after mid-night, they went to a fast-food restaurant, Dick's, in the neighborhood of Wallingford (Figure 4). Her daily activity realm was created by linking all places that had been recorded during the survey (Figure 5).

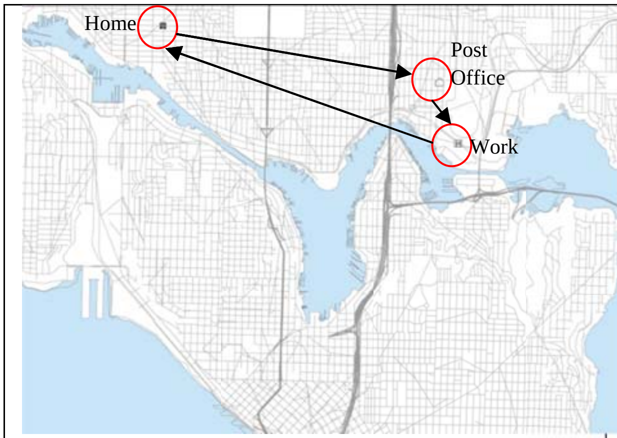

Figure 2-3 Activity Location – Day 1

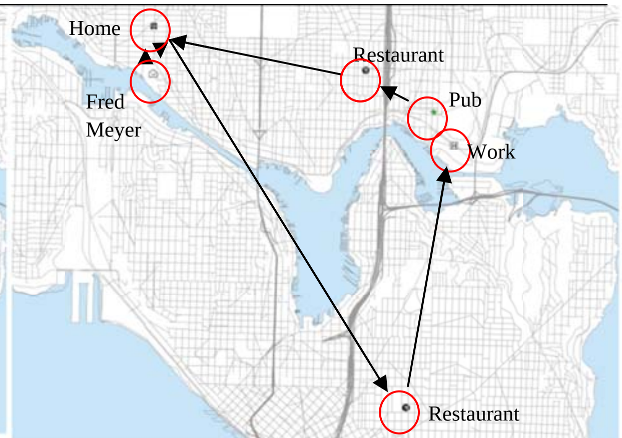

Figure 2-4 Activity Location – Day 2

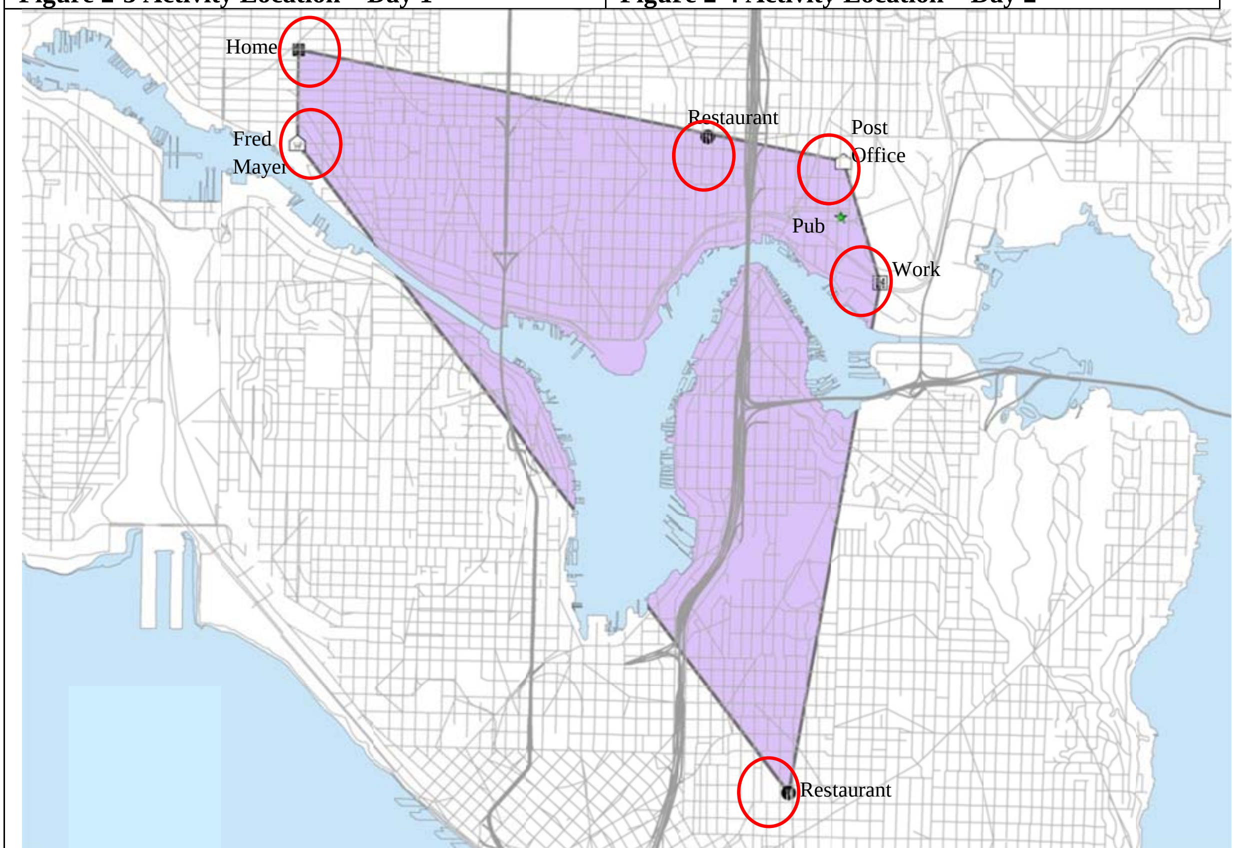

Figure 2-5 Daily Activity Realm

Independent Variables

Independent variables were selected according to the conceptual framework and grouped based on the constructs with individual level factors, household factors, and environmental factors. Variables for individual level factors and household factors came from the 2006 PSRC Household Activity and Travel Survey. About 28% of households (1,322 households) surveyed had, collectively, 2,297 children aged 0-18. Table 2-6 summarizes the household distribution by county.

Table 2-6 Households Sampled by County

County	Households with children aged 0-18	Percentage of Households with children aged 0-18	Total Households included in the survey
King	794	29.42%	2699
Kitsap	134	21.61%	620
Pierce	188	27.93%	673
Snohomish	206	27.32%	754
Total	1322	27.86%	4746

Residential density was measured within a 10-minute walking radius around each household's home. Assuming that the average walking speed is 5km/h, a 10-minute walk corresponds to a Euclidean distance of 833 meters (0.52 miles). The detailed operation of measuring was done in ArcGIS. After all residential parcels in the study area were selected, residential units were summed up at 30ft (9.14 meters) by 30ft and parcel polygons were converted to raster using a 30ft by 30ft cell. The raster then was converted to point. Residential density was calculated using point density function in spatial analyst tools with a neighborhood defined as circle with a radius of 833 meters. A 30m by 30m cell was used as the output cell. Then the residential density at respondents' home locations was obtained from the raster residential density data generated.

The 2006 PSRC Household Activity and Travel Survey contained 8,213 persons aged 19 and above. Due to missing values, the analysis included 7,709 persons aged 19 and above. Table 2-7 summarizes the original values in the survey and recoded values in the analysis of independent variables.

Table 2-7 Individual and Household Characteristics Variables

		Original Value in the survey Mean (SD), Min, Max	Recoded and Included in the Analysis Mean (SD), Min, Max
	Age	51.35 (15.23), min=19, max=99 Don't Know <998>: 20 ; Refused <999>: 35	51.09 (15.17), min=19, max=99
	Gender	Men: 3789 Women: 4421 Unknown: 3	Men: 3566 Women: 4143
	Education	1 Less than high school: 109 2 High school Graduate: 1281 3 Some collage: 1562 4 Vocational/Technical training: 241 5 Associates degree: 679 6 Bachelors degree: 2309 7 Graduate/Post-graduate degree: 2010 8 Not Applicable (Too Young): 3 98 Dont Know: 14 99 Refused: 5	1 Less than high school: 108 2 High school Graduate: 1223 3 Some collage: 1465 4 Vocational/Technical training: 223 5 Associates degree: 647 6 Bachelors degree: 2163 7 Graduate/Post-graduate degree: 1880
	Employment status	Employed: 5259 Unemployed: 2954	Employed: 4976 Unemployed: 2733
Individual	Average Time spent at work per survey day	253.67 (254.53), min=0, max=1240 0 minute: 3516[a]	11 not working (0 minute): 3262 12 part time (less than 7.5 hours): 1687 13 full time (more than 7.5 hours): 2760
	Household income	1 Less than $10,000 : 122 2 $10,000 to less than $20,000 : 318 3 $20,000 to less than $30,000 : 455 4 $30,000 to less than $40,000 : 549 5 $40,000 to less than $50,000 : 730 6 $50,000 to less than $60,000 : 738 7 $60,000 to less than $70,000 : 726 8 $70,000 to less than $80,000 : 719 9 $80,000 to less than $90,000 : 508 10 $90,000 to less than $100,000 : 566 11 $100,000 to less than $110,000 : 359 12 $110,000 to less than $120,000 : 317 13 $120,000 to less than $130,000 : 241 14 $130,000 to less than $140,000 : 141 15 $140,000 to less than $150,000 : 148 16 $150,000 or more: 601 17 Below $50,000 - Dont know/Refused : 140 18 $50,000 to $100,000 - Dont know/Refused: 228 19 Above $100,000 - Dont know/Refused: 161 98 Don't Know: 131 99 Refused: 315	11 Below $50,000: 2297 12 $50,000 to $100,000: 3458 13 Above $100,000: 1954
	Number of adult household members	1 adult: 1676 2 adults: 5472 3 adults: 786 4 adults: 228 5 adults: 45 6 adults: 6	1 adult: 1591 2 adults: 5129 3 adults: 729 4 adults: 210 5 adults: 44 6 adults: 6
	Vehicles	2.12 (1.10), min=0, max=10	2.11 (1.09), min=0, max=10
Household SES	Number of children younger than 18 in the household	Adults with 1 child: 1199 Adults with 2 children: 1123 Adults with 3 children: 265 Adults with 4 and more children: 86 Adults without children aged 18 and younger: 5540	Adults with children aged 18 and younger: 2547 Adults without children aged 18 and younger: 5162
Home Neighborhood Environment	Residential density	3.12 (3.40), min=0.007, max=30.81 (measured in units/acre)	0.60 (1.19), min=-4.93, max=3.43 (logged transform)
	# of observations	8213	7709

Note: [a] 2954 persons do not work and 3516 adults did not record time on working during the time of survey.

Regression Models

Multilevel regression models with the individual as the first level and the household as a second level were developed to investigate how individual and household social-demographic characteristics and physical environment of home neighborhoods associate with travel patterns of individual adult household members. The household as a second level, accounting for the random effects of the household, was to adjust for variation among households. To investigate the interactions between gender, work, and whether adults lived with children at the individual level, two sets of models were developed: one without any interactions, and one including full interactions.

Table 2-8 summarizes the measures of travel patterns and the corresponding regression model developed for each measure. The measures for the average number of trips and average number of non-work trips per survey day were discrete variables, which could only take non-negative values. Therefore, it was inappropriate to use the classical linear regression model for the analysis of data of this nature. Trip frequency was modeled as a Poisson variable for more accurate results than those of classical linear regression models (Barmby and Doornik 1989). Consequently, two Poisson models were developed for average trips and average non-work trips per survey day. Both measures of travel time and travel space are interval variables. Linear models were developed for individual travel time and the size of the daily activity realm. Yet the value of the size of the activity realm have outliers on the high end, thus a natural logarithmic transform was applied to pull the outliers back in closer to the rest of the data. Three binary variables were used to measure travel modes: 1) whether an individual made any trip using active transport such as walking and biking, 2) whether an individual made any trip using transit, and 3) whether an individual made all trips using an automobile only. Three binomial logistic regression models were developed for travel modes.

Table 2-8 Regression Models

Travel Patterns	Measurement	Adults (altogether) Mean (SD), Min, Max		Type of Variable	Regression Model
Trip Frequency	Average Trips per Survey Day	4.15 (2.41), min= 0, max=21		Integer	Poisson (Multilevel Model)
Trip Frequency by Purpose	Average Non Work Trips per Survey Day	3.46 (2.33), min=0, max=21		Integer	Poisson (Multilevel Model)
Travel Time	Average Travel Time per Survey Day (in minute)	82.73 (57.24), min=0, max=840		Interval	Multilevel Linear Model
Travel Space	Size of Activity Realm [a]	14259.15 (27951.62), min=0.000333, max=525631.3 (in acre)	18.980 (1.884), min=2.673, max=23.850 (logged sq ft)	Interval	Multilevel Linear Model
Travel Mode	Active Transportation (Walk or Bike) vs. motorized travel modes	1434 (18.6%) active transportation		Binary	Binominal logistic regression (Multilevel Model)
	Transit Users vs. non-transit users	931 (12.1%) transit users		Binary	Binominal logistic regression (Multilevel Model)
	Automobile only vs. alternative travel modes	5676 (73.6%) automobile only		Binary	Binominal logistic regression (Multilevel Model)
	# of observations	7709			

Note: [a] Due to lack of location information, the values of the size of activity realm for 1763 adults were zero, and were excluded from the study. As a result, 5946 adults were included here.

Correlations among independent variables tested for multicollinearity. The correlation results showed that all independent variables were not strongly correlated using 0.5 as a threshold, except for the number of vehicles available to a household and the number of adult household members. These two variables were tested separately in the models.

Results

A total of 7709 respondents aged 19 and above were included in the analysis. 33% of the respondents lived with children aged 18 and younger. The average age of the respondents was 51, 54% were females, 52% had Bachelor's degree or higher, more than one third were unemployed, and 30% had a household income of less than $50,000. In terms of trip frequency, the average number of trips of a respondent was 4.15 and the average number of non-work trips was 3.46. The average time spent on travel was 82.73 minutes a day. The average activity realm size was 22.28 square miles (57.7 square kilometers). 18.6% of respondents recorded using active transportation and 12.1% were transit users; while 73.6% did their all trips by car, either as a driver or as a passenger.

Trip Frequency, Travel Time, and Activity Realm

Table 2-9 summarizes the fixed effect (first level) results of regression models of average number of trips, average number of non-work trips, average travel time, and size of activity realm without any interaction terms. Multilevel models of average trips, average non-work trips, and size of individual activity realm used the same sets of independent variables. For average travel time, two sets of multilevel models were developed, with one containing the same sets of independent variables as for average trips, average non-work trips, and size of individual activity realm, and the other adding a travel mode behavior variable—automobile dependence (whether or not all surveyed trips done by automobile)—to the models with the independent variables included in models of average trips, average non-work trips, and size of individual activity realm. The model for average travel time that included the travel mode behavior variable had lower -2 log likelihood values than its counterpart, which indicated a better model fit.

The results showed that controlling for other variables, individuals who lived with children did make more trips in general, and non-work trips in particular, and spent more time on travel than their counterparts who did not live with children. On the other hand, individuals who lived with children did not show a significant difference in terms of activity realm size from those who did not live with children. All other variables being the same, women made more trips in general and non-work trips in particular but spent a shorter time on travel with a smaller activity realm than men. Individuals who worked full time made fewer trips in general, and non-work trips in particular, but spent more time on travel with a larger activity realm than those who did not work. Individuals who work part time made more trips in general than those who did not work, spent even longer on travel with a larger activity realm than those who work full time. In terms of average travel time, if an individual was automobile dependent, s/he would significantly spend 30 minutes less on travel on average than those who made at least one trip using alternative modes. No significant association was found between residential density and the frequency of trips. However, residential density was found to have a quadratic association with travel time, as well as a negative association with the size of the individual activity realm. Since the dependent variable, size of activity realm, and the independent variable, residential density, were in natural logs, the estimated coefficient of residential density (-0.353) of this linear regression model was residential density elasticity of size of individual activity realm.

Table 2-9 Regression Results of Average Trips, Average Non-Work Trips, Average Travel Time, and Size of Activity Realm—Without Interaction

				Average Trips per Survey Day	Average Non Work Trips per Survey Day	Average Travel Time per Survey Day		Size of Activity Realm
						Model 1	Model 2	
		Constant		0.632***	0.571***	50.539***	71.845***	18.009***
Independent Variables	Individual Characteristics	Age	Age	0.022***	0.022***	0.794**	0.938***	0.024*
			Squared of age	-0.0002***	-0.0003***	-0.008***	-0.009***	-0.0003**
		Gender	1. Woman	0.095***	0.125***	-6.017***	-6.381***	-0.152***
			0. Man					
		Education	Education level	0.032***	0.035***	1.706***	1.129**	0.030*
		Average Time spent at work per survey day (work)	13 full time	-0.046*	-0.424***	20.401***	18.845***	0.141**
			12 part time	0.222***	-0.014	29.224***	27.317***	0.644*
			11 no work					
	Household SES	Household income	13 Above $100,000	0.090	0.095	7.076***	8.035***	0.124
			12 $50,000 to $100,000	0.065	0.073	3.996*	4.822**	0.194**
			11 Below $50,000					
		Number of adult household members		-0.065•	-0.077*	-3.575**	-2.635*	
		Vehicles						0.138***
		Having children younger than 18 in the household (kid)	1. live with children younger than 18 in the household	0.190***	0.235***	2.683	3.588*	0.061
			0. do not live with children younger than 18 in the household					
	Household Environment	Residential density	Residential density within 10 minute walk of a household logged transformed (density)	0.024	0.026	-3.265***	-5.717***	-0.353***
			Squared of density			0.639*	-0.174	
	Travel Mode	Automobile dependence	1. All trips done by driving or being a passenger (car)				-30.886***	
			0. alternative travel modes used					
		Loglikelihood		-7452	-7116	-41697	-41479	-11842
		-2 log likelihood		14904	14232	83394	82958	23684
		# of individuals		7709	7709	7709	7709	5946
		# of households		4469	4469	4469	4469	3850

Note: *******: p-value <0.001; ******: p-value <0.01; *****: p-value <0.05; •: p-value<0.1

Table 2-10 summarizes the results for the corresponding models presented in Table 2-9 with full interaction terms of gender, work status, and whether an individual lived with children. The models had a lower -2 log likelihood value, which indicated a better model fit than the models without interaction terms. The only estimated coefficients that were changed when the full interaction terms were added were the independent variable indicating whether an individual lived with children. To examine the impact of residential density on travel patterns of parents and non-parents, the interaction term of home neighborhood residential density and whether an individual lived with children was tested. This interaction term did not show significance in any of models, and thus was excluded from the models.

Table 2-10 Regression Results of Average Trips, Average Non-Work Trips, Average Travel Time, and Size of Activity Realm—Including Full Interactions of Gender, Work Status, and Lived with Children

				Average Trips per Survey Day	Average Non Work Trips per Survey Day	Average Travel Time per Survey Day		Size of Activity Realm
						Model 1	Model 2	
		Constant		0.645***	0.611***	50.511***	82.656***	18.017***
Independent Variables	Individual Characteristics	Age	Age	0.021***	0.023***	0.760**	0.903***	0.023*
			Squared of age	-0.0002***	-0.0003***	-0.008***	-0.009***	-0.0003**
		Gender	1. Woman	0.033	0.033	-3.633●	-4.527**	-0.084
			0. Man (ref)					
		Education	Education level	0.032***	0.034***	1.768***	1.109**	0.032*
		Average Time spent at work per survey day (work)	13 full time	-0.006	-0.419***	20.824***	18.537***	0.129
			12 part time	0.248***	-0.039	34.000***	31.498***	0.683***
			11 no work (ref)					
		Gender × work	Woman × 13 full time	0.009	0.031	-1.869	-0.835	-0.127
			Woman × 12 part time	-0.017	0.033	-12.115***	-10.811**	-0.105
	Household SES	Household income	13 Above $100,000	0.059	0.069	6.962***	7.827***	0.126
			12 $50,000 to $100,000	0.086	0.093	3.934*	4.384**	0.196**
			11 Below $50,000 (ref)					
		Number of adult household members		-0.065●	-0.078*	-3.489**	-2.464*	
		Vehicles						0.140***
		Having children younger than 18 in the household (kid)	1. live with children younger than 18 in the household	-0.020	-0.010	-13.014**	-17.931***	-0.327*
			0. do not live with children younger than 18 in the household (ref)					
		Gender × kid	Woman × kid	0.361***	0.361***	17.470***	18.209***	0.344●
		Work × kid	Work 13 × kid	0.124●	0.155*	16.446***	17.150***	0.467*
			Work 12 × kid	0.158*	0.182*	21.181***	21.352***	0.432*
		Gender × work × kid	Woman × 13 full time × kid	-0.299***	-0.257**	-19.930**	-21.340***	-0.307
			Woman × 12 part time × kid	-0.237**	-0.202*	-20.164**	-21.574**	-0.478●
	Household Environment	Residential density	Residential density within 10 minute walk of a household logged transformed (density)	0.024	0.027	-3.307***	-14.953***	-0.353***
			Squared of Density			0.657*	0.785**	
	Travel Mode	All trips done by driving or being a passenger (car)					-43.736***	
		Car × kid					7.186**	
		Car × density					11.769***	
		Loglikelihood		-7409	-7081	-41658	-41397	-11843
		-2 log likelihood		14818	14162	83316	82794	23686
		# of individuals		7709	7709	7709	7709	5946
		# of households		4469	4469	4469	4469	3850

Note: *******: p-value <0.001; ******: p-value <0.01; *****: p-value <0.05; •: p-value<0.1

Interaction Terms of Gender, Work Status, and Whether an Individual Lived with Children

The full interaction terms for variables of gender (male/female), work status (working full time, part time, and not working), and whether an individual lived with a child or not grouped the entire respondent sample into 12 categories. Table 2-11 showed the estimated coefficients of the 12 categories using an unemployed man with no children as the reference category.

Table 2-11 Estimated Coefficients of Gender, Work Status, and Whether an Individual lived with a Child or not for the Models of Average Number of Trips, Average Number of Non-Work Trips, Average Travel Time, and Size of Individual Activity Realm

Category	Count		Average trips per survey day	Average non-work trips per survey day	Average time spent on travel per survey day		Activity Realm
					Model 1	Model 2	
Woman, full time, lived with a child	338	4.38%	0.202	-0.106	16.295	9.263	0.095
Woman, full time, did not live with a child	827	10.73%	0.036	-0.355	15.323	13.175	-0.082
Man, full time, lived with a child	712	9.24%	0.098	-0.274	24.257	17.756	0.269
Man, full time, did not live with a child	883	11.45%	-0.006	-0.419	20.824	18.537	0.129
Woman, part time, lived with a child	398	5.16%	0.526	0.358	23.725	16.215	0.465
Woman, part time, did not live with a child	583	7.56%	0.264	0.027	18.252	16.160	0.494
Man, part time, lived with a child	271	3.52%	0.386	0.133	42.167	34.919	0.788
Man, part time, did not live with a child	435	5.64%	0.248	-0.039	34.000	31.498	0.683
Woman, not working, lived with a child	635	8.24%	0.374	0.384	0.824	-4.249	-0.067
Woman, not working, did not live with a child	1362	17.67%	0.033	0.033	-3.633	-4.527	-0.084
Man, not working, lived with a child	241	3.13%	-0.020	-0.010	-13.014	-17.931	-0.327
Man, not working, did not live with a child (ref)	1024	13.28%	0	0	0	0	0
Total Observations	7709	100%					

The results revealed that different groups subscribed to different travel patterns controlling for other variables. Women with children who worked part time made the highest frequency of trips overall as well as the second highest frequency of non-work trips after women who were unemployed and lived with children, while men with children who worked part time spent the longest time on travel with the largest individual activity realm. Interestingly, men who had children but did not work generated the lowest frequency of trips overall, and spent the least amount of time on travel with the smallest individual activity realm.

Travel Time

Two interaction models were developed for average travel time. The first included the same independent variables as included in the average number of trips per day model, and the full interaction terms of gender, work status, and whether an individual lived with children. The other included all the independent variables of the first plus a variable of travel mode behavior, whether an individual was depending solely on an automobile, and its interactions with living with a child and residential density.

The interaction term of automobile dependence and whether an individual lived with children further grouped the whole samples into four categories. Table 2-12 shows the estimated coefficients of those four categories using individuals without children who used alternative modes as the reference category for the model results of average travel time. An individual who lived with children would reduce more than 54 minutes a day on travel if s/he did all trips by automobile, compared with those who did not live with children but used alternative modes.

Table 2-12 Estimated Coefficients of Automobile Dependence and Whether an Individual Lived with Children of Travel Time

Category	Estimated Coefficients
Automobile dependent, lived with a child	-54.480
Automobile dependent, did not live with a child	-43.736
Alternative modes, lived with a child	-17.931
Alternative modes, did not live with a child	0

The interaction of residential density and automobile dependence was found to be significant in the model with full interaction terms for travel time. Based on the model results, travel time may be written as

$$f(Y_{tt}) = 0.785D^2 - 14.953D + 11.769D \times C - 43.736C + \mathrm{E} + \delta + \varepsilon \qquad \text{(Equation 1)}$$

where Y_{tt} denotes travel time, D as residential density, C as automobile dependence, E as other variables in the model, δ as household random effect, and ε as error terms.

If an individual was automobile dependent, Equation 1 may be written as

If C=1, $f(Y_{tt}) = 0.785(\mathrm{D} - 2.028)^2 + \mathrm{E} + \delta + \varepsilon$

As residential density was logged transformed, the exponential of 2.028 is about 7.6. The interpretation of the result is that if an individual being automobile dependent, the person's travel time first decreases as residential density increases until it reaches 7.6 units per acre. The person's travel time increases as the residential density increases after 7.6 units per acre.

If an individual used alternative modes for daily travel, Equation 1 may be written as

If C=0, $f(Y_{tt}) = 0.785(\mathrm{D} - 9.524)^2 + \mathrm{E} + \delta + \varepsilon$

The exponential of 9.524 is 13684.24, which is beyond the maximum value of the residential density measure of this study. If an individual did one of his/her trips using alternative travel modes, the person's travel time will decrease as residential density increases.

Travel Modes

Table 2-13 summarizes the fixed effect (first level) results of three regression models of travel modes: 1) active transportation modes vs. motorized travel modes, 2) transit users vs. non-transit users, and 3) automobile vs. alternative travel modes.

Table 2-13 Regression Results of Travel Modes

				Active Transportation vs. motorized travel modes	Transit Users vs. non transit users	Automobile vs. alternative travel modes
		Constant		-2.248***	-4.540***	0.701***
Independent Variables	Individual Characteristics	Age	Age	-0.021***	-0.038***	0.019***
			Squared of age			
		Gender	1. Woman	0.277*	-0.236	-0.043
			0. Man (ref)			
		Education	Education level	0.201***	-0.021	-0.138***
		Average Time spent at work per survey day (work)	13 full time	-0.093	2.153***	-0.368***
			12 part time	0.385*	1.207***	-0.484***
			11 no work (ref)			
		Gender × work	Woman × 13 full time	-0.416*		
			Woman × 12 part time	-0.224		
	Household Characteristics	Vehicles		-0.388***	-1.324***	0.489***
		Having children younger than 19 in the household (kid)	1. live with children younger than 18 in the household	-0.018	-3.179***	0.106
			0. do not live with children younger than 18 in the household (ref)			
		Work × kid	13 full time × kid		2.975***	
			12 part time × kid		2.699***	
	Household Environment	Residential density within 10 minute walk of a household		0.782***	0.367	-0.545***
		Loglikelihood		-3220	-2375	-3923
		# of observations		7709	7709	7709

Note: ***: p-value <0.001; **: p-value <0.01; *: p-value <0.05; •: p-value<0.1

People who lived in high residential neighborhoods were more likely to walk and bike, and less likely to depend on automobiles alone. However, residential density did not show significance in the model of transit users. Interaction terms of gender, work status, and whether an individual lived with children were significant in the models of active transport and transit users. The interaction between gender and work status was significant in the model of active transport, and the interaction term of work status and whether an individual lived with children was significant in the model of transit users. The variable of household income did not show significance in any of the models for travel modes, and thus was excluded from the models. Whether an individual lived with children was not a key predictor of whether an individual used active transportation modes, or was automobile dependent.

Table 2-14 shows the estimated coefficients of the interaction term of time spent on work and gender for the model of active transportation (walking and biking). Both full time working men and women were less likely to make trips using active transportation modes than men who did not work. On the other hand, part-time working men and women were more likely to walk and bike.

Table 2-14 Estimated Coefficients of Work Status and Gender of Active Transportation

	Active Transportation Model	
Category	Estimated Coefficients	Odds Ratio
Full time, woman	-0.232	0.793
Part time, woman	0.438	1.550
Not working, woman	0.277	1.319
Full time, man	-0.093	0.911
Part time, man	0.385	1.470
Not working, man (ref)	0	1

Table 2-15 shows the estimated coefficients of the interaction term of work status and whether an individual lived with children for the model of transit users. Individuals who worked full time or part time (both with and without children) were more likely to be transit users compared with those who did not work or had children. Meanwhile individuals who did not work but lived with children are less likely to be transit users.

Table 2-15 Estimated Coefficients of Work and Kid of Transit Users

	Transit Users Model	
Category	Estimated Coefficients	Odds Ratio
Full time, lived with a child	1.949	7.022
Part time, lived with a child	0.727	2.069
Not working, lived with a child	-3.179	0.042
Full time, did not live with a child	2.153	8.611
Part time, did not live with a child	1.207	3.343
Not working, did not live with a child (ref)	0	1

Effects of Individual and Household Variables on Individual Activity-Travel Patterns

The summary of regression results of other individual variables, such as age and education, and household variables such as income, the number of adult household members or vehicles, and the built environmental variable – residential density around respondent's home – was included in Table 2-16.

Age has a quadratic association with trip frequency, travel time, and the size of an individual activity realm. In addition, age has a negative association with walking, biking, or using transit, but a positive association with automobile dependence. Individuals with higher education generated higher rates of trips, spent more time on travel, and had a larger size of activity realm. At the same time, individuals with a higher level of education were more likely to walk and bike, and less likely to be automobile dependent. People who had higher household income made more trips, spent more time on travel, and had a larger daily activity realm. People who lived with more adult household members made fewer trips, spent less time on travel, but had a larger daily activity realm. With more vehicles in a household, an individual was less likely to walk, bike, or take transit, and more likely to be automobile dependent. People who lived in high residential neighborhood were more likely to walk and bike, and less likely to depend on automobiles alone. They also spent less time on travel and had a smaller daily activity realm than their counterparts who lived in a low residential neighborhood.

Table 2-16 Effects of Individual and Household Variables on Individual Activity-Travel Patterns

			Dependent Variables						
			Travel Frequency		Travel Time	Travel Time and Space	Travel Mode		
			Average Trips per Survey Day (Y1)	Average Non Work Trips per Survey Day (Y2)	Average Travel Time per Survey Day (in minute) (Y3)	Size of Activity Realm (in logged acre) (Y4)	Active Transport (Walk or Bike) vs. motorized travel modes (Y5)	Transit Users vs. non-transit users (Y6)	Automobile only vs. alternative travel modes (Y7)
Independent Variables	Individual	Age	Quadratic relationship (48)	Quadratic relationship (38)	Quadratic relationship (48-50)	Quadratic relationship (38)	- ***	- ***	+ ***
		Education	+ ***	+ ***	+ ***	+ *	+ ***		- ***
	Household SES	Household income			+ ***	Household income ($50,000-$100,000) are more likely to have larger activity realm			
		Number of adult household members	- ●	- *	- **				
		Vehicles				+ ***	- ***	- ***	+ ***

Note: *******: p-value <0.001; ******: p-value <0.01; *****: p-value <0.05; •: p-value<0.1
+: positive association; -: negative association
Results that were not significant were not shown in the table.

Discussion

Few studies examined the impacts of children on travel patterns of individual adults or household. This study provided insights on how individual activity-travel patterns of adults in the Puget Sound Region, were impacted by whether they lived with children or not. The results supported two of the hypotheses of this study that individuals who lived with children made more non-work trips and spent more time on daily travel than those who did not live with children. On average, an individual who lived with children made about one fifth more non-work trips and spend about 4% more time on daily travel than their counterparts. The results for individuals who lived with children with more non-work trips were consistent with previous studies (McGinnis 1980; Srinivasan and Athuru 2005; Lee et al. 2007). The results for individuals who lived with children spending more time on travel were consistent with the more trips and more non-work trips for individuals who lived with children. However, other studies have found that household with children spent less time on work and work related trips, and social and recreational activities (Stopher and Metcalf 1999; Lee et al. 2009). This might imply that individuals who live with children spend more travel time on maintenance activities such as shopping, picking-up and dropping-off trips, etc. Further examining the travel time durations by trip purposes could provide insights on how individuals allocate time for different activities at the different life stages.

This study, however, did not support other hypotheses such as adults living with children would have a larger size of daily activity realm and be more likely to be automobile dependent than their counterparts who did not live with children. Other variables being the same, individuals who lived with children did not show significant difference in terms of size of activity realm from those who did not live with children. This might imply that parents and children shared similar activity places, or that parents accommodated their children's activities within their own activity space. Whether or not children were present in a household was found to be an insignificant variable for predicting an individual's automobile dependence. Thus, the results did not support the hypothesis that parents were more likely to be automobile dependent than non-parents. Even though individuals who lived with children made more non-work trips, they were not more dependent on automobiles than their counterparts who did not live with children. The results implied that individuals would not exclude alternative travel modes such as walking, biking, and using transit even if they lived with children and made more non-work trips.

To examine and compare the impact of residential density on travel patterns of parents and non-parents, the interaction term of home neighborhood residential density and whether an individual lived with children was tested. This interaction term did not show significance in any of the models. The results suggested that the impact of residential density on parents was not different from that of non-parents, which opposed the proposed hypothesis.

The results of this study corresponded to previous findings that women made more non-work trips, but spent less time traveling with smaller activity realms than men (Blumen 1994; Schintler et al. 2000; Crane 2007). The interactions between gender, work status, and whether adults lived with children or not, however, revealed more complex travel patterns according to different population subgroups. Women who worked part time and lived with children made the second highest number of non-work trips after women who were unemployed and lived with children, while men who worked part time and lived with children had the largest individual activity realm. Women who worked part time and lived with children likely shared considerable amount of household and childcare activities, such as shopping, and picking-up or dropping-off children at school (Meloni et al. 2009). At the same time, a majority of their trips were short trips. Men who worked part time and lived with children spent the longest time on travel on a weekday, yet had a relatively low frequency of non-work trips; this might be explained by their having to travel the longest distance to their work places, be responsible for relatively long distance non-work trips, or some combination of the two. Compared with other studies, this study identified more population subgroups with distinctive activity-travel patterns. This could contribute to more accurate travel demand forecasting.

Unemployed men living with children spent the least amount of time on travel with the smallest individual activity realms. On the other hand, their female counterparts generated the highest frequency of non-work trips. Both females and males who did not work but had children shared similar individual and household characteristics: both groups were in their early 40s at the time of the survey; about half had Bachelor's degrees or graduate degrees; and less than a quarter had an annual household income below $50k. These findings might suggest different household task allocations. While women who did not work but had children might share a large portion of out-of-home household activities, their male counterparts might contribute to in home household tasks.

Instead of categorizing age into different groups, age was included as an interval variable in this study. Age was found to have a quadratic association with trip frequency, travel time, and the size of individual activity realms. A recent study also found age to have a quadratic association with commuting distance (Crane 2007). An individual appeared to reach his or her peak frequency of trips on a week day around the age of 48. This coincided with a rise to a peak of time spent on travel every day. This individual mobility patterns might be related to the expenditure patterns, as household income and expenditure peak when the representative household member is 45-54 years old (Kitamura 1988; 2008). Individuals seemed to make the largest number of non-work trips and to have the largest activity realm around age 38. This travel pattern could correspond to parallel trends in entertainment, with entertainment expenditures peaking at 35-44 years (Kitamura 1988; 2008). The concurrency of peaks of non-work trips and the sizes of individual activity realm also suggested that non-work activities were widely distributed in urban space, and composed a large part of the individual activity realm.

Consistent with previous studies, age was found to have a negative association with walking and biking (Lee and Moudon 2006; Agrawal and Schimek 2007), but a positive association with automobile use (Chen et al. 2008). Therefore, improving alternative travel modes such as transit services and the walking and biking environment for older people might allow seniors to be less dependent on automobiles.

The model results showed that people who lived in higher density residential neighborhood were more likely to walk and bike, and less likely to depend on automobiles. This study confirmed that residential density was positively associated with multimodal travel, which corresponded to other studies where higher rates of walking, biking, and transit use were associated with higher residential density (Frank and Pivo 1994; Moudon et al. 2005; Moudon et al. 2007). The results of this study also verified that trip frequency was independent of residential density (Ewing and Cervero 2001).

Residential density was found to be negatively associated with the size of individual activity realms, which was consistent with a study using North Carolina travel survey data (Fan and Khattak 2008). The residential density elasticity of the size of individual activity realm was -0.353. In other words, all other variables being the same, increasing residential density by 10% would reduce the size of an individual activity realm by 3.53%. This was also in line with the positive association between residential density and multimodal travel. Walking, biking, and taking transit tended to be short distance trips. Increasing residential density would encourage more short distance trips using these alternative travel modes. As a result, the size of individual activity realms could be reduced.

While previous studies found that the effect of density on travel time seemed to be significant and non-linear (Mokhtarian and Chen 2004), this study revealed a quadratic association between residential density and travel time. Additionally, residential density was found to interact with travel mode behavior, which further complicated the relationship between residential density and travel time. If an individual did one of his or her trips using alternative travel modes, the person's travel time decreased as residential density increased. On the other hand, if an individual was automobile dependent, the person's travel time first decreased as residential density increased until it reached 7.6 units per acre. Then the person's travel time decreased as residential density increased after 7.6 units per acre. The value of 7.6 units per acre coincided surprisingly with the density values – 7 to 15 units per acre –suggested by transportation planners as that which can support moderate public transportation (Downs 2004). This result supported the commonly accepted rule in the transportation field that as residential density increases, especially when residential density reaches 8 units per acre or higher, people's dependence on automobiles decreases.

The full interaction model of travel time including a travel mode behavior variable showed that if a person was automobile dependent, their travel time expenditure during a weekday was reduced by 30 minutes. This finding provided one reason why people might choose to drive.

Consistent with previous findings, people who had higher household income made more trips (Ewing and Cervero 2001), and had a larger daily activity realm (Fan and Khattak 2008). With more vehicles in a household, an individual was more likely to depend on automobiles. People who lived with more adult household members and had access to more vehicles made fewer trips and spent less time on travel, but had a larger daily activity realm than their counterparts. The results suggested that household members tended to collaborate on daily activity travels; however their activity locations might be more spatially distributed across the region than in households with fewer adults.

This study had its limitations. It used self-reported survey diary data, which depended on the recollection and memory of respondents. Respondents might have over-reported long and major activities, and underreported short and minor activities. Also, the inclusion of data on individual perceptions of environment and attitudes toward travel, as well as on transit service in the region, had they been available, would have improved the explanatory power of the analyses. Future studies would benefit from detailed built environment measures.

Conclusion

This study highlighted differences in activity-travel patterns between individuals or households with and without children aged 18 or younger. People who lived with children generated more non-work related trips and spent more time on daily travel. Other differences in travel between parents and non-parents were explained by complex interactions between gender and work status. Women in general made more trips than men, but had a smaller daily activity realm. Interestingly, men who did not work but lived with children traveled the least. On the other hand, men who worked part time and lived with children had the longest travel time and the largest daily activity realm. Individuals who lived in higher residential density had smaller size of individual activity realm, and were less likely to be automobile dependent.

Chapter 3 How are children and household characteristics, parents' travel patterns, and environments around home and school associated with children commuting to school?

Introduction

Active commuting to school had been an overlooked source of physical activity for children (Tudor-Locke et al. 2001). Many empirical studies have concluded that active commuting has a positive association with overall levels of physical activity in children (Lee et al. 2008; Faulkner et al. 2009). Evidence shows that sedentary children were more likely to become sedentary adults (Kelder et al. 1994). In addition, active commuting may also encourage healthy behavior into adulthood (Black et al. 2001). However, the prevalence of children actively commuting to school in the U.S. has decreased from 41% in 1969 to only 13% by 2001 (McDonald 2007).

Research on children's active commuting has grown over the past few years. A recent review of research identified the predictors of active commuting to school to be demographic factors, individual and family factors, school factors (including the immediate area surrounding schools), and social and physical environmental factors (Davison et al. 2008). However, previous studies demonstrated inconsistent results regarding the association of a child's age and active commuting. No agreement was reached in terms of the effects of a child's gender on travel modes to school. Even though the literature has identified that the environment around schools was associated with active commuting to school, few studies have investigated this empirically. Studies that measured the effect of the subjective environment yielded inconsistent results about the association of perception of destinations (that is, possible destinations within a neighborhood, e.g. a supermarket) and active commuting to school. On the other hand, studies on physical activity and built environment have consistently found that the presence of local stores and other retailers, measured subjectively or objectively, to be associated with higher rate of walking for adults (Lee and Moudon 2004; McCormack et al. 2008; Saelens and Handy 2008; Lin and Moudon 2010). Objective measures, which could serve as tangible and measurable counterparts to subjective measures, might help clarify the associations between built environment and active commuting to school. Furthermore, research needs to consider that the activity-based travel patterns of individuals often include interaction with other household members. This is particularly true for children, since the final decision about travel is most often made not by them but by the household caregiver. Therefore, travel decisions are likely not limited to the schedule, constraints, or preferences of the child, but rather to those of the caregiver (McMillan 2007). Yet, few studies have investigated how intra-household interactions affect children's commuting.

Using a recent household activity survey that included detailed travel activity records for children aged 5-18, this study investigated and compared travel modes to school by different age groups. With geocoded home and school locations, home and school environmental attributes were measured objectively at the neighborhood level. In addition, the reciprocal relationships between the travel patterns of children and adults were explored. This study not only identified environmental factors around homes, but also environmental factors around schools, various individual characteristics of children, and those constraints and interactions of household members that have impact on how children travel to school. The results of this study are intended to contribute to a better understanding of the travel patterns of school children, necessary for the development of effective interventions.

Literature Review

Previous studies were reviewed to identify factors found to be associated with children's commuting to school. A critical review of these factors will serve to structure the analyses performed in this study and to determine which domains and variables should be included in the analysis.

Several review articles have summarized studies published before May 2008 on children’s commuting to school (McMillan 2005; Davison et al. 2008; Sirard and Slater 2008; Pont et al. 2009; Panter et al. 2010). Studies conducted since June 2008 were searched and identified using three different electronic databases (Web of Science, PubMed, and TRIS). Included were studies that met three criteria: 1) the unit of analysis was at the individual level, 2) the research population was between 5 and 18 years old, and 3) the outcome was measured as travel modes to school. Ten studies were identified (Wen et al. 2008; Yeung et al. 2008; Babey et al. 2009; Hume et al. 2009; Zhu and Lee 2009; McDonald et al. 2010; Nelson and Woods 2010; Panter et al. 2010; Voorhees et al. 2010; Zhou et al. 2010). These studies were conducted in the U.S., Australia, and the U.K. Travel modes were measured based on the parent’s, or child’s self-reported travel, or they were extracted from a travel diary. Table 3-1 lists these ten recent studies.

Table 3-1 List of Recent Studies Reviewed

Reference	Study Area	Data Source	Age of children	Gender	Sample Size
Yeung et al. 2008	Queensland, Australia	Self-administered parental survey	4-12	Boys and girls	324
Wen et al. 2008	Inner western Sydney, Australia	Students completed a 5-day travel survey; their parents completed a questionnaire.	9-11	Boys and girls	1603
Babey et al. 2009	California, U.S.A.	2005 California Health Interview Survey	12-17	Boys and girls	3983
Hume et al. 2009	Melbourne, Australia	2 years cohort study	5-14	Boys and girls	121 children 188 adolescents
Zhu and Lee 2009	Austin, TX	Parental survey	Elementary school students	Boys and girls	2695
Zhou et al. 2010	Pinellas County, Florida	Parent and student survey of Safe Route to School program	Elementary and middle school students	Boys and girls	347 classroom tallies 2551 parental surveys
Voorhees et al. 2010	Baltimore, MD, Minneapolis/St. Paul, MN, Columbia, SC, Tucson, AZ, San Diego, CA, New Orleans, LA	Student survey	8^{th} grade	Girls	890
Panter et al. 2010	Norfolk, U.K.	Parent and student survey from the SPEEDY study	9-10	Boys and girls	2012
Nelson and Woods 2010	Ireland	Adolescents self-reported survey	15-17	Boys and girls	1143 males and 1016 females
McDonald et al. 2010	San Francisco Bay Area	Parental survey	10-14	Boys and girls	357

All the studies applied a social ecological framework, which considers several levels of influence on behavior, ranging from intrapersonal level factors, interpersonal level processes, and institutional, community, and environmental level factors, to public policy. As mentioned, predictors of active commuting to school were identified as demographic factors, individual and family factors, school factors (including the characteristics of the immediate area surrounding schools), and social and physical environmental factors (Davison et al. 2008). Study findings were discussed based on the structure of the social ecological framework. Table 3-2 summarizes the findings of those ten recent studies.

Individual Factors

Child characteristics that were examined in the school travel studies included gender, age, and ethnicity. Two reviews found inconsistent results for the effect of gender on travel. One article, which reviewed literature on children's active commuting to school published before June 2007, concluded that boys were more likely than girls to actively commute (Davison et al. 2008). However, another article, which reviewed relevant studies on active commuting to school between 1975 to March 2007, reported that some studies found no association between gender and active commuting to school (Sirard and Slater 2008). Of the ten recent studies reviewed, only one found that boys were more likely to actively commute to school (Babey et al. 2009). This finding suggested that parents might be more protective of girls and place greater restrictions on girls' independent mobility. However, gender-related gains in mobility could be overridden in places where schools were not accessible by active modes of transportation. Hence, to better understand children's travel to school, research should consider the measures of environment that support different travel modes.

Age was another variable that exhibited inconsistent findings among studies regarding active commute to school. Some studies indicated that older children were more likely than younger children to actively commute to school, whereas other studies showed the opposite pattern (Davison et al. 2008). Most of the recent studies selected study populations with little variation in age. Only three studies included children of different ages (Yeung et al. 2008; Babey et al. 2009; Zhu and Lee 2009). One Australian study on active commuting to school investigating children between 4 and 12 of age found that age was not associated with active commuting to school (Yeung et al. 2008). Two studies in the U.S. – Zhu and Lee (2009) and Babey et al. (2009) –included elementary school children and adolescents between the ages of 12 and 17, respectively. Zhu and Lee found the elementary grade level to be unassociated with active commuting; whereas Babey et al. found that older adolescents were less likely to walk or bike to school. These inconsistent results might reflect a non-linear relationship between age and active commuting. Children’s age-related gains in independent mobility may be linked with increasing rates of active commuting until they can acquire a driver’s license and begin to drive alone. It seems significant that research on travel modes to school distinguished between children who have reached driving age and those who had not.

Regarding the possible effects of race/ethnicity on school travel, a recent review of 38 peer-reviewed journal articles published between 1985 and May 2008 found convincing evidence of a positive relationship between children of minority ethnic backgrounds and active commuting (Pont et al. 2009). Four additional U.S. studies published since June 2008 investigated the effects of ethnicity on school travel. Consistent with previous findings, one study found that Latino and mixed race participants were more likely to walk and bike to school (Babey et al. 2009). Another study found that if parents perceived higher levels of child-centered social control, defined as the expectation of neighborhood residents intervening on the behalf of children, the impact on increased walking and biking to school was strongest among non-Hispanic whites (McDonald et al. 2010). Two other studies found no significant association between a Hispanic ethnicity and more active commuting to school (Zhu and Lee 2009; Voorhees et al. 2010).

Table 3-2 Summary of Recent Studies on Active commuting to School

Reference	School travel modes	Individual characteristics	Household characteristics	Distance from home to school	Environment		Findings
					School environment	Home neighborhood environment	
Yeung et al. 2008	Parent reported active commuting to school at least once a week	Child's age, and gender	NA	Parent's perceived distance from home to school	Not clearly stated	Not clearly stated	Logistic regression revealed only commuting distance to be significantly associated with increased odds of active commuting.
Wen et al. 2008	Child self-reported car passengers (being driven to or from school five times or more per week) and non-car travelers	Child's gender; parent's age, education, employment status, living with partner, language spoken at home, travel mode to work, and attitude towards walking and environment	Number of children in the household, number of cars in household	Parent's perceived distance from home to school	NA	NA	Factors that were found to be associated with being driven to school were the mode of parents' journey to work, parents' attitudes towards walking to school, number of cars available in the household and distance from home to school.
Babey et al. 2009	Child self-reported active commuting to or from school at least once a week	Child's age, gender, and ethnicity; parent's walking for transportation, perception of neighborhood safety,	Household income,	Objectively measured Euclidean distance between home and school	NA	Urbanicity levels (urban, suburban, and rural) were defined based on population density of the household's zip code and surrounding areas	Distance to school was the strongest predictor of active commuting to school. Males, Latinos, adolescents from lower-income families, attending public school, whose parents know little or nothing about their whereabouts after school, and living in urban areas were more likely to walk, bike or skateboard to school.
Hume et al. 2009	Parent reported active commute to or from school	Parent's education, perception of social environment around home; Child's BMI,	NA	NA	NA	Parental perception of neighborhood environment (neighborhood design and infrastructure, traffic, and aesthetic and safety)	Children whose parents knew many people in their neighborhood were more likely to increase their active commuting compared with other children. Adolescents whose parents perceived there to be insufficient traffic lights and pedestrian crossings in their neighborhood were less likely to increase their active commuting over 2 years, whereas adolescents of parents who were satisfied with the number of pedestrian crossings were more likely to increase their active commuting compared with other adolescents.
Zhu and Lee 2009	Parent reported the use of walking as a typical mode of travel to/from school	Child's gender, grade level, and ethnicity; parent's education; parent and child's personal barriers, and attitudes towards walking	Household car ownership, household size	Parental perceived distance (close enough or not)	School bus availability, peer influence, parental perception of safety, physical barriers, walking environment, and presence of land uses en route	NA	Among the personal and social factors, negative correlates were parents' education, car ownership, personal barriers, and school bus availability; positive correlates were parents' and children's positive attitude and regular walking behavior, and supportive peer influences. Of physical environmental factors, the strongest negative correlates were distance and safety concerns, followed by the presence of highways/freeways, convenience stores, office buildings, and bus stops en route.

Zhou et al. 2010	Child self-reported travel modes to school and parent reported children's travel modes to school	Child's age, gender,	Number of children in the family ; parent's attitudes toward walking and biking to school	Parents self-reported distancefrom home to school	Parent reported school attitudes toward walking and biking to school	Parent reported environmental concerns of walking or biking to school : traffic safety, traffic volume, speed, crime,	Significant factors on walking or biking to school : traffic safety-related issues, distance, lack of sidewalk access to school, school attitudes, and student's attridues.
Voorhees et al. 2010	child self-reported any weekday walking to or from school	Child's ethnicity	NA	Objectively measured network distance between home and school	NA	Child's perception of neighborhood safety, aesthetics, access to facilities, and facilities; objectively measured neighborhood (1/2 mile of network buffer around each respondent's home) environment: neighborhood SES based on census, street connectivity, block size, population density based on census, and percentage African American and Hispanic based on census, land use mix, and active destinations,	Girls were nearly twice as likely to walk to or from school if they perceived their neighborhoods as safe and pleasant to walk in, controlling for other potential confounders. Additionally, girls who lived closer to school, had more active destinations in their neighborhood, and smaller sized blocks were more likely to walk to or from school than those who did not.
Panter et al. 2010	Child's self-reported usual travel mode to school (motorized, cycle, and walk)	Child's age, gender, and BMI ; Parent's education	Household car access	Objectively measured network distance between home and school	Each route was buffered by a distance of 100m to measure environment en route: streetlight density, traffic accident, presence of different types of road, land-use mix, and route directness. Environment around school: land-use mix, pavements, traffic calming, and pedestrian crossing. School policies	Neighborhood (defined as 800 m network buffer around each respondent's home). Objectively measured neighborhood environment : traffic safety, the provision of pavements for walking, street connectivity, and SES deprivation	Children who lived in a more deprived area and whose route to school was direct were less likely to walk or cycle to school, whereas those who had a higher density of roads in their neighborhood were more likely to walk. Further, children whose routes had a high density of streetlights were less likely to cycle to school. Distance did not moderate the observed associations.
Nelson and Woods 2010	Adolescent self-reported usual mode of transport to school (active commuting and inactive commuting)	Child's gender	NA	Adolescent self-estimated distance from home to school	NA	Child's perception of neighborhood in terms of traffic safety, crime, aesthetics, land use mix, land-use mix access, convenience of PA facility, places for walking and cycling, neighborhood satisfaction, connectivity	Land-use-mix diversity, and the perceived presence of public parks remained significant among males, whereas excess traffic speed, shops within walking distance, and paths separate from the road remained significant among females.
McDonald et al. 2010	Parent reported the primary way travel to school: walk and bike, or others	Child's age, gender, ethnicity,	Household income, vehicles	Network distance between home and school	NA	Social environment of neighborhood on child-centered social control "expectation that neighborhood residents can and will intervene on the behalf of children"	Higher levels of parent-perceived child-centered social control are associated with more walking and biking to school. The association was strongest for girls and non-Hispanic whites.

Household Factors

Previous studies have considered household characteristics such as household income, household car ownership, and parents' social and demographic characteristics, including their activity behaviors, and their attitudes towards physical activity. A review concluded that children were less likely to actively commute when their parents worked and when it interfered with the parents’ work schedules and the children's own after-school commitments (Davison et al. 2008). Using a parental survey and a 5-day travel survey for children aged 9 to 11 in Inner Western Sydney, Australia, Wen and colleagues (2008) found that the travel mode of parents’ journey to work, and their attitudes towards walking to school had an impact on children being driven to school. On the other hand, children were more likely to actively commute when parents valued physical activity (Davison et al. 2008). Pont and colleagues’ review (2009) of active commuting to school found convincing evidence of a negative association between household car ownership and children's active commuting. A study using a parental survey of 2695 respondents in Austin, TX, also found that car ownership was negatively correlated with active commuting to school (Zhu and Lee 2009). In addition, a convincing relationship was found between increases in household income and decreasing rates of children’s active commuting (Pont et al. 2009).

Previous studies have examined the relationship between parents' marital status and children's active commuting. Their findings showed considerable variance (Pont et al. 2009). Some studies found that children living with a parent who described their marital status as divorced, widowed, separated, or single, had lower rates of active commuting compared with children with parents who were married, in a de facto relationship, or with two adults living at home; some studies reported a non-significant association; and others found that children of parents who described their marital status as divorced, widowed, separated or single had higher rates of active commuting.

It is believed that household members allocate and distribute tasks and activities among each other and jointly participate in them (Bhat and Pendyala 2005). Two studies investigated how parents' commuting to work pattern affected children's travel to school (McDonald 2008; Yarlagadda and Srinivasan 2008). McDonald used 2001 National Household Travel Survey data, including 8231 children aged between 5 and 18, to investigate children's commuting to school (McDonald 2008). In addition to household SES variables, the study included variables indicating if the mother/father travels to work in the morning or the afternoon, the number of siblings, and the ages of the oldest and youngest sibling to examine household interaction. The findings suggested that mothers traveling to work in the morning found it more convenient to drop younger children at school on their way to work rather than walking with them. One of the limitations of the study is that built environmental variables were not included.

Yarlagadda and Srinivasan (2008) used 2000 San Francisco Bay Area Travel Survey data, with 4,352 children aged between 0 and 18, to examine children's travel modes to and from school. The dependent variable of the study included nine different travel modes. Besides household and individual social demographic variables, the model included variables indicating both the mother’s and father’s employment and flexibility of work schedule and found that these have strong impacts on the mode-choice decisions. However, this study did not include network distance from home to school.

Environmental Factors

Distance from Home to School

Distance has been the most frequently reported barrier and the strongest predictor of children's walking and biking to school (Davison et al. 2008). Studies that investigated distance from home to school, measuring it subjectively and/or objectively, found consistently that increases in distance traveled were inversely associated with rates of children's active commuting (Panter et al. 2008; Pont et al. 2009). Furthermore, studies found that Australian children were more than 5 times more likely to walk or bicycle to school at least once per week if they lived within 800 m of their school than were children who lived farther away. In the U.S., children who lived within 1 mile of their school were more than 3 times as likely to walk or bicycle to school as children who lived a greater distance from school (Davison et al. 2008).

Given the short distance that people walk or bike and a high percentage of students being driven to school even if living nearby (Martin et al. 2007), recent studies have started to focus on children who lived close to school. Voorhees and Colleagues (2010) examined the travel modes to school of 8th grade girls who live within 1.5 miles of school. Nonetheless, network distance from home to school was still significantly associated with active commuting to school. Another study in Ireland focused on adolescents who lived within 2.5 miles of their school and found that self-estimated distance from home to school was inversely associated with active commuting to school for both boys and girls as well (Nelson and Woods 2010).

Children were more likely to walk or bicycle to school when the route to school was direct, and navigation of steep roads was minimal (Davison et al. 2008). Recent studies have started to include environmental measures en route from home to school (Zhu and Lee 2009; Panter et al. 2010). Panter and colleagues (2010) used a 100m buffer to measure such characteristics of the environment along the route as streetlight density, the number of traffic accidents, the presence of different classifications of road, and mixed land use. The study found that children whose route to school was direct were less likely to walk or cycle to school, and children whose routes had a high density of streetlights were less likely to cycle to school. Zhu and Lee (2009) surveyed parents with children in elementary school and included survey questions with respect to perception of safety, physical barriers, walking environment, and the presence of specific land uses en route. This study found that parents' safety concerns, perception of the presence of highway/freeways, convenience stores, office buildings, and bus stops en route were negatively associated with active commuting to school.

Home and Neighborhood Environment

Home neighborhood environment has been the focus of many physical activity studies. Both the social and physical environment of a home neighborhood has been examined in previous studies. Reviews showed a positive association between social interactions and active travel in children (Panter et al. 2008). Children were more likely to walk or bicycle to school when their parents perceived that other children in the area actively commuted (Davison et al. 2008).

Intuitively, traffic safety and personal safety should be two major concerns influencing parents' decision to let children walk or bike to school. Yet three articles, which reviewed the effects of the perception of traffic safety and concerns over crime or strangers on children’s active commuting, reached different conclusions. Two articles concluded that perceived traffic safety and parental or youth concerns about personal safety were not associated with children’s active commuting (Davison et al. 2008; Pont et al. 2009); whereas one reported that parental or youth concerns about personal safety produced mixed associations (Panter et al. 2008). On the other hand, some studies found that children were more likely to walk or bicycle to school when parents perceived the neighborhood as safe (Davison et al. 2008). It should be noted that all these previous studies applied subjective measures for traffic safety, crime and neighborhood safety. The inconsistent findings might be due to the variable definitions of safety which were used and interpreted by different participants. To further investigate the effects of traffic safety and personal safety on active commuting, objective measures such as pedestrian and bicycle collisions and reported crimes within the neighborhood could be used.

The physical environment of the children's home neighborhood was measured either subjectively or objectively by different studies. Attributes of density, land use, destinations/facilities, transportation infrastructure, and design have been investigated. Studies found that a positive association existed between increases in density and active commuting to school (Panter et al. 2008; Pont et al. 2009), which was consistent with the findings of studies comparing urban and rural areas and finding that children who lived in rural areas to be less likely than children who live in urban areas to actively commute to school (Davison et al. 2008).

A literature review (Pont et al. 2009) concluded that evidence for a possible significant positive association was found between having mixed or commercial land-use in the neighborhood and rates of children's active commuting. In addition, some studies found that children were more likely to walk or bicycle to school when the neighborhoods in which the children live were deemed "walkable" (as measured by residential density, retail floor area ratio, intersection density, and land use mix) (Davison et al. 2008).

Findings regarding the association of the perception of having destinations to walk or bike to and active commuting to school were mixed. Some studies found no association between parental reports of access to destinations and active commuting in children; yet others found that youths whose parents reported having stores within a 20 minute walk of their home were more likely to report walking and biking to school (Panter et al. 2008). Furthermore, findings of research considering adolescents' own perceptions of the presence of destinations or shops in close proximity to their home were in general also equivocal (Panter et al. 2008). On the other hand, the most recent review on children's active commuting found that having parks, play areas, sporting venues or recreation facilities in neighborhoods had a possible association with higher rates of active commuting among children (Pont et al. 2009). The ambiguous results of the association of perceptions of destination and active commuting to school suggested the need for studies using objective measures of destination, which could serve as a tangible and measurable counterpart to subjective measures.

Studies also examined the impacts of the presence of sidewalks on active commuting to school. Reviews concluded that a possible positive association existed between the presence of sidewalks and/or bike paths and children's active commuting (Panter et al. 2008; Pont et al. 2009). A few studies investigated public transportation and active commuting to school. They found that access to public transportation was not associated with children's walking and bicycling to school (Davison et al. 2008). Finally, attributes of neighborhood design have been investigated in limited studies. One study found that children were more likely to walk and bike to school when a greater percentage of houses within 0.25 miles from the school had windows facing the street—this was considered a measure of "eyes on the street", or social support (Davison et al. 2008).

School Environment

Compared to the home neighborhood environment, fewer studies have investigated attributes of school environment. Some studies found that lower school enrollment and greater population density within 0.5 miles of the school were associated with higher rates of walking and biking to school

(Davison et al. 2008). A recent U.K. study, which objectively measured land-use mix, the presence of pavement, traffic calming measures, and pedestrian crossings around the school, found that none of their school-related environmental measures proved to be significant predictors of travel modes to school (Panter et al. 2010). The lack of association between school environment and active commuting to school might be related to the lack of heterogeneity of the school environmental variables.

In summary, previous studies demonstrated inconsistent results regarding the influences of a child's age and gender on active commuting to school. Limited studies have investigated how the intra-household interactions affect children's commuting to school. Studies that measured the effect of the subjective environment yielded inconsistent results about the association of perception of destinations and active commuting to school. Few studies have investigated the environment around a school.

Hypotheses

Based on the literature review, I formulated the following working hypotheses: active commuting to school is more likely associated with:

- a shorter distance from home to school
- being a boy
- older children
- a lower household income
- a head of the household who is not in the labor force or employed part-time compared with those in full-time employment.

Methodology

This section describes the research design used in this study, summarizes data sources, states how built environment around school and home was measured, and explains how multinomial logistic regression models were constructed.

Research Design

This study used a cross-sectional research design and explored influences on the travel mode choice of school age children (5-18) who lived in King County. Multinomial logistic regression models with school travel modes as the dependent variables were developed to investigate how individual and household social-demographic characteristics and the physical environment of home and school neighborhoods were associated with children's commuting to school.

School age children were divided into three age groups for the analysis: elementary school (ages 5-11), middle school (ages12-15), and high school (ages 16-18). Since the minimum age for obtaining a driver license in Washington State is 16, and for convenience of the analysis, 16 was used as both as the starting age of the high school age group and eligibility for driving to school.

In addition to investigating and comparing the travel modes of different age groups, this study also compared the school travel modes of elementary school age children who lived within 1 mile from their school. Previous studies have found distance to be one of the most important factors on active commuting to school (Davison et al. 2008; Panter et al. 2008; Pont et al. 2009). A majority of school districts in King County provide school busing for elementary school children who live more than 1 mile from their school, or live in designated safety areas within 1 mile of their school. This transportation policy assumes that up to one mile is a walkable distance for elementary school children. Nevertheless, more than a third of youths in the U.S. live within a mile of their school, but less than half of these walk or bike to school (Martin et al. 2007).

King County was chosen as the study area for its large population and rich GIS data on land use, traffic, and street networks. King County has more than half of the population in the Puget Sound Region. Furthermore, geospatial data on land uses, bus ridership, street networks, and traffic conditions are readily available for the county, enabling the capture of objective micro-scale environmental measures.

Data

The primary data source of travel activity was the 2006 Puget Sound Regional Council (PRSC) Household Activity and Travel Survey (HATS). HATS collected basic demographics, activities, and tour and travel characteristics for every member (including children) of 4,746 households (10,510 individuals), in King, Kitsap, Pierce, and Snohomish Counties during a consecutive 48-hour travel period. The survey was conducted during the weekdays from April to June of 2006. This study limits itself to the data from King County. The 2006 HATS included 974 children aged 5-18 from King County, which accounted for 58% of all school children in the survey. Due to missing information, this study only included 749 school aged children from King County with at least one reported school travel activity in the 2006 HATS. Figure 3-1 shows the spatial distribution of the home locations of those school age children in King County and included in the study.

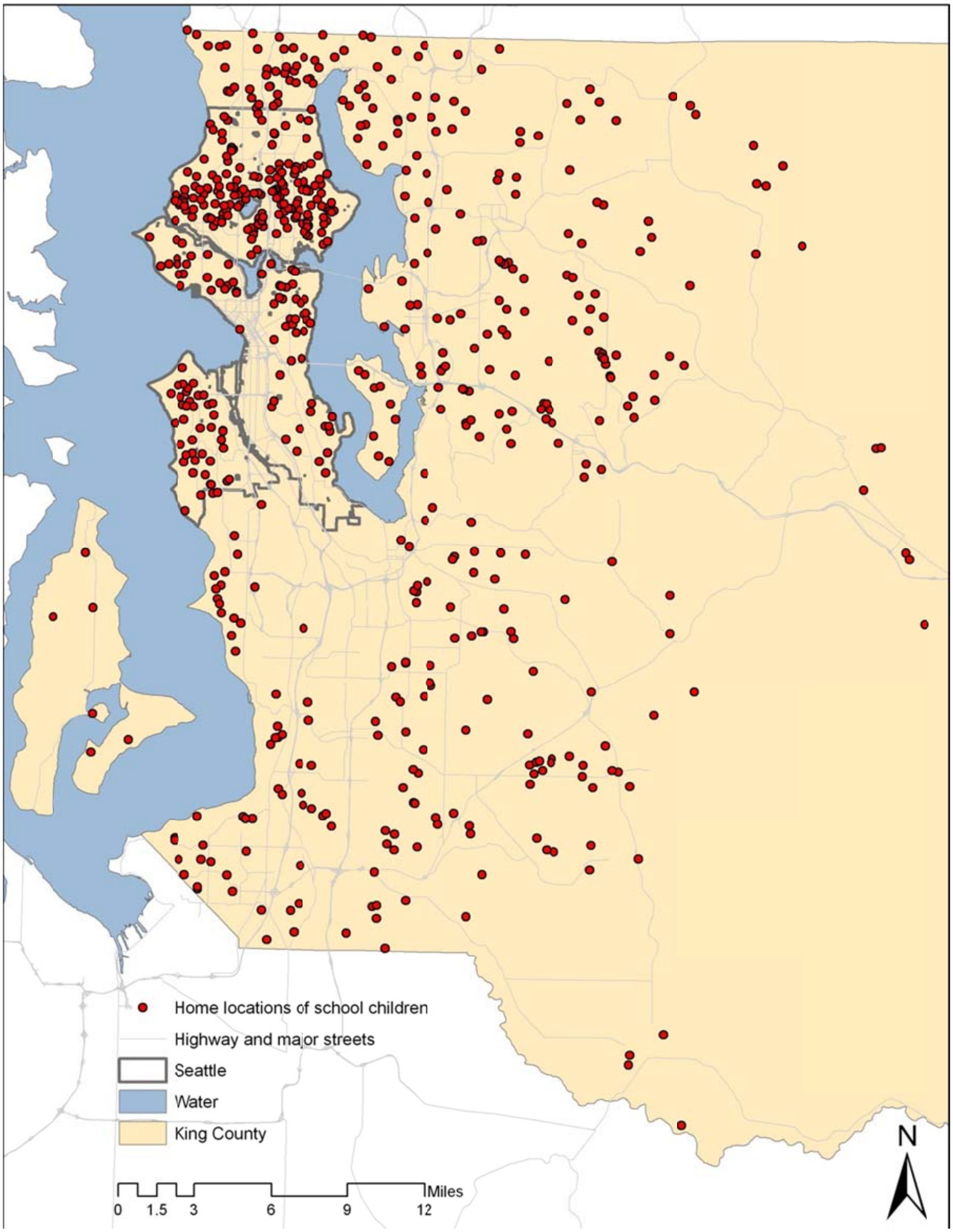

Figure 3-1 Home Locations of School Age Children in King County

Table 3-3 summarizes the data sources used in this study. Environment data included residential density, land uses, destinations, traffic volume, bus ridership, street network, and pedestrian and bicycle collisions. Information on local retailers—food stores and restaurants— was extracted from the current land use description of the 2007 King County parcel data, and food permits active in 2008 obtained from the King County Public Health Compliance Office. All permitted consumer food sources operating within King County were obtained by the Urban Form Lab (UFL) from Public Health -Seattle & King County. The UFL geocoded the permits and categorized the food sources based on methods drawn from literature on food environment, obesity and environment, and nutrition. Food stores included produce markets, fish/meat markets, drugstores that sell food stuffs, convenience stores, different ethnic and chain grocery stores, supermarkets, and food wholesale stores. Restaurants consisted of full service restaurants, such as traditional restaurants, taverns/pubs, ethnic dining, and limited service restaurants such as fast food restaurants, bakery/deli, quick services, coffee shops, and dessert shops.

Data on parks compiled by the Urban Form Lab (UFL) at the University of Washington in 2009 were also used in this study. UFL obtained data on parkland from King County GIS and all 39 cities located within the County boundary. The UFL food source and park data were processed using ArcGIS 9.3 and Microsoft Access to create a single geospatial database.

Traffic volume data from PSRC were extracted from the 2006 estimated results of EMME2, a multi-model transportation planning system. It provided average weekday traffic volume on major streets in the Puget Sound Region. Bus ridership data, summarized daily boardings and alightings using automatic passenger counters between 2006 and 2007, were from King County Metro. Street network data which recorded local streets, state routes, and interstate highways were from King County GIS.

The collision data comprised all collisions involving pedestrians and cyclists on all streets in King County, recorded over a period of four years (2001 to 2004). These data came from the Transportation Data Office (TDO) of the Washington State Department of Transportation's (WSDOT) Strategic Planning and Programming Division. They originated from collision reports submitted by both police officers and citizens.

Table 3-3 Data Sources

	Information		Data Source
Travel Activity Data	Socio-demographic characteristics	Individual's age, gender, education, and employment status	2006 PSRC Household Activity and Travel Survey
		household's income, size, and vehicle availability	
	Individual travel-activity characteristics	Travel time, travel frequency, travel distance, travel modes, etc.	
Environment Data	Residential density	2007 King County parcel data	King County Assessor's offices
	Destinations (Local stores/retails: food stores and restaurants)	2007 King County parcel data & 2008 food permits	King County Assessor's office & King County Public Heath Compliance Office
	Park		King County GIS & 39 cities located within King County boundary
	Traffic volume	Estimated traffic volume on major streets	PSRC
	Bus rishership		King County Metro
	Street density	Street network	King County
	Pedestrian and bicycle collisions	2001-2004	Washington State Department of Transportation

Measurements

School Trips and Travel Modes to School

School trips were defined based on the trip purposes recorded in the survey such as “Attending school”, “Attending daycare”, and “Attending college”. Travel modes to school were classified into four categories: single occupancy vehicle (SOV), being driven to school (two or more passengers per automobile), taking the bus (either on a school bus or by public transit), and active transport (walking or biking). 749 of those school age children had one or more school trips in King County. Table 3-4 summarizes the school travel modes by age group.

Table 3-4 Number of Children by School Travel Modes by Age Group

	Age			
	5-11 years old	12-15 years old	16+ years old	Total
11 SOV			43	43
12 Being driven to school	205	96	58	359
13 Taking the bus	123	79	33	235
14 Active transport	68	25	19	112
Total	396	200	153	749

Individual and Household SES

Variables of characteristics of child and household were taken from the survey. Characteristics of household head included education level, work status, and activity realm. The daily activity realm of the household head measured the geographical dispersion of individual daily activity locations, which could be used to indicate the travel pattern of the household head. Minimum Convex Polygons of all locations visited by a person during the survey, used to measure the daily activity realm, were created using Hawth's Tools.

For example, a 34-year-old woman with a Bachelors Degree lived in a 4-person household with two young children in the Bryant neighborhood of Seattle, and worked part-time for University of Washington. On the first day of the household survey, she commuted to work by bicycle in the morning, and returned home in the afternoon in the same manner. She then walked to a playground with her partner and two children. After half an hour's activity, they walked home (Figure 3-2). On the second day, she drove to the Gymboree Children's program at Sand Point Way in the morning with her partner and two children. After 1.5 hours, they drove back home. That afternoon, she took one of her children on foot to a nearby playground. After 40 minutes, they walked back home again (Figure 3-3). Her daily activity realm was created by linking all the places recorded during the survey (Figure 3-4).

Figure 3-2 Activity Location – Day 1

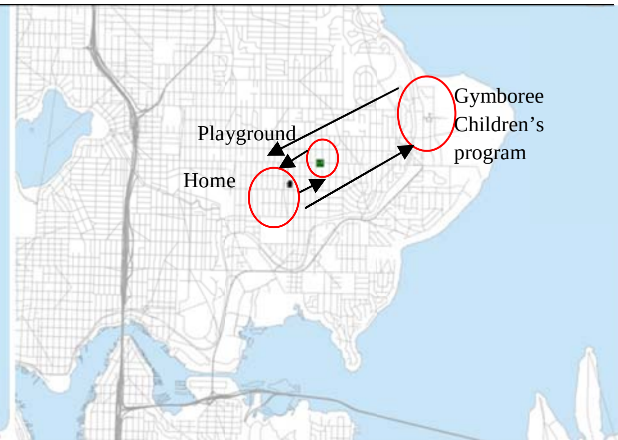

Figure 3-3 Activity Location – Day 2

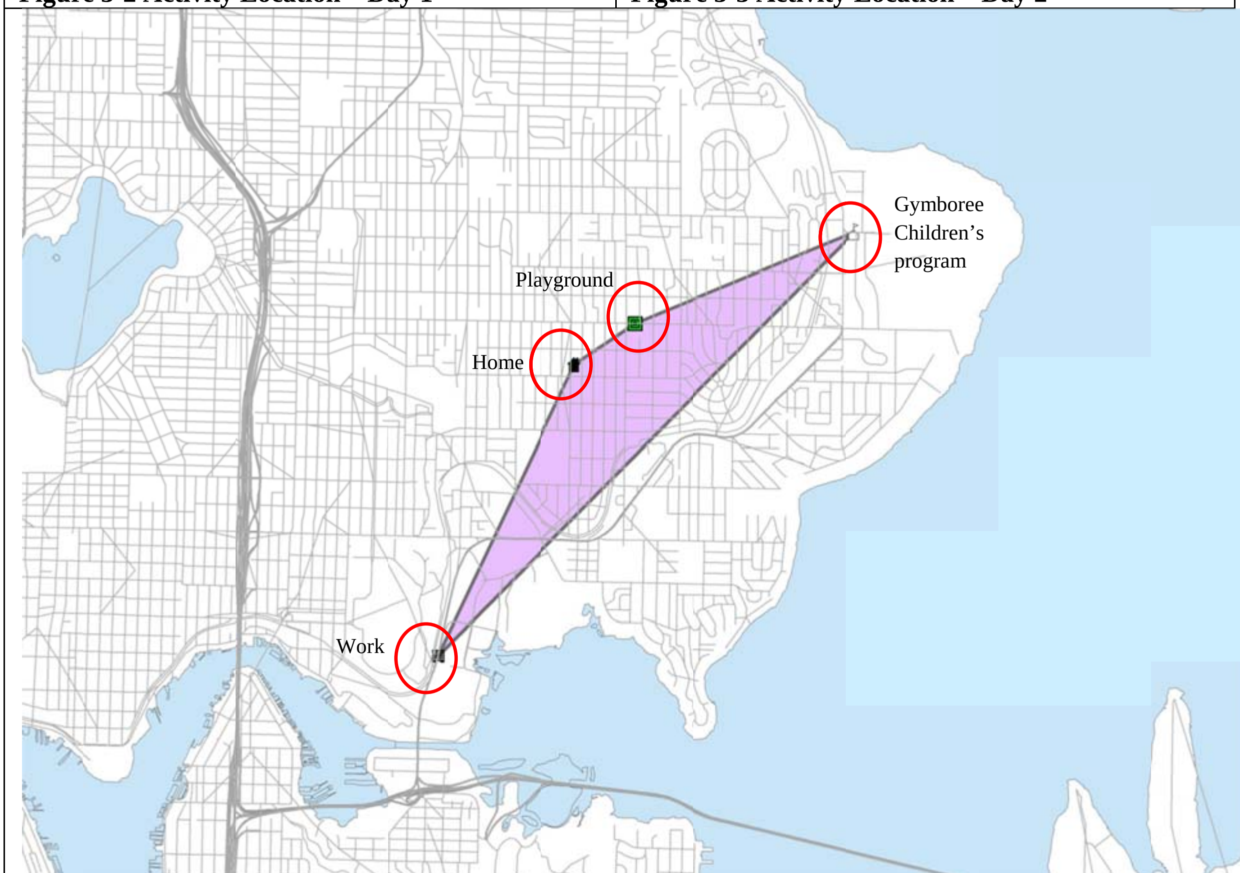

Figure 3-4 Daily Activity Realm

Table 3-5 summarizes a child's characteristics, household characteristics, and the head of the household's characteristics, by children's age group.

Table 3-5 Individual Child and Household SES Variables by Age Group

	Variables		Elementary school children (age 5-11)	Middle school children (age 12-15)	High school children (age 16-18)	Overall (age 5-18)
Child's characteristics	Age [a]		8.15 (1.96)	13.56 (1.06)	16.92 (0.77)	11.39 (3.94)
	Sex	Males	198	104	96	398
		Females	198	96	57	351
Household characteristics	Household income	Below $50,000	46	24	19	89
		$50,000 to $100,000	177	77	74	328
		Above $100,000	173	99	60	332
	Number of school age children in a household	1 school age child	111	66	91	268
		2 school age children	219	92	45	356
		3 and more school age children	66	42	17	125
	Number of adults in a household	1 adult	35	15	15	65
		2 adults	346	175	112	633
		3+ adults	15	10	26	51
	Female household member work status	Female adult, not working	177	74	45	296
		Female adult, part-time	149	74	51	274
		Female, full-time	70	52	57	179
Head of household characteristics	Education	Associates degree or less	106	60	65	231
		Bachelors degree	167	72	43	282
		Graduate/Post-graduate degree	123	68	45	236
	Work status	No working	137	59	41	237
		Part-time	144	63	41	248
		Full time	115	78	71	264
	Activity realm [a]	(in squared mile)	13.81 (21.21)	14.62 (17.24)	14.15 (20.34)	14.09 (20.02)
		Number of observations	396	200	153	749

Note: [a] the variables were summarized by mean (SD) for each age group.

Built Environment

Environmental attributes based on the Behavioral Model of Environment (BME) proposed by Lee and Moudon (2004), and reflecting a variety of characteristics within the neighborhood, were chosen to be measured. In particular, area characteristics such as residential density, street network, transportation conditions (pedestrian and bicycle collision counts, bus ridership, and traffic volume), and origin/destination measures such as local retailers and parks, within the neighborhoods of respondent's home and school, were objectively measured. Children's homes and schools were geocoded based on data recorded in the PSRC survey.

A neighborhood was defined as the area within a 10 minute walk (assuming a walking speed of 5 km/h, 10-min walk is 2734 feet or 833 meters). Neighborhood measures were developed by the UFL, and included: residential density, measures of transportation conditions and land uses, etc.

To calculate residential density, all residential parcels in the study area were selected, and residential units were summed up and normalized by parcel area. Parcel polygons were converted to a 30ft (9.14 meters) by 30ft raster cell. The raster was then converted to a point. Residential density was calculated using the point density function in the GIS spatial analyst tools, with a neighborhood defined as a circle with a radius of 833 meters. A 30m by 30m cell was used as the output cell. Street density was calculated as the total length of road within the neighborhood and normalized by the area of the neighborhood.

Measures of transportation conditions included pedestrian and bicycle collision counts, bus ridership counts, and average weekday traffic volume for respondent's home and school neighborhoods. As an objective measure of pedestrian and cyclist safety, pedestrian and bicycle collisions were tallied within respondent's home and school neighborhoods. Bus riders were summed up from all bus stops within a respondent's home and school neighborhoods, as an indicator of levels of bus services. Average weekday traffic volume was summed up and normalized by the length of road in a neighborhood.

Abundant empirical evident showed the presence of local stores/retails to be associated with physical activity for adults (Lee and Moudon 2004; McCormack et al. 2008; Saelens and Handy 2008; Lin and Moudon 2010). Hence, retailers, such as food stores and restaurants, within respondent’s home and school neighborhoods were tallied. Parks were assessed using the percentage of land within a neighborhood used as a park.

Previous studies focusing on King County have found that there were significant differences for pedestrian collisions within Seattle and outside of Seattle (Moudon et al. 2008; Moudon et al. in press). This might be related to the uniqueness of the urban form and urban services of Seattle. Thus, a regional location variable indicating whether a child’s home is located within Seattle was included in the study. Table 3-6 summarizes the environmental measures for home and school neighborhoods by school age group.

Table 3-6 Home Neighborhood and School Environment Measures

	Domains	Variables		Elementary school children (age 5-11)	Middle school children (age 12-15)	High school children (age 16-18)	Overall (age 5-18)
Home Neighborhood Environment	Area	Residential density [a]	Units per acre	3.57 (2.32)	3.58 (2.22)	3.40 (2.09)	3.54 (2.25)
			Logged units per acre	1.03 (0.78)	1.04 (0.80)	0.99 (0.79)	1.02 (0.78)
		Street density [a]	Total length of street segments standardized by the size of the neighborhood	86.68 (29.43)	90.25 (29.52)	85.44 (29.42)	87.38 (29.47)
		Pedestrian and bicycle collisions	0 collisions	73	37	25	135
			1-3 collisions	79	50	36	165
			4-6 collisions	52	25	27	104
			7-14 collisions	95	50	29	174
			15-25 collisions	54	18	20	92
			26 and above collisions	43	20	16	79
		Bus ridership	0 rider	36	31	17	84
			less than 100 riders	84	31	36	151
			100-400 riders	68	41	23	132
			400-1000 riders	50	25	23	98
			1000-2000 riders	86	39	29	154
			2000 and up	72	33	25	130
		Traffic volume [a]	Annual average weekday traffic volume on major streets	76.42.77 (7269.65)	6364.95 (6301.79)	7829.50 (7605.99)	7339.70 (7111.99)
			Logged	8.29 (1.82)	7.83 (2.33)	8.30 (1.82)	8.17 (1.98)
	Origin/Destination	Land uses	0 food stores, 0 restaurants	116	74	57	247
			1 of the two land uses (food store, restaurant)	55	28	22	105
			2 of the two land uses (food store, restaurant)	52	29	17	98
			3 of the two land uses (food store, restaurant)	173	69	57	299
		Parkland	Percentage of land used for parks [a]	6.86 (8.68)	6.23 (8.34)	5.91 (6.40)	6.50 (8.17)
		Seattle	Outside Seattle	226	111	99	436
			Within Seattle	170	89	54	313
School Environment	Area	Residential density [a]	Units per acre	4.60 (4.41)	4.57 (3.97)	4.40 (4.72)	4.55 (4.36)
			Logged units per acre	1.52 (0.60)	1.51 (0.65)	1.45 (0.64)	1.50 (0.62)
		Street density [a]	Total length of street segments standardized by the size of the neighborhood	93.51 (32.84)	93.43 (34.42)	88.07 (28.00)	92.39 (32.38)
		Pedestrian and bicycle collisions	0 collisions	52	35	12	99
			1-3 collisions	80	32	29	141
			4-6 collisions	76	16	27	119
			7-14 collisions	73	36	23	132
			15-25 collisions	45	47	20	112
			26 and above collisions	70	34	42	146
		Bus ridership	0 rider	22	14	6	42
			less than 100 riders	89	29	25	143
			100-400 riders	68	46	28	142
			400-1000 riders	59	17	22	98
			1000-2000 riders	52	30	24	106
			2000 and up	106	64	48	218
		Traffic volume [a]	Average weekday traffic volume on major streets	7500.23 (6315.73)	6876.66 (4783.94)	7827.71 (6363.01)	7400.62 (5957.87)
			Logged	8.47 (1.32)	8.45 (1.24)	8.40 (1.67)	8.45 (1.38)
	Origin/Destination	Land uses	0 food stores, 0 restaurants	97	50	32	179
			1 of the two land uses (food store, restaurant)	54	25	36	115
			2 of the two land uses (food store, restaurant)	58	17	15	90
			3 of the two land uses (food store, restaurant)	187	108	70	365
		Parkland [a]	Percentage of land used for parks	6.65 (7.30)	5.96 (7.44)	5.86 (6.19)	6.31 (7.13)
			Number of observations	396	200	153	749

Note: [a] the variables were summarized by mean (SD) for each age group.

Distance Measures

Euclidean (airline) and network distances between a respondent's home and school were measured. Airline distance was measured using Hawth's Tools, and network distance measured using GIS network analyst. A study comparing the GIS and GPS measures showed that no differences were observed between GIS and GPS measures of travel distance (Duncan and Mummery 2007). Thus, the network distance can be assumed to reflect the actual distance traveled by the respondents. Route directness, which was calculated as network distance from home to school divided by the corresponding Euclidean distance, indicated the quality of the street connection between home and school.

Analyses

Three multinomial logistic regression models that corresponded to three age groups were developed: 1) elementary school children, aged 5-11, 2) middle school children, aged 12-15, and 3) high school children, age 16-18. Both elementary school children and middle school children had three kinds of travel modes to school: automobile (as a passenger), bus (school bus and/or public transit), and active transport (walk and/or bike). High school children with a driver license and access to private vehicle could also drive themselves to school. For the reference category in the three multinomial logistic regression models, being driven to school was used, as it was the most common travel mode reported by the school children.

To compare the school travel modes of elementary school age children who lived within 1 mile of their school, a binary logistic regression model was developed. The dependent variable included two school travel modes: being driven to school and active transport (walk and/or bike). Elementary school children who took the bus to school were excluded, because of the policy in King County of providing school buses for elementary school children who live more than 1 mile, or live in designated safety areas within 1 mile, from their school. Except for those who took a bus, elementary school children who lived within 1 mile from their school were assumed to be able to walk or bike to school.

The model development process was the same for both the multinomial logistic regression models and the binary logistic regression models. Base models that included variables of individual and household characteristics and distance measures were developed. Distance has been the most frequently reported barrier and the strongest predictor of children’s walking and biking to school (Davison et al. 2008), thus distance measures were included in the base models. The neighborhood built environmental variables were investigated using one-by-one testing: adding to the base models one at a time. Final models were developed based on results of the one-by-one testing.

Results

Descriptive Statistics

A total of 749 school age children (5-18) in King County were included in the analysis. 396 children were in elementary school (age 5-11), 200 in middle school (age 12-15), and 153 in high school (age 16-18). 52% of elementary school children were driven to school, 31% took a bus, and 17% walked or biked. 48% of middle school children were driven to school, 40% took a bus, and 13 walked or biked. For high school children, 28% drove to school, 38% were driven to school, 22% took a bus, and 12% walked or biked. More than half (211) of the elementary school children lived within 1 mile from their school; however, 40% of these were driven, 30% took a bus, and only 29% walked or biked to school. 42% of school age children (5-18) in King County lived in Seattle. The average residential density of the home neighborhood of school age children (5-18) in King County was 3.54 units per acre. About one third of the school age children (5-18) lived in a neighborhood without any food stores or restaurants. Meanwhile, the average residential density of school neighborhoods where those school age children attended school was 4.55 units per acre. Slightly less than one quarter of schools did not have any food store or restaurant within a 10-minute walking distance (2734 feet or 833 meters).

Table 3-7 summarizes the distance measures from home to school. 42 % school age children (5-18) lived within 1 mile from their school. The average network distance from home to school for elementary school children was 2.43 miles, 3.56 miles for middle school children, and 4.64 miles for high school children.

Table 3-7 Distance Measures

			elementary school children (age 5-11)	middle school children (age 12-15)	high school children (age 16-18)	Overall (age 5-18)
Distance from Home to School	Airline distance	1 mile or less	211	65	37	313
		1-2 miles	95	69	39	203
		2 and more miles	90	66	77	233
	Network distance [a]	(in mile)	2.43 (2.72)	3.56 (3.64)	4.64 (4.56)	3.18 (3.56)
		(logged feet)	8.97 (0.99)	9.43 (0.91)	9.69 (0.95)	9.24 (1.01)
	Route directness		1.55 (0.47)	1.58 (0.47)	1.59 (0.50)	1.57 (0.48)
		Number of observations	396	200	153	749

Note: [a] the variables were summarized by mean (SD) for each age group.

Table 3-8 summarizes school travel modes by distance. 87% of school age children (5-18) who walked or biked to school lived within 1 mile from their school. Furthermore, even though more than two fifth of school age children (5-18) lived within 1 mile from their school, less than one third of those children (97 out of 313) walked or biked to school.

Table 3-8 Distance and Travel Modes to School

	Euclidean Distance from Home to School							
	1 mile or less		1-2 miles		2+ miles		Total	
11 SOV	5	2%	12	6%	26	11%	43	6%
12 Being driven to school	133	42%	96	47%	130	56%	359	48%
13 Taking bus	78	25%	86	42%	71	30%	235	31%
14 Active transport	97	31%	9	4%	6	3%	112	15%
Total	313		203		233		749	

Base Models

Table 3-9 summarizes the base models for all elementary school children, elementary school children who live within 1 mile from their school, middle school children, and high school children.

The base models included a child’s characteristics such as age and gender, household characteristics such as household income and the number of adults in a household, characteristics of the household head (such as education level, work status, and daily activity realm), and distance measures such as network distance from home to school and route directness from home to school. The number of school age children in a household was not included in the base models, because it did not show significant associations with travel modes to school for any age groups.

For all elementary school children living in King County and included in the survey, compared with children who were driven to school and adjusting for other variables, those who walked or biked were more likely to be older; children living in a household with two adults were less likely to walk or bike to school, and children who lived further away from school were less likely to actively commute to school. For children who took a school bus or public transit to school, those whose household income was less than $50k were more likely to take a bus than to be driven to school; children coming from a household with a household head working part-time were less likely to take the bus to school.

Table 3-9 Results of Base Models

			Elementary school children (age 5-11)			Middle school children (age 12-15)		High school children (age 16-18)		
			All Elementary school Child included in the survey in King County		Live within 1 Mile from Their School					
			Odds Ratio		Odds Ratio	Odds Ratio		Odds Ratio		
			Bus vs. Driven to school	Active transport vs. driven to school	Active transport vs. driven to school	Bus vs. Driven to school	Active transport vs. driven to school	Bus vs. Driven to school	Active transport vs. driven to school	SOV vs. driven to school
Child's characteristic	Age		1.090	1.279 **	1.193 •	0.783	1.183	1.094	2.018	2.612 **
	Sex	Males	1.456	1.200	1.460	1.852 •	1.046	0.566	1.214	0.593
		Females (ref)								
Household characteristics	Household income	Below $50,000	3.951 **	0.687	0.253 •	2.094	0.895	2.507	0.608	0.257
		$50,000 to $100,000	1.680 •	0.747	0.772	0.961	0.827	1.454	0.384	0.623
		Above $100,000 (ref)								
	Number of adults in a household	1 adult	0.355	0.254	0.328	1.489	6.309	0.736	3.290	0.212
		2 adults	0.273 •	0.142 *	0.194	0.699	1.334	1.425	2.547	1.489
		3+ adults								
Head of household characteristics	Education	Associates degree or less	1.163	1.459	2.495	1.347	0.558	1.874	2.217	3.622 *
		Bachelors degree	0.691	1.373	1.515	1.271	0.534	1.168	3.877 •	2.326
		Graduate/Post-graduate degree (ref)								
	Work status	No working	0.973	0.876	0.839	0.723	2.199	0.397	0.197 *	0.358
		Part-time	0.403 **	0.862	0.844	0.332 **	0.286	0.579	0.217 •	0.705
		Full time (ref)								
	Activity realm	(in squared mile)	0.926 •	0.935	0.935	1.043	1.024	0.964	0.966	0.927
Distance	Network distance	Network distance from home to school	0.897	0.126 ***	0.167 ***	1.449 •	0.091 ***	1.723 •	0.309 **	1.161
	Route directness	Route directness	1.481	1.237	0.937	1.182	3.877 *	0.475	0.527	1.126
		Number of observations	396		147	200		153		
		-2 log likelihood	627.324		161.785	310.699		334.463		

Note: *******: p-value <0.001; ******: p-value <0.01; *****: p-value <0.05; •: p-value<0.1

For those elementary school children living within 1 mile from their school, children who walked or biked to school were compared with those who were driven to school. The base model showed network distance from home to school to be negatively associated with active commuting to school.

For middle school children, network distance from home to school was also negatively associated with active transport to school, and route directness from home to school was positively associated with active transport to school. Middle school children who came from a household with a household head working part-time were less likely to take bus. Age was not significantly associated with travel mode to school in middle school children.

The results for high school children were similar to those for elementary and middle school children. Network distance from home to school was negatively associated with active commuting to school. High school children were less likely to walk or bike to school if the household head was not working. The base model also showed that older children were more likely to drive to school than be driven. If the household head had an education level of Associates degree or below, the high school child was more likely to drive to school.

Results of One-by-One Testing

The neighborhood built environment variables were investigated using one-by-one testing: adding to the base models one at the time. Table 3-10 summarizes the results of one-by-one testing for home neighborhood and school environmental attributes.

Table 3-10 Results of One-By-One Testing for Home Neighborhood and School Environmental Attributes

	Domains			Elementary school children (age 5-11): All Elementary school Child included in the survey in King County		Elementary school children (age 5-11): Live within 1 Mile from Their School	Middle school children (age 12-15)		High school children (age 16-18)		
				Bus vs. Driven to school	Active transport vs. driven to school	Active transport vs. driven to school	Bus vs. Driven to school	Active transport vs. driven to school	Bus vs. Driven to school	Active transport vs. driven to school	SOV vs. driven to school
Home Neighborhood Environment	Area	Residential density	Logged units per acre	- ns	+ ns	+ ns	- ns	+ ns	+ ns	+ ns	- ns
		Street density		- (*)	- ns	- (•)	- ns	- ns	+ ns	+ (*)	- ns
		Collisions	Pedestrian and bicycle collisions	- ns	+ ns	- ns	- ns	- ns	+ ns	+ (*)	- ns
		Bus ridership		- (*)	+ ns	+ ns	- (•)	- ns	+ ns	+ (*)	- ns
		Traffic volume		+ ns	+ ns	+ ns	+ ns	- ns	- ns	- ns	- ns
	Origin/ Destination	Land uses	0 food store, 0 restaurant	+ ns	+ ns	+ ns	+ns	+ns	+ ns	+ ns	- ns
			1 of the two land uses (food store, restaurant)	+ (•)	+ ns	+ ns	+(**)	+ (*)	+ ns	- ns	+ ns
			2 of the two land uses (food store, restaurant)	- ns	+ ns	+ ns	+ns	+ ns	- ns	- ns	- ns
			3 of the two land uses (food store, restaurant)								
		Park	Percentage of land used for park	- ns	+ (*)	+ (•)	+ ns	- ns	- ns	- ns	+ ns
		Seattle	Outside Seattle Within Seattle	+ ns	- ns	- ns	+ ns	- ns	- ns	- (•)	- ns
School Environment	Area	Residential density	Logged units per acre	- ns	+ ns	- ns	- (*)	- ns	+ (*)	+ (*)	+ ns
		Street density		- ns	+ ns	- ns	- (*)	- ns	+ ns	+ (•)	- ns
		Collisions	Pedestrian and bicycle collisions	- (•)	+ ns	- ns	- ns	- ns	+ (•)	+ (*)	+ ns
		Bus ridership		- (•)	+ ns	- ns	- (*)	- ns	+ (*)	+ (**)	+ ns
		Traffic volume		+ ns	+ ns	+ ns	- ns	- (*)	+ ns	+ (*)	+ ns
	Origin/ Destination	Land uses	0 food store, 0 restaurant	+ ns	+ ns	+ ns	+ ns	- ns	- ns	- ns	- ns
			1 of the two land uses (food store, restaurant)	+ (*)	- ns	+ ns	+ (•)	+ ns	- (*)	- ns	- ns
			2 of the two land uses (food store, restaurant)	- ns	- ns	- ns	+ ns	+ ns	- ns	- ns	- ns
			3 of the two land uses (food store, restaurant)								
		Park	Percentage of land used for park	+ (**)	+ ns	+ ns	+ ns	- ns	- ns	- ns	- ns
			Number of observations	396		147	200		153		

Note: Direction indicates direction of association (+=positive association, -=negative association) when variables were tested for trend. All associations are adjusted for child age, gender, household income, number of adults in a household, head of household's characteristics (education, work status, and daily activity realm), network distance from home to school, and route directness from home to school.

•p<0.1, *p<0.05, **p<0.01, ns, not significant

Final Models

Tables 3-11 – 3-14 summarize the final model results for all elementary school children, elementary school children who lived within 1 mile from their school, middle school children, and high school children, respectively. Compared with the base models, all of the four final models that added variables of home neighborhood environment or school environment had lower values of -2 log likelihood, which indicated a better model fit.

Table 3-11 Final Model Result for Elementary School Children (Age 5-11)

			Elementary school children (age 5-11)					
			Bus vs. Driven to school			Active transport vs. Driven to school		
			Odds Ratio	95% CI		Odds Ratio	95% CI	
Child's characteristic	Age		1.115	0.974	1.276	1.275 *	1.049	1.551
	Sex	Males	1.464	0.873	2.456	1.291	0.636	2.620
		Females						
Household characteristics	Household income	Below $50,000	4.096 **	1.650	10.168	0.665	0.172	2.569
		$50,000 to $100,000	1.634	0.924	2.889	0.906	0.407	2.014
		Above $100,000						
	Number of adults in a household	1 adult	0.552	0.100	3.038	0.424	0.040	4.442
		2 adults	0.307	0.072	1.312	0.143	0.018	1.139
		3+ adults						
Head of household characteristics	Education	Associates degree or less	0.929	0.453	1.906	1.168	0.378	3.613
		Bachelors degree	0.630	0.338	1.174	1.093	0.440	2.712
		Graduate/Post-graduate degree (ref)						
	Work status	Not working	1.001	0.531	1.886	0.695	0.259	1.869
		Part-time	0.416 *	0.214	0.808	0.743	0.301	1.837
		Full time						
	Activity realm	logged	0.927	0.849	1.011	0.955	0.836	1.091
Distance	Network distance	Network distance from home to school	0.933	0.700	1.243	0.111 ***	0.063	0.196
	Route directness	Route directness	1.612	0.876	2.967	1.263	0.565	2.824
Home Neighborhood Environment	Park		0.866	0.651	1.151	1.879 *	1.112	3.176
	Bus ridership		0.647 **	0.472	0.887	1.443	0.950	2.190
	Collisions	Pedestrian and bicycle collisions	1.420 *	1.029	1.960	0.865	0.576	1.298
School Environment	Park		1.804 ***	1.311	2.482	0.948	0.577	1.557
	Land uses	0 food store, 0 restaurant	1.155	0.553	2.413	2.916	0.852	9.983
		1 of the two land uses (food store, restaurant)	2.396 *	1.082	5.307	0.794	0.188	3.349
		2 of the two land uses (food store, restaurant)	0.627	0.272	1.446	0.721	0.225	2.308
		3 of the two land uses (food store, restaurant)						
		Number of observations	396					
		- 2 log likelihood	580.055					

Note: *****: p-value <0.001; ****: p-value <0.01; ***: p-value <0.05

Table 3-12 Final Model Result for Elementary School Children (Age 5-11) Living within 1 Mile of Their School

			Elementary school children (age 5-11)		
			Active transport vs. Driven to school		
			Odds Ratio	95% CI	
Child's characteristic	Age		1.193	0.954	1.491
	Sex	Males	1.504	0.654	3.456
		Females			
Household characteristics	Household income	Below $50,000	0.344	0.062	1.900
		$50,000 to $100,000	1.023	0.400	2.617
		Above $100,000			
	Number of adults in a household	1 adult	1.520	0.068	34.061
		2 adults	0.929	0.061	14.246
		3+ adults			
Head of household characteristics	Education	Associates degree or less	2.184	0.489	9.749
		Bachelors degree	1.010	0.351	2.905
		Graduate/Post-graduate degree (ref)			
	Work status	Not working	0.786	0.236	2.615
		Part-time	0.887	0.301	2.619
		Full time			
	Activity realm	logged	0.953	0.814	1.116
Distance	Network distance	Network distance from home to school	0.170 ***	0.072	0.401
	Route directness	Route directness	0.799	0.339	1.886
Home Neighborhood Environment	Park		2.067 *	1.193	3.581
	Bus ridership		1.433	0.975	2.106
School Environment	Land uses	0 food store, 0 restaurant	6.658 *	1.303	34.015
		1 of the two land uses (food store, restaurant)	2.658	0.542	13.025
		2 of the two land uses (food store, restaurant)	0.893	0.240	3.322
		3 of the two land uses (food store, restaurant)			
		Number of observations	147		
		- 2 log likelihood	149.181		

Note: *******: p-value <0.001; ******: p-value <0.01; *****: p-value <0.05

Table 3-13 Final Model Result for Middle School Children (Age 12-15)

			Middle school children (age 12-15)					
			Bus vs. Driven to school			Active transport vs. Driven to school		
			Odds Ratio	95% CI		Odds Ratio	95% CI	
Child's characteristic	Age		0.811	0.583	1.126	1.362	0.729	2.545
	Sex	Males	2.124	0.992	4.550	0.800	0.205	3.120
		Females						
Household characteristics	Household income	Below $50,000	2.345	0.649	8.471	1.235	0.134	11.429
		$50,000 to $100,000	1.016	0.472	2.187	0.831	0.203	3.406
		Above $100,000						
	Number of adults in a household	1 adult	0.875	0.106	7.191	4.459	0.119	166.941
		2 adults	0.434	0.087	2.153	0.717	0.044	11.808
		3+ adults						
Head of household characteristics	Education	Associates degree or less	1.967	0.725	5.336	0.374	0.061	2.297
		Bachelors degree	1.516	0.616	3.730	0.394	0.071	2.197
		Graduate/Post-graduate degree						
	Work status	Not working	0.511	0.198	1.322	3.324	0.657	16.815
		Part-time	0.275 **	0.115	0.662	0.122	0.013	1.172
		Full time						
	Activity realm	logged	1.024	0.902	1.162	1.010	0.774	1.320
Distance	Network distance	Network distance from home to school	1.486	0.949	2.326	0.078 ***	0.023	0.261
	Route directness	Route directness	1.000	0.458	2.185	4.841 *	1.197	19.571
Home Neighborhood Environment	Land uses	0 food store, 0 restaurant	1.017	0.410	2.521	0.708	0.121	4.145
		1 of the two land uses (food store, restaurant)	6.034 **	1.712	21.274	4.224	0.577	30.906
		2 of the two land uses (food store, restaurant)	1.483	0.477	4.607	4.794	0.519	44.300
		3 of the two land uses (food store, restaurant)						
School Environment	Traffic volume		0.975	0.683	1.392	0.567 *	0.366	0.879
	Street density		0.985	0.973	0.997	0.988	0.962	1.015
		Intercept						
		Number of observations	200					
		- 2 log likelihood	282.034					

Note: *******: p-value <0.001; ******: p-value <0.01; *****: p-value <0.05

Table 3-14 Final Model Result for High School Children (Age 16-18)

			High school children (age 16-18)								
			Bus vs. Driven to school			Active transport vs. Driven to school			SOV vs. Driven to school		
			Odds Ratio	95% CI		Odds Ratio	95% CI		Odds Ratio	95% CI	
Child's characteristic	Age		1.129	0.571	2.233	1.988	0.776	5.093	2.823 **	1.470	5.420
	Sex	Males	0.578	0.210	1.591	1.471	0.316	6.847	0.617	0.228	1.666
		Females									
Household characteristics	Household income	Below $50,000	3.052	0.594	15.680	0.870	0.097	7.805	0.340	0.054	2.137
		$50,000 to $100,000	1.827	0.573	5.822	0.406	0.079	2.081	0.762	0.277	2.098
		Above $100,000									
	Number of adults in a household	1 adult	0.811	0.121	5.432	5.936	0.345	102.134	0.197	0.017	2.344
		2 adults	1.862	0.469	7.394	6.444	0.717	57.925	1.406	0.414	4.773
		3+ adults									.
Head of household characteristics	Education	Associates degree or less	2.436	0.691	8.585	5.454	0.837	35.547	3.482 *	1.018	11.902
		Bachelors degree	1.198	0.316	4.551	5.261	0.867	31.917	2.177	0.641	7.393
		Graduate/Post-graduate degree									
	Work status	Not working	0.316	0.096	1.039	0.153 *	0.026	0.913	0.315 *	0.101	0.986
		Part-time	0.537	0.160	1.801	0.197	0.028	1.382	0.663	0.221	1.993
		Full time									
	Activity realm	logged	0.988	0.857	1.139	1.025	0.833	1.261	0.954	0.833	1.093
Distance	Network distance	Network distance from home to school	1.552	0.872	2.765	0.245 **	0.102	0.588	1.081	0.630	1.855
	Route directness	Route directness	0.618	0.193	1.982	1.227	0.201	7.503	1.020	0.428	2.432
Home Neighborhood Environment	Collisions	Pedestrian and bicycle collisions	0.779	0.532	1.141	1.435	0.749	2.751	0.674 *	0.464	0.978
School Environment	Bus ridership		1.786 **	1.198	2.663	1.819	0.923	3.585	1.377	0.977	1.941
		Number of observations	153								
		- 2 log likelihood	311.446								

Note: *******: p-value <0.001; ******: p-value <0.01; *****: p-value <0.05

The final model for elementary school children included environmental attributes for both a child's home and school neighborhood, in addition to the variables included in the base model. For the environment around a child's home neighborhood, parkland was found to have a positive association with active transport to school, bus ridership was found to have a negative association with taking the bus, and counts of pedestrian and bicycle collisions to have a positive association with taking the bus. In terms of the environment around a school, parkland was found to have a positive association with taking the bus, and the presence of 2 food stores or restaurants within 10 minute walking distance of a school to have a positive association with taking the bus.

In addition to the variables from the base model, the final model for the elementary school children living within 1 mile of their school added two home neighborhood measures (parkland and bus ridership) and one school environmental measure (the counts of local stores/retails). Parkland around a child's home neighborhood was positively associated with active transport to school. Schools without any food stores or restaurants within 10-minute walking distance were found to be positively associated with active transport to school.

The final model for middle school children added the measure of local stores/retails in a child's home neighborhood and the traffic volume and street density of a child's school neighborhood, besides the variables included in the base model. Children who lived in a neighborhood with one food store or restaurant were found to be more likely to take the bus to school; if schools were located in a neighborhood with high traffic volume, middle school children who attended the school were less likely to walk or bike to school.

The final model for high school children included counts of pedestrian and bicycle collisions within a child's home neighborhood and bus ridership within the child's school environment. The number of pedestrian and bicycle collisions around a child's home environment was found to be negatively associated with being driven to school. High bus ridership around the school was related to a higher likelihood of riding the bus to school.

Discussion

The results supported one of the hypotheses that the distance from home to school was inversely associated with active commuting for all school age groups, which was consistent with previous findings (Davison et al. 2008; Panter et al. 2008; Yeung et al. 2008; Babey et al. 2009; Pont et al. 2009; Zhu and Lee 2009; Voorhees et al. 2010). Furthermore, network distance from home to school continued to have a negative relation with walking or bike, even for elementary school children living within 1 mile from their school. This result indicated that even if children lived close to their school, the actual walking and biking distance from home to school was still one of the key concerns in travel mode selection. It was noted that route directness between home and school showed significance only in the final model for middle school children. The strong inverse association between distance and active commuting to school suggested that programs that promote and support active commute to school – such as Safe Route to School – should first target children who live close to their school.

This study did not support the hypothesis that active commuting to school was more likely associated with boys. Gender has constantly shown a non-significant association with travel mode to school in the four final models. In other words, all other variables being the same, travel modes to school showed no difference between girls and boys. This finding was consistent with a few previous studies (Sirard and Slater 2008; Zhu and Lee 2009).

Age was positively associated with active commuting to school in the final model for elementary school children only. This finding suggested that the association between age and active commuting to school was not linear, thus, did not fully support the hypothesis that active commuting to school was more likely associated with older children. This finding accorded with previous finding that children in the United States began to acquire travel independence around the age of 10 (Matthews 1992). To encourage and increase active commuting in elementary school children, especially for those younger than 10 years old, programs that introduce adult supervision of children to school, such as Walking School Bus, could be effective.

Interestingly, age was also positively associated with driving to school for high school children. This might relate to the fact that older high school children were more likely to acquire a driver license and have access to an automobile, which posed a challenge to increasing high school children to walk and bike to school. Education programs such as informing high school children of the health and environmental benefits of active commuting might be helpful to encourage them to choose active commuting to school.

This study did not support the hypothesis that active commuting to school was more likely associated with lower household income. Household income did not exhibit strong associations with active commuting to school for any age groups. Household income showed significance only in the final model for the elementary school children. Elementary school children from a household with income of $50k or less were more likely to take the bus to school. This finding was inconsistent with the conclusion of previous literature that increasing household income decreases rates of children's active commuting (Pont et al. 2009).

The work status of a household head was found to be associated with children's travel modes to school. On the other hand, the daily activity realm of a household head was not. In particular, elementary and middle school children with household heads employed on a part-time basis were less likely to take the bus to school; high school children with unemployed household heads were less likely to actively commute or drive to school, compared with being driven. In other words, elementary and middle school children whose household heads worked part time were more likely to be driven to school; whereas high school children who household heads did not work were more likely to be driven to school. This finding did not support the hypothesis that active commuting to school was more likely associated with children whose household heads worked part-time or were not working; instead it suggested that part-time and unemployed household heads were likely to be responsible for dropping off their children to school, than their full-time counterparts.

Other household characteristics such as the number of adults in a household and the number of school age children were not found to be associated with children's travel modes to school. These findings might suggest that travel to school, like adult's commute to work, was a regular activity with a routine pattern across households with school age children.

This study found that different environment attributes were associated with different travel modes to school by different age groups. Traffic conditions, such as traffic volume, bus ridership, and pedestrian and bicycle collisions, were found to be associated with school travel modes. Bus ridership in the home neighborhood was negatively associated with bus travel for elementary school children. And bus ridership around the school was positively associated with taking the bus in high school children. Higher pedestrian and bicycle collision counts in a home neighborhood made it more likely for elementary school children to take the bus; whereas higher pedestrian and bicycle collision counts made it less likely for high school children to drive.

Land use characteristics of home and school neighborhood were also found to be associated with school travel modes. The percentage of land used as parkland in an elementary school child's home neighborhood was positively associated with active commuting to school. And higher percentage of parkland around a school was associated with a greater likelihood of taking bus to school in elementary school children. Furthermore, elementary school children were more likely to take the bus to school if there was one local retailer around school compared with three or more; whereas elementary school children who lived within 1 mile of their school were more likely to walk or bike to school if there was no any local retailer around school. Middle school children were more likely to take the bus to school if there was one local retailer in their home neighborhood compared with three or more local retailers.

Unlike the strong impacts of residential density found on adult travel behavior (Steiner 1994; Ewing and Cervero 2001; Fan and Khattak 2008; Lee et al. 2009), residential density (both around a child's home and their school) was not found to be significantly associated with children's commute to school. Similar to residential density, street density (both around a child's home and their school) was not found to be significantly associated with school travel modes in any of the four final models.

The results of different environment attributes associated with different travel modes to school by different age groups suggested that policies or programs that aim to encourage and increase active commuting to school should be tailored to different age groups. The positive association of the percentage of land used as parkland in home neighborhoods and the absence of local retailers around a school with active commute to school for elementary school children who live within 1 mile might be related to the perception of parents that residential only neighborhoods with a high percentage of parkland were considered as safe for elementary school children to walk or bike. Other research has shown that personal safety was one of the foremost concerns of the parents' selections of travel modes to school for their elementary school age children. Programs that strengthen personal safety both around home and school might encourage more walking and biking to school for elementary school children. Future studies that identify objective environmental attributes that are associated with parents' safety perception would further direct and develop interventions to increase rates of elementary school children active commuting.

As middle school children gain independent mobility, route directness from home to school and traffic volume around a school, in addition to the distance from home, became key concerns in choosing to actively commute. These findings implied that programs that focus on controlling or reducing traffic volume around middle schools could increase active commuting rates for middle school children.

This study had limitations. Since the area of this study was King County, Washington State, the findings could be generalized to the many metropolitan areas of the nation with similar characteristics, but they were not relevant to low density suburban or rural environments. The sample size of high school children was relatively modest. High school children were further divided into four travel modes to school and the number of the high school children who walked or biked to school was small. Thus, any interpretation of these results as regards active commuting for high school children should be approached with prudence. Information on the availability of school buses and children's acquisition of driver's license, which might be two of the determining factors in the selection of school travel modes, were not included in this study. Both parents' and children's attitude towards physical activity were missing. Future research should also investigate the environmental characteristics of the routes that children took to school.

Conclusion

A strong inverse association between network distance from home to school and active commuting to school was found in all school age groups, even for those who lived near to their school. Age was positively associated with active commuting in elementary school children only. Gender has been consistently shown to be a non-significant association with travel modes to school for all school age groups. Elementary and middle school children whose household heads worked part time were more likely to be driven to school, whereas it was more likely for high school children whose household heads did not work. Different environmental attributes were associated with different travel modes by different age groups. The percentage of land used as parkland in home neighborhoods and the absence of local retailers around a school were positively associated with active commute to school for elementary school children who live within 1 mile. Route directness from home to school and traffic volume around a school were two key concerns in choosing to actively commute for middle school children.

Reference

(2006). Puget Sound Regional Council Household Travel Survey Geocoding Procedures Manual, Puget Sound Regional Council

(2008). Age of reference person: Average annual expenditures and characteristics, Bureau of Labor Statistics.

Agrawal, A. W. and P. Schimek 2007. Extent and correlates of walking in the USA. *Transportation Research Part D-Transport and Environment* **12**(8): 548-563.

Allaman, P., T. Tardiff and F. Dunbar (1982). New approaches to understanding travel behavior. Washington D.C., Transportation Research Board National Research Council**:** 142.

Anderson, P. M. and K. E. Butcher 2006. Childhood obesity: trends and potential causes. *Future Child* **16**(1): 19-45.

Babey, S. H., T. A. Hastert, W. Huang and E. R. Brown 2009. Sociodemographic, family, and environmental factors associated with active commuting to school among US adolescents. *Journal of Public Health Policy* **30 Suppl 1**: S203-220.

Barmby, T. and J. Doornik 1989. Modelling Trip Frequency as a Poisson Variable. *Journal of Transport Economics and Policy* **23**(3): 309-315.

Bhat, C. R. and R. M. Pendyala 2005. Modeling intra-household interactions and group decision-making. *Transportation* **32**(5): 443-448.

Black, C., A. Collins and M. Snell 2001. Encouraging Walking: The Case of Journey-to-school Trips in Compact Urban Areas. *Urban Stud* **38**(7): 1121-1141.

Blumen, O. 1994. Gender Differences in the Journey to Work. *Urban Geography* **15**(3): 223-245.

Bohte, W., K. Maat and B. van Wee 2009. Measuring Attitudes in Research on Residential Self-Selection and Travel Behaviour: A Review of Theories and Empirical Research. *Transport Reviews* **29**(3): 325-357.

Bradley, M. and P. Vovsha 2005. A model for joint choice of daily activity pattern types of household members. *Transportation* **32**(5): 545-571.

Brail, R. K. and F. S. Chapin 1973. Activity Patterns of Urban Residents. *Environment and Behavior* **5**(2): 163-190.

Bray, G. A. and C. Bouchard 2008. Handbook of obesity : clinical applications. New York, Informa Healthcare.

Brownson, R. C., C. M. Hoehner, K. Day, A. Forsyth and J. F. Sallis 2009. Measuring the built environment for physical activity: state of the science. *American Journal of Preventive Medicine* **36**(4 Suppl): S99-123.e12-S99-123.e12.

Buliung, R. and P. Kanaroglou 2007. Activity-Travel Behaviour Research: Conceptual Issues, State of the Art, and Emerging Perspectives on Behavioural Analysis and Simulation Modelling. *Transport Reviews* **27**: 151-187.

Buliung, R. N. and P. S. Kanaroglou 2006. Urban Form and Household Activity-Travel Behavior. *Growth and Change* **37**(2): 172-199.

Catenacci, V. A., J. O. Hill and H. R. Wyatt 2009. The obesity epidemic. *Clin Chest Med* **30**(3): 415-44, vii.

Chatman, D. 2003. How Density and Mixed Uses at the Workplace Affect Personal Commercial Travel and Commute Mode Choice. *Transportation Research Record* **1831**(1): 193-201.

Chen, C., H. Gong and R. Paaswell 2008. Role of the built environment on mode choice decisions: additional evidence on the impact of density. *Transportation* **35**(3): 285-299.

Chung, J.-H., T. Kim, H. Baik and Y.-S. Choi 2009. A structural equation model of activity participation and travel behavior using longitudinal data. *Transportation Planning and Technology* **32**(2): 163-185.

Churchman, A. 1999. Disentangling the Concept of Density. *Journal of Planning Literature* **13**(4): 389-411.

Colditz, G. A. 1999. Economic costs of obesity and inactivity. *Medicine and Science in Sports and Exercise* **31**(11 Suppl): S663-S667.

Crane, R. 2007. Is There a Quiet Revolution in Women's Travel? Revisiting the Gender Gap in Commuting. *Journal of the American Planning Association* **73**(3): 298-298.

Daniels, S. R. 2006. The consequences of childhood overweight and obesity. *Future Child* **16**(1): 47-67.

Davison, K. K., J. L. Werder and C. T. Lawson 2008. Children's active commuting to school: current knowledge and future directions. *Prev Chronic Dis* **5**(3): A100.

Downs, A. 2004. Still stuck in traffic : coping with peak-hour traffic congestion. Washington D.C., Brookings Institution Press.

Duncan, M. J. and W. K. Mummery 2007. GIS or GPS? A comparison of two methods for assessing route taken during active transport. *American Journal of Preventive Medicine* **33**(1): 51-53.

Ettema, D., T. Schwanen and H. Timmermans 2007. The effect of location, mobility and socio-demographic factors on task and time allocation of households. *Transportation* **34**(1): 89-105.

Ewing, R. and R. Cervero 2001. Travel and the Built Environment: A Synthesis. *Transportation Research Record: Journal of the Transportation Research Board* **1780**: 87-114.

Fan, Y. L. and A. J. Khattak 2008. Urban Form, Individual Spatial Footprints, and Travel Examination of Space-Use Behavior. *Transportation Research Record*(2082): 98-106.

Faulkner, G. E. J., R. N. Buliung, P. K. Flora and C. Fusco 2009. Active school transport, physical activity levels and body weight of children and youth: A systematic review. *Preventive Medicine* **48**(1): 3-8.

Finkelstein, E. A., I. C. Fiebelkorn and G. Wang 2003. National medical spending attributable to overweight and obesity: how much, and who's paying? *Health Affairs (Project Hope)* **Suppl Web Exclusives**: W3-219-26-W3-219-26.

Flegal, K. M., M. D. Carroll, C. L. Ogden and C. L. Johnson 2002. Prevalence and trends in obesity among US adults, 1999-2000. *JAMA: The Journal of the American Medical Association* **288**(14): 1723-1727.

Flegal, K. M., B. I. Graubard, D. F. Williamson and M. H. Gail 2005. Excess deaths associated with underweight, overweight, and obesity. *JAMA: The Journal of the American Medical Association* **293**(15): 1861-1867.

Frank, L., M. Bradley, S. Kavage, J. Chapman and T. K. Lawton 2008. Urban form, travel time, and cost relationships with tour complexity and mode choice. *Transportation* **35**(1): 37-54.

Frank, L. D. and G. Pivo 1994. Impacts of Mixed Use and Density on. Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and. Walking. *Transportation Research Record* **1466**: 44-52.

Gliebe, J. P. and F. S. Koppelman 2005. Modeling household activity-travel interactions as parallel constrained choices. *Transportation* **32**(5): 449-471.

Goldin, C., L. F. Katz and I. Kuziemko 2006. The Homecoming of American College Women: The Reversal of the College Gender Gap. *The Journal of Economic Perspectives* **20**(4): 133-156.

Gossen, R. and C. L. Purvis (2005). Activities, time, and travel: Changes in women's travel time expenditures, 1990–2000. Washington DC, National Research Council**:** 19.

Handy, S. L., M. G. Boarnet, R. Ewing and R. E. Killingsworth 2002. How the built environment affects physical activity: views from urban planning. *Am J Prev Med* **23**(2 Suppl): 64-73.

Hanson, S. and P. Hanson 1981. The Travel-Activity Patterns of Urban Residents: Dimensions and Relationships to Sociodemographic Characteristics. *Economic Geography* **57**(4): 332-347.

Hedley, A. A., C. L. Ogden, C. L. Johnson, M. D. Carroll, L. R. Curtin and K. M. Flegal 2004. Prevalence of overweight and obesity among US children, adolescents, and adults, 1999-2002. *JAMA: The Journal of the American Medical Association* **291**(23): 2847-2850.

Hensher, D., Ed. (2001). Travel behaviour research : the leading edge. Amsterdam;New York, Pergamon.

Hume, C., A. Timperio, J. Salmon, A. Carver, B. Giles-Corti and D. Crawford 2009. Walking and cycling to school: predictors of increases among children and adolescents. *American Journal of Preventive Medicine* **36**(3): 195-200.

International, M. (2007). PSRC 2006 Household Activity Survey Analysis Report, Appendix A: Survey Methods, Puget Sound Regional Council**:** 16.

Jago, R. and T. Baranowski 2004. Non-curricular approaches for increasing physical activity in youth: a review. *Prev Med* **39**(1): 157-63.

Kelder, S. H., C. L. Perry, K. I. Klepp and L. L. Lytle 1994. Longitudinal tracking of adolescent smoking, physical activity, and food choice behaviors. *American Journal of Public Health* **84**(7): 1121-1126.

Kitamura, R. (1988). Life-style and travel demand. Special Report 220: A Look Ahead: Year 2020. Washington, D.C., Transportation Research Board, National Research Council**:** 149-189.

Kutter, E. 1973. A model for individual travel behavior. *Urban Studies* **10**: 235-258.

Lee, C. and A. V. Moudon 2004. Physical activity and environment research in the health field: Implications for urban and transportation planning practice and research. *Journal of Planning Literature* **19**(2): 147-181.

Lee, C. and A. V. Moudon 2006. Correlates of Walking for Transportation or Recreation Purposes. *Journal of Physical Activity and Health* **3**(Suppl 1): S77-S98.

Lee, M. C., M. R. Orenstein and M. J. Richardson 2008. Systematic review of active commuting to school and childrens physical activity and weight. *J Phys Act Health* **5**(6): 930-49.

Lee, Y., M. Hickman and S. Washington 2007. Household type and structure, time-use pattern, and trip-chaining behavior. *Transportation Research Part a-Policy and Practice* **41**(10): 1004-1020.

Lee, Y., S. Washington and L. D. Frank 2009. Examination of relationships between urban form, household activities, and time allocation in the Atlanta Metropolitan Region. *Transportation Research Part A: Policy and Practice* **43**(4): 360-373.

Lin, J. and L. Long 2008. What neighborhood are you in? Empirical findings of relationships between household travel and neighborhood characteristics. *Transportation* **35**(6): 739-758.

Lin, L. and A. V. Moudon 2010. Objective versus subjective measures of the built environment, which are most effective in capturing associations with walking? *Health Place* **16**(2): 339-48.

MacDonald, H. I. 1999. Women's Employment and Commuting: Explaining the Links. *Journal of Planning Literature* **13**(3): 267-283.

Martin, S. L., S. M. Lee and R. Lowry 2007. National prevalence and correlates of walking and bicycling to school. *American Journal of Preventive Medicine* **33**(2): 98-105.

Matthews, M. 1992. Making Sense of Place: Children's Understanding of Large-Scale Environments. Hemel Hempstead, Hertfordshire Harvester Wheatsheaf

McCormack, G. R., B. Giles-Corti and M. Bulsara 2008. The relationship between destination proximity, destination mix and physical activity behaviors. *Prev Med* **46**(1): 33-40.

McDonald, N. C. 2007. Active transportation to school: trends among U.S. schoolchildren, 1969-2001. *Am J Prev Med* **32**(6): 509-16.

McDonald, N. C. 2008. Household interactions and children's school travel: the effect of parental work patterns on walking and biking to school. *Journal of Transport Geography* **16**(5): 324-331.

McDonald, N. C., E. Deakin and A. E. Aalborg 2010. Influence of the social environment on children's school travel. *Preventive Medicine* **50**(1): S65-S68.

McGinnis, R. G. (1980). Influence of Employment and Children on Intra-Household Travel Behavior. Women's travel issues : research needs and priorities : conference proceedings and papers.

Washington D.C., U.S. Department of Transportation, Research and Special Programs Administration.

McMillan, T. E. 2005. Urban form and a child's trip to school: The current literature and a framework for future research. *Journal of Planning Literature* **19**(4): 440-456.

McMillan, T. E. 2007. The relative influence of urban form on a child's travel mode to school. *Transportation Research Part a-Policy and Practice* **41**(1): 69-79.

Meloni, I., M. Bez and E. Spissu 2009. Activity-Based Model of Women's Activity-Travel Patterns. *Transportation Research Record* **2125**: 26-35.

Mokhtarian, P. L. and C. Chen 2004. TTB or not TTB, that is the question: a review and analysis of the empirical literature on travel time (and money) budgets. *Transportation Research Part A: Policy and Practice* **38**(9-10): 643-675.

Moudon, A. V., C. Lee, A. D. Cheadle, C. W. Collier, D. Johnson, T. L. Schmid and R. D. Weather 2005. Cycling and the built environment, a US perspective. *Transportation Research Part D: Transport and Environment* **10**(3): 245-261.

Moudon, A. V., C. Lee, A. D. Cheadle, C. Garvin, D. B. Rd, T. L. Schmid and R. D. Weathers 2007. Attributes of environments supporting walking. *Am J Health Promot* **21**(5): 448-59.

Moudon, A. V., L. Lin, P. Hurvitz and P. Reeves 2008. Risk of Pedestrian Collision Occurrence Case Control Study of Collision Locations on State Routes in King County and Seattle, Washington. *Transportation Research Record*(2073): 25-38.

Moudon, A. V., L. Lin, J. Jiao, P. Hurvitz and P. Reeves in press. The Risk of Pedestrian Injury and Fatality in Collisions with Motor Vehicles, A Social Ecological Study of State Routes and City Streets in King County, Washington. *Accident Analysis & Prevention*.

Nelson, N. M. and C. B. Woods 2010. Neighborhood perceptions and active commuting to school among adolescent boys and girls. *J Phys Act Health* **7**(2): 257-66.

Ogden, C. L., M. D. Carroll, L. R. Curtin, M. A. McDowell, C. J. Tabak and K. M. Flegal 2006. Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA: The Journal of the American Medical Association* **295**(13): 1549-1555.

Ogden, C. L., K. M. Flegal, M. D. Carroll and C. L. Johnson 2002. Prevalence and trends in overweight among US children and adolescents, 1999-2000. *JAMA: The Journal of the American Medical Association* **288**(14): 1728-1732.

Ogden, C. L., S. Z. Yanovski, M. D. Carroll and K. M. Flegal 2007. The epidemiology of obesity. *Gastroenterology* **132**(6): 2087-102.

Panter, J. R., A. P. Jones and E. M. van Sluijs 2008. Environmental determinants of active travel in youth: A review and framework for future research. *Int J Behav Nutr Phys Act* **5**: 34.

Panter, J. R., A. P. Jones, E. M. F. Van Sluijs and S. J. Griffin 2010. Neighborhood, Route, and School Environments and Children's Active Commuting. *American Journal of Preventive Medicine* **38**(3): 268-278.

Pas, E. 1998. Time in travel choice modeling : from relative obscurity to center stage. *Theoretical foundations of travel choice modeling.*: 250-250.

Pinjari, A. R., C. R. Bhat and D. A. Hensher 2009. Residential self-selection effects in an activity time-use behavior model. *Transportation Research Part B: Methodological* **43**(7): 729-748.

Pont, K., J. Ziviani, D. Wadley, S. Bennett and R. Abbott 2009. Environmental correlates of children's active transportation: A systematic literature review. *Health Place* **15**(3): 827-40.

Primerano, F., M. Taylor, L. Pitaksringkarn and P. Tisato 2008. Defining and understanding trip chaining behaviour. *Transportation* **35**(1): 55-72.

Pucher, J., J. Dill and S. Handy 2009. Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine* **50**(Supplement 1): S106-S125.

Saelens, B. E. and S. L. Handy 2008. Built environment correlates of walking: a review. *Medicine and Science in Sports and Exercise* **40**(7 Suppl): S550-S566.

Saelens, B. E., J. F. Sallis and L. D. Frank 2003. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Ann Behav Med* **25**(2): 80-91.

Sallis, J. F., R. B. Cervero, W. Ascher, K. A. Henderson, M. K. Kraft and J. Kerr 2006. An ecological approach to creating active living communities. *Annu Rev Public Health* **27**: 297-322.

Schintler, L., A. Root and K. Button 2000. Women's Travel Patterns and the Environment: An Agenda for Research. *Transportation Research Record* **1726**(1): 33-40.

Simma, A. and K. W. Axhausen 2001. Within-household allocation of travel - Case of Upper Austria. *Transportation Research Record*(1752): 69-75.

Sirard, J. R. and M. E. Slater 2008. Walking and Bicycling to School: A Review. *American Journal of Lifestyle Medicine* **2**(5): 372-396.

Srinivasan, K. K. and S. R. Athuru 2005. Analysis of within-household effects and between-household differences in maintenance activity allocation. *Transportation* **32**(5): 495-521.

Srinivasan, S. and C. R. Bhat 2005. Modeling household interactions in daily in-home and out-of-home maintenance activity participation. *Transportation* **32**(5): 523-544.

Steiner, R. L. 1994. Residential Density and Travel Patterns: Review of the Literature. *Transportation Research Record* **1466**: 37-43.

Stern, E. and H. Richardson 2005. Behavioural modelling of road users: current research and future needs. *Transport Reviews* **25**(2): 159-180.

Stopher, P. and H. Metcalf 1999. Household Activities, Life Cycle, and Role Allocation Tests on Data Sets from Boston and Salt Lake City. *Transportation Research Record: Journal of the Transportation Research Board* **1676**: 95-102.

Sun, X., C. Wilmot and T. Kasturi 1998. Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Activity-Based Travel Survey. *Transportation Research Record: Journal of the Transportation Research Board* **1617**: 10-17.

Thorpe, K. E., C. S. Florence, D. H. Howard and P. Joski 2004. The impact of obesity on rising medical spending. *Health Affairs (Project Hope)* **Suppl Web Exclusives**: W4-480-6-W4-480-6.

Tudor-Locke, C., B. E. Ainsworth and B. M. Popkin 2001. Active commuting to school: an overlooked source of childrens' physical activity? *Sports Med* **31**(5): 309-13.

Voorhees, C. C., J. S. Ashwood, K. R. Evenson, J. R. Sirard, A. L. Rung, M. Dowda and T. L. McKenzie 2010. Neighborhood Design and Perceptions: Relationship with Active Commuting. *Medicine & Science in Sports & Exercise* **Publish Ahead of Print**.

Wang, G. and W. H. Dietz 2002. Economic burden of obesity in youths aged 6 to 17 years: 1979-1999. *Pediatrics* **109**(5): E81-81-E81-81.

Wang, Y., M. A. Beydoun, L. Liang, B. Caballero and S. K. Kumanyika 2008. Will all Americans become overweight or obese? estimating the progression and cost of the US obesity epidemic. *Obesity (Silver Spring)* **16**(10): 2323-30.

Wen, L. M., D. Fry, C. Rissel, H. Dirkis, A. Balafas and D. Merom 2008. Factors associated with children being driven to school: implications for walk to school programs. *Health Education Research* **23**(2): 325-334.

Wolf, A. M. and G. A. Colditz 1998. Current estimates of the economic cost of obesity in the United States. *Obesity Research* **6**(2): 97-106.

Yarlagadda, A. K. and S. Srinivasan 2008. Modeling children's school travel mode and parental escort decisions. *Transportation* **35**(2): 201-218.

Yeung, J., S. Wearing and A. P. Hills 2008. Child transport practices and perceived barriers in active commuting to school. *Transportation Research Part A: Policy and Practice* **42**(6): 895-900.

Zhou, H., J. Yang, P. Hsu and S. Chen 2010. Factors Affecting Students' Walking/Biking Rates: Initial Findings from a Safe Route to School Survey in Florida. *Journal of Transportation Safety & Security* **2**(1): 14-14.

Zhu, X. and C. Lee 2009. Correlates of Walking to School and Implications for Public Policies: Survey Results from Parents of Elementary School Children in Austin, Texas. *Journal of Public Health Policy* **30**(Suppl 1): S177-S202.

Curriculum Vitae

EDUCATION

University of Washington

Doctorate of Philosophy - Urban Design and Planning *Aug 2010*

Dissertation: An Ecological Study of Children Commuting to School

Committee: Professors Anne Vernez Moudon (chair), Scott Rutherford, Hendrika Meischke, Qing Shen, David Levinger, and Marieka Klawitter (GSR)

Master of Public Administration *Aug 2004*

Master of Urban Planning *Aug 2004*

Thesis: How Perceptions of Environment Relate to the Physical Environment

Committee: Professors Anne Vernez Moudon and Rachel Kleit

University of Electronic Science and Technology of China

Bachelor of Art, English of Science and Technology *Jul 2001*

PEER-REVIEWED JOURNAL ARTICLES

Lin, Lin and Anne Vernez Moudon. 2010. Objective Versus Subjective Measures of the Built Environment, Which Are Most Effective in Capturing Associations With Walking? *Health and Place* 16 (2): 339-348.

Moudon, Anne Vernez, **Lin Lin**, Junfeng Jiao, Philip Hurvitz, and Paula Reeves. (In press) The Risk of Pedestrian Injury and Fatality in Collisions with Motor Vehicles, A Social Ecological Study of State Routes and City Streets in King County, Washington. *Accident Analysis & Prevention*.

Moudon, Anne Vernez, **Lin Lin**, Philip Hurvitz, and Paula Reeves. 2008. The Risk of a Pedestrian Collision Occurrence: A Case-Control Study of Collision Locations on State Routes in King County and Seattle, Washington. *Transportation Research Record* 2073: 25-38.

Moudon, Anne Vernez, Chanam Lee, Allen D. Cheadle, Cheza Garvin, Donna Johnson, Thomas L. Schmid, Robert D. Weathers, and **Lin Lin**. 2006. Operational Definitions of Walkable Neighborhood: Theoretical and Empirical Insights. *Physical Activity and Health* 3 (Supplement 1): 99-117.

TECHNICAL REPORTS

Moudon, Anne Vernez, Orion Stewart, and **Lin Lin**. 2010. Safe Routes to School (SRTS): Statewide Mobility Assessment Study Phase I Report. Seattle: Washington State Transportation Center (TRAC).

Moudon, Anne Vernez, **Lin Lin**, and Philip Hurvitz. 2008. Managing Pedestrian Safety II: A Case-Control Study of Collision Locations on State Routes in King County and Seattle, Washington. Seattle: Washington State Transportation Center (TRAC).

Moudon, Anne Vernez, **Lin Lin**, and Philip Hurvitz. 2007. Managing Pedestrian Collision I: Injury Severity. Seattle: Washington State Transportation Center (TRAC).

PRESENTATIONS

Lin, Lin. 2009. *Children Commuting To School And The Environment: An Ecological Study Of Associations Of Neighborhood Environment Of Home, School, And Work, Household Characteristics, And Parents´ Travel Patterns On Children's Commuting To School.* Paper presented at the Association of Collegiate Schools of Planning (ACSP) Conference, October 4, 2009, at Crystal City, VA.

Lin, Lin and Anne Vernez Moudon. 2009. *Predicting Pedestrian Collision Frequency on State Routes in King County, Washington.* Poster presented at the 88th Annual Meeting of Transportation Research Board (TRB), January 13, 2009, at Washington DC.

Moudon, Anne Vernez, **Lin Lin**, Junfeng Jiao, Philip Hurvitz, and Paula Reeves. 2009. *Risk of Pedestrian Injury and Fatality in Collisions with Motor Vehicles: An Ecological Study of State Routes and City Streets in King County, Washington.* Poster presented at the 88th Annual Meeting of Transportation Research Board (TRB), January 13, 2009, at Washington DC.

Lin, Lin and Anne Vernez Moudon. 2008. *Subjective Versus Objective Measures of Built Environment, Which Are More Effective in Capturing Associations with Walking?* Poster presented at Active Living Research Annual Conference, April 11, 2008, at San Diego, CA.

Moudon, Anne Vernez, **Lin Lin**, Philip Hurvitz, and Paula Reeves. 2008. *The Risk of a Pedestrian Collision Occurrence: A Case-Control Study of Collision Locations on State Routes in King County and Seattle, Washington*. Poster presented at the 87th Annual Meeting of Transportation Research Board (TRB), January 14, 2008, at Washington DC.

Moudon, Anne Vernez, **Lin Lin**, and Philip Hurvitz. 2007. *Estimating Risk of Pedestrian Severe Injury or Fatality on State Routes in King County, WA.* Paper presented at the Association of Collegiate Schools of Planning (ACSP) Conference, October 19, 2007, at Milwaukee, WI.

Lin, Lin, Luc de Montigny, and Anne Vernez Moudon. 2006. *Comparing the Use of Subjective and Objective Measures of Built Environment*. Paper presented at the Association of Collegiate Schools of Planning (ACSP) Conference, November 11, 2006, at Fort Worth, TX.

Lin, Lin, Chanam Lee, and Anne Vernez Moudon. 2005. *Perceptual Versus Actual Measures of Neighborhood Environment*. Paper presented at the Association of Collegiate Schools of Planning (ACSP) Conference, October 29, 2005, at Kansas City, MO.