PUBLIC TRANSIT USE AS A CATALYST FOR AN ACTIVE LIFESTYLE: MECHANISMS, PREDISPOSITIONS AND HINDRANCES

by

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Abstract

In this thesis, I use the concept of a catalyst to analyze the relationships between transit use and measures of physical activity in neighborhoods with contrasting walkability and income levels. These analyses are preceded by an exploration of the long-term housing location preferences that enable people to live near transit, and ultimately to choose public transit.

Three separate analyses using the Neighborhood Quality of Life Study (NQLS, 2002-2005; n=2199), provided by collaborators, form the core chapters of this thesis. The NQLS is a cross-sectional, matched community observational study of adults randomly sampled across 32 neighborhoods in Metro Seattle, WA and Baltimore, MD to compare behaviors of residents. Neighborhoods either had high or low median income and high or low walkability (4 neighborhood of each types in each cities). Causal mechanisms are explored, but cross-sectional data prevents concluding on causal relationships.

In the first manuscript, the choice to use transit is analyzed in the context of long-term housing decisions. Some respondents wanting to locate near transit were not able to. Increasing housing opportunities near transit could improve the viability of using public transit, and support its potential health benefits.

For public transportation to be considered a catalyst for physical activity, it must have a positive association independent of neighborhood walkability, car availability, and enjoyment of moderate physical activity. These issues are confirmed in the second manuscript. Transit commuters' higher frequencies of utilitarian walking to destinations near the home and workplace is presented as a potential explanation for higher levels of physical activity.

Additionally, active transportation time should not displace time used for leisure physical activity, and this relationship should hold whether transit users have access to an automobile (choice riders) or not (transit-dependent riders). This is confirmed in the third manuscript.

In light of the active lifestyle benefits of public transit use, public health agencies may promote transit use through social marketing, and promote transit infrastructure development to policy-makers. Urban planners and transit agencies should consider the ability of households to locate near transit, and the lifestyle burden of transit-dependent riders, in order to promote healthier, inclusive and sustainable cities.

Preface

The three empirical chapters of the thesis (4, 5, 6) are written as research manuscripts. Chapter 5 was accepted for publication in a special issue of the Journal of Physical Activity and Health, and chapter 4 and 6 will be submitted as co-authored manuscripts with Ugo Lachapelle as first author, Larry Frank, Brian Saelens, Jim Sallis, and Terry Conway as co-authors. A list is provided below. Co-authors Frank, Saelens and Sallis were co-PIs on the Neighborhood Quality of Life Study (NQLS) project. Dr. Conway has been involved in all NQLS discussion and has provided statistical and theoretical support to the research. The NQLS team provided the survey data as well as guidance in the analytical process.

I identified and designed a research program that the research team challenged and commented on. It was agreed that I would be first author in each publication. From the NQLS survey data that I was granted accessed to, I also coded the variables of interest for this thesis, elaborated hypotheses, designed and ran the analyses, interpreted the results and prepared all Tables and Figures included in the manuscripts. Two regional maps and a Figure included in the theoretical and method chapters are however reproduced from the literature and referenced accordingly.

The current manuscripts were not directly modified by any of the co-authors with the exception of chapter 5, which underwent peer-review for publication and co-author rewrite simultaneously with thesis submission. This is because the manuscript was presented at the Active Living Research conference in February 2010 and was invited for submission to a peer reviewed special issue associated with the conference. Otherwise, it was agreed that in order to comply with the spirit of an independently produced PhD thesis, co-authors would only review other manuscripts after they had been submitted to the Faculty of Graduate Studies, and before being submitted to research journals. Chapter 4 and 6 were respectively presented in 2010 at the 51st annual conference of the Association of Collegiate Schools of Planning and in 2009 at the 50th annual conference of the Association of Collegiate Schools of Planning. An earlier version of Chapter 2 and 3 was presented in 2008 at the International Conference on Urban Health.

The three manuscripts are the following:
Lachapelle, U., Frank, L.D., Sallis J.F., Saelens, B.E., Conway, T.L. Public transit service and housing location choice: predisposition, satisfaction and transit use.

Lachapelle, U., Frank, L.D., Sallis J.F., Saelens, B.E., Conway, T.L. Commuting by public transit and physical activity: where you live, where you work and how you get there.

Lachapelle, U., Frank, L.D., Sallis J.F., Saelens, B.E., Conway, T.L. Active transportation of choice and dependent transit riders: associations and potential displacement of other physical activity.

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APTA	American Public Transit Association
CDC	Center for Disease Control
CBD	Central Business District
DHHS	Department of Health and Human Services
FAR	Floor Area Ratio
GIS	Geographical Information Systems
HUD	Housing and Urban Development
IOM	Institute of Medicine
IPAQ	International Physical Activity Questionnaire
IPEN	International Physical Activity and Environment Network
KC	King County
LOS	Level of Service
LRT	Light Rail Transit
MVPA	Moderate to vigorous physical activity
NHLBI	National Heart Lung and Blood Institute
NIH	National Institute of Health
NQLS	Neighborhood Quality of Life Study
OECD	Organization for Economic Cooperation and Development
SLOTH (model)	Sleep, Leisure, Occupation, Transportation, Home-based activities
TCRP	Transit Cooperative Research Program
TCQSM	Transit Capacity and Quality of Service
TDM	Travel Demand Management
TOD	Transit-Oriented Development
TRB	Transportation Research Board
US	United States
WHO	World Health Organization
*, **, ***	Significance levels: * 5%, or $p<0.05$; ** 1%, or $p<0.01$; *** 0.1%, or $p<0.001$
var1*var2	(* Between two independent variables) Interaction term
Adj.	Adjusted
ChiSq.	Chi Square test of significance
Coef.	Coefficient
Df	Degrees of freedom
HLM	Hierarchical Linear Modeling
LL	Log-likelihood
-2ll	Log-likelihood ratio
MLE	Maximum Likelihood Estimators
OR	Odds Ratio
OLS	Ordinary Least Square Regression
Sig.	Significance
SD	Standard deviation

Acknowledgements

Many people have had a key contribution to the production of this thesis, and I would like to acknowledge them for their help and support.

First, my supervisor, Larry Frank, for his insights in the world of academic research, his support in providing me access to data and allowing me the opportunity to collaborate and learn from a larger research community. I also thank him for providing financial support to me through the Joseph Armand Bombardier Chair in Sustainable Transportation.

Members of my committee Stephanie Chang and Brian Klinkenberg have followed through the research process with me from the very beginning. I thank you for always having been available when I needed your support. My thanks also go to Kay Teschke for having accepted to be an external examiner for my comprehensive exam.

I would also like to acknowledge the financial support of the Fonds Québécois de la recherche sur la société et la culture (FQRSC), the Fonds de recherche en santé du Québec (FRSQ) and the Ministère de la santé et des services sociaux (MSSS), who provided generous support for this research through the innovative concerted action program (*Programme québécois de recherche sur les politiques publiques favorables à la santé et au bien-être*). The Social Science and Humanities Research Council of Canada, the Bombardier Foundation, as well as the government of British Columbia also provided support for the completion of this research. None of this would have been possible without their generosity. The National Heart Lung and Blood Institute (NHLBI) must also be acknowledged for funding the NQLS study.

I would also like to thank the Neighborhood Quality of Life Study (NQLS) team for including me in their endeavor. Not only did they provide me with interesting, progressive and exclusive data, but they also enabled the important experience of working collaboratively with an experienced research team. Their insights, guidance and responsiveness helped me forward my research.

I thank my parents Margo Nobert, Réjean Lachapelle and my sister Sofie Lachapelle, for their supportiveness, and informed thoughts on academic life and the research process.

Reviewers, anonymous or friends have been a tremendous source of support and inspiration throughout my PhD and have helped me improve my writing style, as well as the content of my research. Special thanks go out to Angie Mae Long, at the UBC Writing center, and Sarah Banting for long hours spent reviewing my work and teaching me grammar at the outset of my doctoral studies. Meghan Winters also deserves special cheers for hours of discussion over data, analysis and interpretation of results.

Finally, the fantastic and supportive group of friends that I made here in Vancouver made this doctoral experience a beautiful, inspiring, and entertaining one.

A mes parents, Margo et Réjean

Les meilleurs enseignements, c'est à la maison que je les ai appris.

Chapter 1 Introduction

Active living, the practice of different forms of physical activity as part of everyday life, is considered an important determinant of population health. The relationship between the built environment, travel behavior and different forms of physical activity has been the recent topic of a wealth of theoretical and empirical research (Frumkin et al. 2004; Frank and Engelke, 2003; Saelens et al., 2003; Sallis et al., 2006; Lee and Moudon, 2004; TRB, 2005). Many researchers have intuitively concluded that the provision of high quality transit service is an essential element of the design of walkable environments and of healthy cities. Built environments supportive of walking are typically also well served by public transit, and typically have higher share of transit ridership (Ewing and Cervero, 2001). A person that walks and cycles for utilitarian purposes also needs motorized modes to get to farther destinations. Yet a process of habituation leads car owners to be less inclined to consider other travel mode options (Zhang, 2006), making walking less likely. On the other hand, because transit journeys typically begin and end on foot, using transit may be associated with a more active lifestyle. Is there more to this relationship than just walking to transit? In order to foster alternative forms of transport such as the combination between walking and public transit, walkable environment that improve local pedestrian access likely need to be accompanied by good regional transit access.

Few empirical analyses have assessed the relationship between transit use and active lifestyles. In this PhD project, the primary aim is to explore associations between transit use and active forms of transportation and to identify the mechanisms involved in this relationship. While this association seems plausible at face value, many complexities arise in the development of an analytical framework, as there are potentially numerous confounding and moderating factors. The secondary aim is to identify the neighborhood pedestrian features, transit service characteristics and attitudes towards transit use associated with the choice to use public transit and to explore the potential inability of some survey respondents to locate in places that enable them to use public transit. In the three empirical chapters of this thesis, I conduct an in-depth exploration of these relationships. The complex pathway through which individuals gain access to transit service and choose whether or not to use it is first assessed. Can individuals wanting to use transit locate in places with good transit? What characteristics of the pedestrian environment, transit network are associated with transit use?

Are transit users walking more than their non-user counter-parts? How do built environments, car ownership, personal attitudes and household constraints influence this relationship? Using the perspectives, theories and approaches of transportation and public health, an empirical exploration of the process of housing location, choice to use public transit, and associated active transportation is conducted. **Active transportation** is the practice is physical activity for the purpose of accessing a destination. Walking, and cycling can be considered as active transportation if they are practiced for a utilitarian purpose. In the transportation literature, active transportation is often referred to as non-motorized transportation.

To carry out these analyses, I used a cross-sectional observational survey instrument, the Neighborhood Quality of Life Study (NQLS) that was designed to study the relationship between multiple health and behavioral outcomes and neighborhood design. Random sampling of adults from 32 purposefully selected neighborhoods in was conducted both in Seattle, WA (16 neighborhoods) and the Baltimore-Washington DC area (16 neighborhoods). Neighborhoods were selected for high or low walkability and high or low income. Co-primary investigators James Sallis, Brian Saelens and Lawrence Frank designed the study, and Lawrence Frank, as my advisor, granted me access to the data. This quasi-experimental survey design was used to identify associations and causal mechanisms, rather than to calculate population prevalence. Because the data is cross-sectional, analyses fall short of providing conclusive causal evidence. Nonetheless, they set the stage for the study of these phenomena in a longitudinal framework.

In the following fictitious accounts, different lifestyles and travel behavior patterns are presented with emphasis on the relationships studied in this thesis. This will help clarify the nature of my research focus and areas of inquiry. The account present a series of opportunities, constraints, attitudes (studied attitudes are italicized) and lifestyle choices made by individuals.

> Lisa lives in a suburban neighborhood near a transit stop that offers fast and frequent service to her workplace downtown. She takes the bus to work every morning and has a favorable attitude towards public transit, which was reflected in *transit's importance in her housing preference*. Her household owns two cars and she could use the second to commute. She eats lunch and shops within walking distance of her workplace. She sometimes runs errands by walking to stores and services near her workplace before going home. Her husband, John, works in an office park not served by transit. He uses the family car every day to get to work and sometimes runs errands by car on the way home. He never walks as part of his daily commute, yet *enjoys practicing physical activity* in his leisure time. They both use the car at night to access destinations outside of their neighborhood and to participate in leisure physical activity.
>
> In another household, Robert and Linda live in a central area with higher residential densities and more services near their house. Some of these services, such as food stores, restaurants and hardware stores, are found within walking distance. Their financial situation prevents them from owning a car. They instead depend on transit to access work, a health clinic, their bank and post office. On most days, they spend a considerable amount of time walking both in their neighborhood and in the places they access via transit. They both do very little leisure physical activity in their daily life for *lack of time*.
>
> In a longer-term perspective, both couples had different housing choice experiences. The first couple did not specifically look for good transit service when they bought a house although Lisa was happy to identify a house that had a good transit connection to her workplace. The direct link to Lisa's workplace from a transit stop

nearby made her decide to start commuting by transit. On the other hand, Robert and Linda, knowing they would frequently use transit, considered *public transit service a very important characteristic* of the neighborhood where they would choose to live. Because of different household constraints, they had to accept moving to a less than optimal location for transit. The stops are relatively far away and Robert requires a long walk at the end of his transit trip to get to his workplace. Furthermore, walking to transit involves crossing busy intersections and passing through poorly lit streets at night. As a result, they are considering the purchase of a vehicle, which would increase the economic burden associated with their transportation patterns.

1.1 Research premises: transit use as a catalyst

Together, the situations presented above attest to the multiplicity of factors impacting transit use and associated active transportation: household income, neighborhood of residence and presence of nearby destinations, quality of transit service at home and work, proximity of services at the workplace, and household constraints such as time availability and vehicle ownership. Preferences, attitudes, lifestyles and housing choices may also shape the studied relationships. The account presented above informs the following research premises.

First, household opportunities and constraints, attitudes and preferences may impact the choice to use public transit over other modes of transportation. Neighborhood walkability is associated with both walking and transit use because transit journeys involve a pedestrian segment. Therefore, one must assess the influence of transit use both in the context of high and low walkability neighborhoods. This issue is addressed in chapter 5. Second, usage of transit may be positively associated with active transportation independently of characteristics of the neighborhood of residence, automobile ownership, and other covariates. Third, part of everyday walking may occur outside of the neighborhood of residence, such as at the workplace. This is likely particularly true for transit users because they find themselves at the workplace without a car and are likely working in central areas well served by transit. Chapter 5 also addresses these two last points. Fourth, based on their travel options, choice and transit-dependent riders may have different patterns of active transportation and leisure physical activity. For the dependent transit market, transit use is the only means of transportation apart from walking, while for the choice market, the benefits of choosing transit must compare favorably to the use of another mode. This may influence how much time they spend on active transportation and on leisure physical activity. Finally, availability of time shapes lifestyles and may differ across transit markets. Analyses related to these last points are provided in chapter 6. None of these proposed relationships have been previously explored in empirical analyses.

Unifying these premises is the overarching concept of transit use as a catalyst for an active lifestyle. What are the mechanisms through which transit use is associated with active transportation and active living? How do lifestyles, preferences, attitudes, economic situations, opportunities and constraints intervene in this relationship? Is there a direct relationship net of other known correlates of active transportation? Can public transit use be considered a catalyst for an active lifestyle? According to the Merriam-Webster, the term catalyst has two potential definitions. I use the first to reformulate a statement pertaining to public transit.

> *Catalyst*: 1: A substance that enables a chemical reaction to proceed at a usually faster rate or under different conditions (as at a lower temperature) than otherwise possible 2: an agent that provokes or speeds significant change or action.
> *Public transit as a catalyst for an active lifestyle*: The use of a PUBLIC SERVICE that enables a BEHAVIOURAL RESPONSE to proceed at HIGHER FREQUENCY OR GREATER DURATION or under different conditions than otherwise possible (AS IN LESS WALKABLE ENVIRONMENTS, for example).

The research premises outlined above can be reformulated as potential mechanisms (Table 1.1)

Table 1.1 Potential mechanisms supportive or deterrent to the catalyst effect

Mechanism Chapter	4	5	6
Supportive of catalyst effect			
Transit users have to walk to access transit stops and stations.		**X**	**X**
Transit service and walkability are associated. Transit service tends to be better in places with high walkability. Ridership is also higher.	**X**		
Transit users may be predisposed to walking through their housing location choice. They may choose to live in high walkability areas with good transit service so as to enable short walk trips.	**X**		
Neighborhood walkability is positively associated with satisfaction with transit service because it impacts the ease and pleasantness of the pedestrian part of the transit journey.	**X**		
Transit users walk to access shops and services near home and avoid long-distance regional trips whenever they can.		**X**	
Transit users travel to areas that are denser and near more services that they can access by walking.		**X**	
Transit-dependent riders have limited alternatives for transportation other than walking, cycling and using transit.			**X**
Deterrent or potentially confounding the catalyst effect			
Enjoyment of physical activity for transit users does not confound relationship between transit use and walking.		**X**	
Transit users, choice or dependent, do not make lifestyle adjustment that reduce their level of leisure physical activity (displacement).			**X**
Lack of time of transit users, choice or dependent, does not reduce their levels of active transportation or leisure physical activity.			**X**

While the term catalyst implicitly suggests a causal relationship, the cross sectional data used in this analysis only allowed the study of associations, and the exploration of ways in which this relationship may occur – what is referred to as causal mechanisms. The analysis falls short of addressing a time order between predictors and outcomes. Only a panel dataset could provide the level of evidence required to establish causality.

The following sections provide some background details on the research questions specific to each manuscript.

1.2 Housing choices, neighborhood walkability, transit service and satisfaction with transit service

A large body of transportation research has focused on the economic, time and service factors associated with transit use. Quality of transit service is a complex multidimensional concept. Ease of access to stop and stations and short walking distance, speed of travel, reliability, comfort, frequency of service, wait time, relative travel time and costs across available options are all referred to in the literature as elements of quality of transit service that influence the choice to use transit (Cervero, 2001; Ben-Akiva and Morikawa, 2002; TRB, 2003; Badoe and Yendeti, 2007). Some of these concepts, such as distance to transit, have been studied more frequently, while others have proved harder to assess.

Personal preferences, as well as opportunities and constraints in decisions regarding housing location choices and travel have been the subject of more recent research. Living in areas and going to places where public transit use is feasible and competitive with car travel can sometimes be difficult for many households (Reconnecting America, 2007). Income and competing needs and interests can limit a person's ability to locate near transit service that meets their travel needs, even though they would want to live near transit. These individuals can be considered as mismatched with respect to public transit service. This limited ability to locate near public transit will be referred to as transit-housing match in chapter 4. Satisfaction with access to transit service can be assessed with respect to this transit-housing mismatch.

In order to use transit as a primary mode of transportation, transit service must be accompanied by good pedestrian access and nearby opportunities. A supportive transit environment maximizes opportunities near home, transit hubs and common destinations, and minimizes motorized trip making. An ideal condition for transit use, it is posited, is one where transit users do not have to make a transit trip to access each of the multiple desired and required destinations, since many opportunities are available near home or near other frequent destinations. Clusters of destinations are supportive of transit use from a user-demand perspective. A supportive transit environment is therefore an environment where: a) a person can reach all needed and most desired destinations within reasonable time with frequent service that spans across the day, b) many potential destinations are congregated near the home, near the most frequent destination (e.g. work, school), and along the way, and c) the transit user does not have to use transit for every trip since walking trips can be taken during a transit journey since many destinations can be accessed on foot.

1.3 Transit use and physical activity

Current evidence on the relationship between transit use and active transportation does not account for the specific characteristics of transit users apart from their socio-demographics. Transit users are more likely to live in walkable areas where they can make local walking trips; they are more likely to take walk trips at their workplace because they do not have a car available; and trips taken by transit are more likely to involve more active transportation. Furthermore, because transit use is so intrinsically tied to walking and the walking environment, there is a possibility that transit users are people that actually enjoy physical activity, or at least that are not averse to it.

1.4 Choice and dependent transit riders and lifestyle differences

Transit agencies seeking to increase ridership sometimes split transit users into categories for marketing and evaluative purposes. Some transit riders use public transit in the absence of other viable alternatives. They are often referred to as transit-dependent. Others have the opportunity to make choices between alternatives, such as using a car, public transit or walking to destinations nearby. They are often referred to as choice riders. Choice and dependent riders are expected to have distinct socio-demographics, lifestyles, housing location, travel behavior and physical activity behavior. Evidently, the latter group may be considerably more sensitive to transit quality of service than individuals not owning a car. Confronted with longer distances to transit, choice riders may decide to forego transit and use their automobile or another alternative. For transit-dependent riders, on the other hand, greater walking distance to transit may translate into more active transportation. This increase in walking could however negatively impact the practice of other forms of physical activity.

1.5 Research questions

1. How does housing location choice influence transit use, and what transit quality of service factors support transit use?

- How important is housing match and satisfaction with transit quality of service at home in explaining the choice to use transit?
- What factors are associated with the importance of transit in neighborhood choices?
- What factors are associated with being satisfied with access to transit service?
- What factors are associated with the probability of using transit?

These questions are explored in chapter 4.

2. What are the relationships between transit use and walking, and what mechanisms are involved?

- Is there an independent relationship between commuting by transit and objectively measured physical activity?
- (Mechanism) Is there evidence of a moderating effect of transit use on the relationship between the built environment and walking?
- (Mechanism) Do transit-dependent riders practice more active transportation than their choice rider counter-parts?
- (Mechanism) Does walking for transportation substitute or displace other physical activities? Is this relationship different for choice and dependent transit riders?
- How do personal attitudes such as enjoyment of physical activity and perceived lack of time for physical activity influence these relationships?

These questions are explored in chapter 5 and 6.

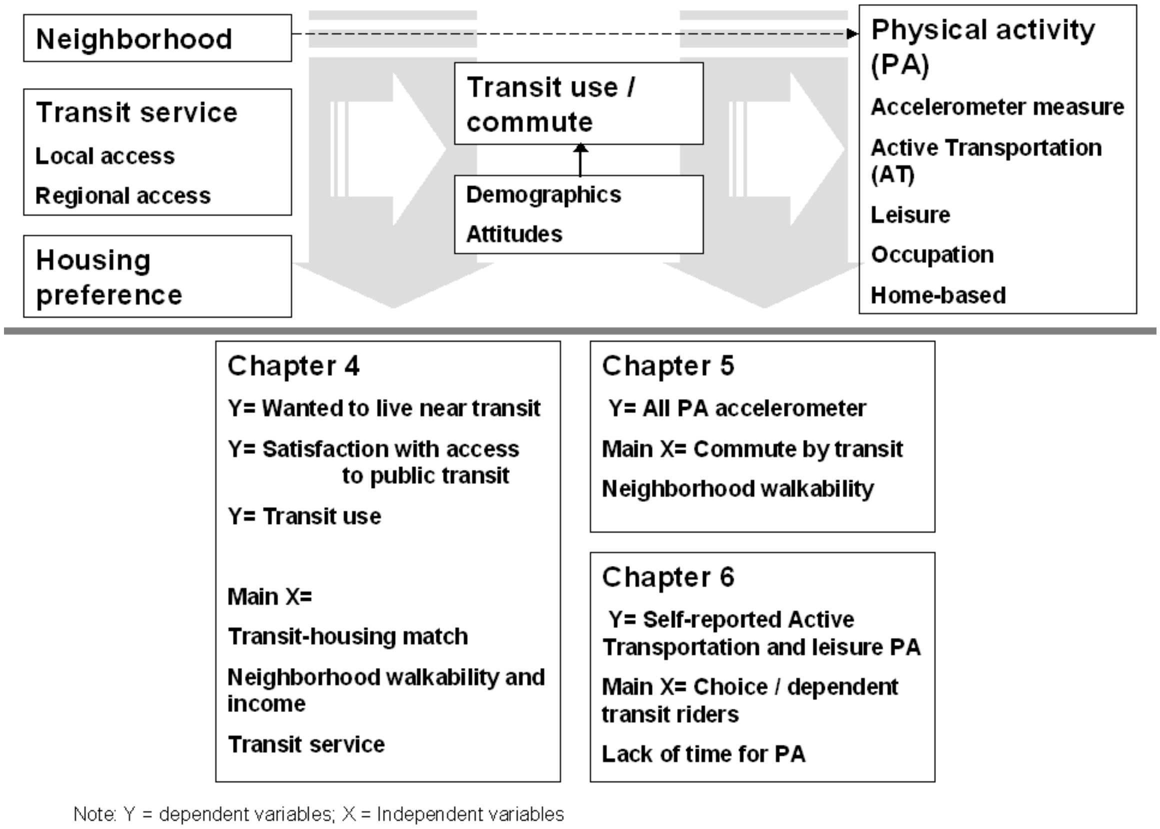
1.6 Presentation of chapters

Before continuing to the core chapters, the reader is reminded that this is a manuscript-based thesis. A manuscript-based approach is used with the following consequences. First of all, the terminology and angle used may vary between manuscripts as they are written for journals that target either planners or public health practitioners and researchers. The targeted journal will also influence the structure of the articles, table formats and titling as well as the citation format. Working across fields of research that have distinct concerns, use different vocabulary and forms of displaying evidence may make separate chapters seem less cohesive. Directly preparing journal manuscripts also ensures a timely dissemination of results in a competitive research environment.

In chapter 2, the theoretical framework, existing evidence and analytical framework are presented. A description of the data sets and statistical methods used in the analyses is presented in chapter 3.

The three empirical chapters of this thesis provide distinct, yet cohesive elements of analyses on the transit use and physical activity relationship (Figure 1.1). Two chapters address the relationships, and are preceded by an assessment of the neighborhood features associated with transit use, and the long-term housing location process that enables (or not) individuals to locate near transit and to choose transit use.

Figure 1.1 Analytical model and associated manuscript chapters



In chapter 4, transit use was explored as a precondition to the studied association with active transportation using the Seattle sample. Personal characteristics such as car ownership and income, and quality of transit service are known factors associated with the probability of using transit. A retrospective assessment of the important factors in housing location choice, and objective measures of transit service near the residents' homes, were used to develop transit-housing match categories and estimate associations between attitudes and transit use. Characteristics of pedestrian environments associated with walking are assessed for associations with transit use. The ability to locate according to preference for transit was not always met. Individuals had to make trade-offs in housing location which prevented them from locating near good transit service. Yet not having located near good transit service was not significantly associated with a lower probability of using public transit. Instead, transit use likely occurred in less than ideal conditions. Provision of different types of housing opportunities (e.g. for smaller households and larger families) of a variety of price ranges within transit access is likely required.

The relationship between transit use, transit service and walkability was described to set the stage for an analysis of how transit use may modify the relationship between walkability and physical activity. As not all transit users were able to locate near good transit service, some transit users living in low walkability neighborhoods with limited transit service may have walked long distances to have access to transit service. In chapter 5, employed individuals working outside the home were used to assess the associations between commuting to work by public transit, and overall physical activity in neighborhoods of high and low walkability. Physical activity was measured objectively by accelerometers and included any form of activity. The analysis was stratified by neighborhood walkability. Transit commuters, especially frequent ones, were found to have the highest levels of physical activity. Transit users living in low walkability had higher mean physical activity levels than those living in higher density neighborhoods, what was shown to be a product of longer walks to neighborhood destinations, and likely to transit stops or stations. These associations were assessed when controlling for socio-demographics and enjoyment of physical activity. As all forms of activities are joined in one accelerometer measure and an association with transit use are still identified, the results suggest that the higher levels of walking associated with transit use were not counter balanced by less practice of other forms of physical activity, a point further explored in chapter 6.

In chapter 5, employed individuals working outside the home were assessed on the associations between commuting to work by public transit, and overall physical activity. Physical activity was measured objectively by accelerometers and included any form of activity. The analysis was stratified by neighborhood walkability. Transit commuters, especially frequent ones, were found to have the highest levels of physical activity. Transit users living in low walkability had higher mean physical activity levels than those living in higher density neighborhoods. These associations were assessed when controlling for socio-demographics and enjoyment of physical activity. As all forms of activities are joined in one accelerometer measure and an association with transit use are still identified, the results suggest that the higher levels of walking associated with transit use were not counter balanced by less practice of other forms of physical activity, a point further explored in chapter 6.

In the previous chapter, the use of an accelerometer-based measure was presented as having both strengths – because of its objective nature – and as a limitation, because of its inability to differentiate between purposes of physical activity. In chapter 6, self-reported measures of physical activity were used to isolate active transportation from other forms of physical activity. Furthermore, a more detailed scrutiny of the potential influence of car ownership on active transportation is required to address the concept of transit dependence present in transportation research. Individuals were categorized into four transit markets based on car availability and reported transit use over the past month: Choice and dependent transit riders, car exclusive travelers and potential transit market. This enabled an analysis of the differences between choice and dependent transit riders. A time use perspective suggests that individuals, based on their characteristics, may use time differently, be associated with different levels of physical activities, and perceived lack of time for physical activity may have a larger influence for some transit markets, namely the transit-dependent riders.

In chapter 6, I demonstrate that transit-dependent riders had the highest levels of active transportation. There was a positive association between active transportation and leisure physical activity, although longitudinal panel data is required to ascertain displacement. Results nonetheless suggest that transit-dependent riders' active transportation levels are not likely to reduce the amount of leisure physical activity they practice. Transit-dependent riders were however associated with the highest negative influence of lack of time on the practice of leisure physical activity. A conclusion unifying each analysis will be presented in Chapter 7.

1.7 Conclusion

Improving access to public transportation is central to creating healthier, more inclusive and sustainable cities. By jointly considering importance of transit in housing choices, distribution of access to transit, and the choice to use transit and practice active transportation, I hope to provide a more complete picture of the lifestyles, needs, opportunities and constraints of transit users. While public transit currently has a low mode share in most North American cities, promoting a mode shift to public transit is supported by many jurisdictions at the local, national and international level (TRB, 2001; OECD, 2001; WHO, 2000; Cambridge Systematics, 2007). Increasing the share of transit users may reduce per capita energy consumption and green house gas emissions (Ewing et al., 2007). Provision of transit in cities can increase the number of people having good access to transit and decrease the proportion of people that have to own and operate a car for lack of adequate transit service. Many health benefits can be associated with increases in all forms of physical activity. The combination of transit use and active transportation, while contributing to addressing environmental and social issues, may also provide considerable health benefits.

1.8 Contribution to knowledge

The work produced as part of this research finds an audience broader than that of urban planning. This PhD project contributes to the fields of public health and active living research, transit planning and travel behavior research. It can also support equity planners in increasing social inclusion through the provision of better access to transit service. Several contributions to theory and practice emerge from this thesis. The most important are to provide detailed evidence of the association between transit use and active transportation, to provide an exploration of the different types of transit users and their activity patterns to assess the contribution of attitudes towards transit use and physical activity, to assess ability to locate near public transportation, and to document the relationship between neighborhood walkability and transit use.

Through this project, I seek to complement the theoretical framework of active living research, and its association with transit use. Through an in-depth exploration of public transit use and associated active transportation, the work presented here provides new evidence that substantiates and elaborates on the current active living theoretical framework. This exploration includes an analysis of access to transit service as measured by self-reported constructs and objective measures of transit service, and how they relate to transit use. The transportation context is further evoked by a description and analysis of individual travel opportunities and constraints using the concept of transit dependence.

The field of public health has directed much interest in the association between physical activity and the built environment. Many of the tools and policies that favor active transportation, however, rest in the hands of urban and transportation planners. If the results of this analysis supports that transit use can serve as a catalyst for an active lifestyle, albeit in a cross-sectional research framework, public health authorities may seek to target social marketing towards promotion of transit use. They may also appeal to urban and transportation planners to strengthen the provision and distribution of transit service for its health and social inclusion benefits.

This research can provide valuable information to policy-makers and is consistent with current policy orientations. For example, the Transportation Research Board suggested in a report on surface transportation environmental research: “The nation must find a way to deliver a transportation system that simultaneously promotes economic growth, adds to the health of communities and individuals, uses energy efficiently, is inclusive, and enhances the natural and built environments” (TRB, 2002; Page 2). By exploring inability to locate near transit, as well as the distinct lifestyles of choice and dependent riders, the results presented in chapters 4 and 6 provide evidence that transportation systems can be more inclusive. The assessment of physical activity and active transportation presented in Chapters 4 and 5 addresses the question of the health of communities and individuals.

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Chapter 2 Theoretical and analytical frameworks

The objectives of this chapter are to present the theoretical frameworks used in the analyses, provide context to the research and frame the hypotheses within existing theories and evidence. The thesis draws concepts from five theoretical frameworks in order to capture complexity in the relationships being studied (Table 2.1).

Table 2.1 Theoretical frameworks used in empirical chapters

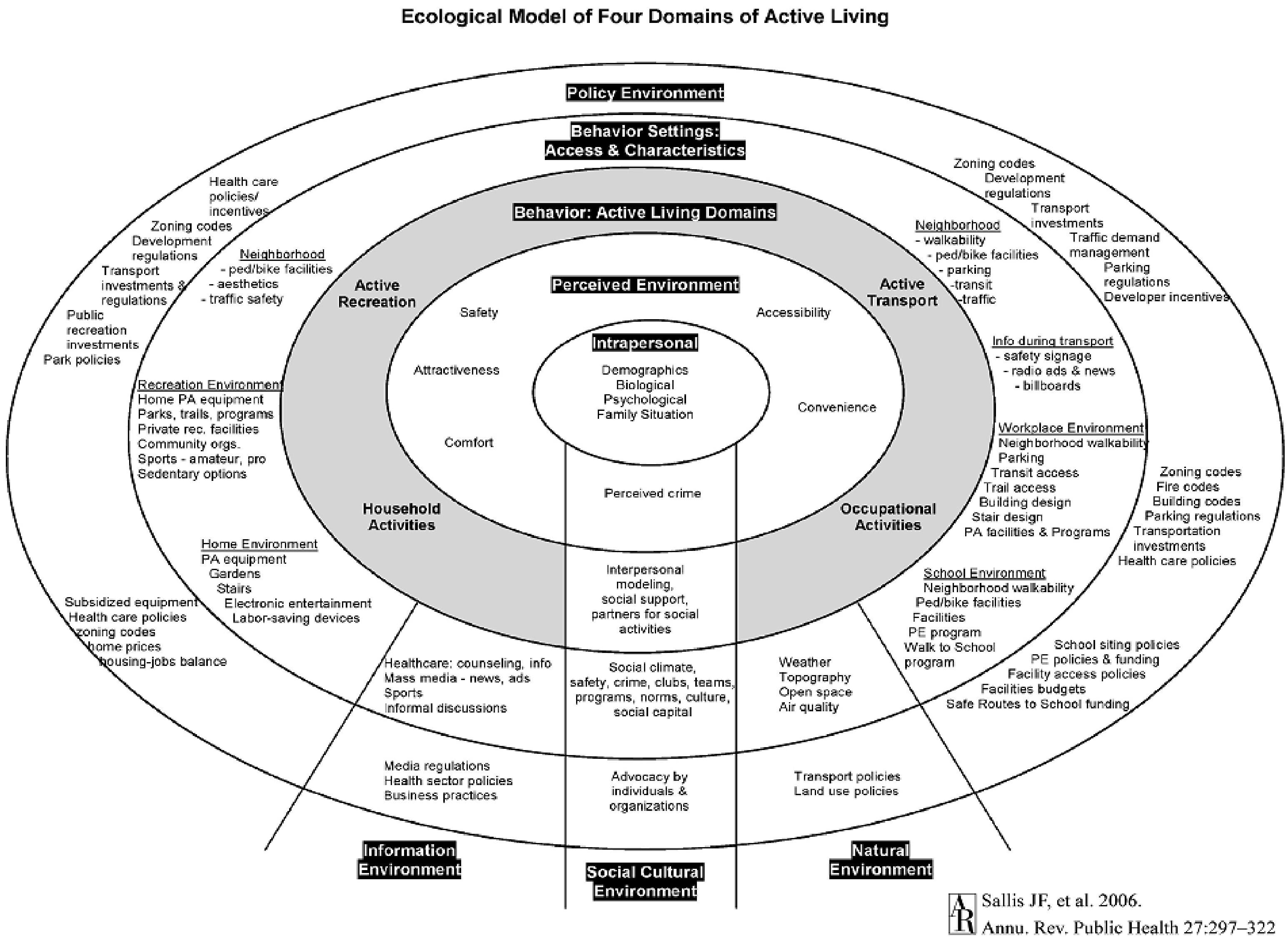
Chapter	4	5	6
Ecological model of active living (Sallis et al., 2006) – a social-ecological model of behavior		X	X
Consumer choice theory applied to transportation (Domencich and McFadden, 1975; Ben-Akiva and Learman, 1985; Meyer and Miller, 2001)	X		
Travel disadvantage (Lucas, 2006) transportation equity (Sanchez and Brenman, 2007) and transit dependence (Bullard et al., 2004)			X
Time use, allocation of time and activity displacement (Becker, 1965; Michelson, 2005)			X
Psychosocial determinants of behavior: attitudes, preference, and inclination (Gärling et al.2002; Stradling et al., 2000; Stradling et al., 2007)	X	X	

2.1 Physical activity and the built environment: the Ecological model of active living

Much attention has been given to inactive lifestyles in recent years and public health specialists have turned to the promotion of moderate physical activity (such as active transportation) to increase the share of active individuals (DHHS, 1996). **Active transportation** is the practice is physical activity for the purpose of accessing a destination. Walking, and cycling for example can be considered forms of active transportation if they are practiced for a utilitarian purpose (defined as *active travel* in the TRB-IOM, 2005 report). In the transportation literature, active transportation is often referred to as non-motorized transportation.

Approaches to addressing the lack of physical activity have been focused on the effects of social, cognitive, behavioral and environmental factors in shaping a person's lifestyle. The ecological model of active living presented by Sallis and colleagues (2006) integrates these factors in an concentric model in which the center is the individual and the superimposed rings represent proximate and distant factors affecting their behavior (Figure 2.1). The behavior of interest, physical activity, is represented in the model by a gray ring, at the interface between individuals and their environment. In this model, physical activity can be achieved during leisure time activities, during home-based activities, at the workplace and for active transportation. Individual, interpersonal and household correlates lie inside the circle, and shape the individual perceptions and preferences that interface behavior. The actual behavior setting, the built environment, and the policy environment are considered as external correlates of physical activity. The general types of correlates of physical activity can then be divided in more specific correlates relevant to the type of physical activity measured. As such, the ecological model provides a flexible framework allowing the formulation of hypotheses to study specific associations. Individual perceptions, the behavior setting, transportation and land use policies (e.g., zoning) can all be modified to enable the practice of physical activity.

Figure 2.1 The ecological model of active living (Sallis et al., 2006)



This thesis draws from the ecological model of active living, and integrates access and consumer choice frameworks common to transportation planning. A number of papers have discussed the dual source of analyses of associations between active transportation and the built environment to stimulate collaborations and expand the scope of research (Sallis et al., 2004; Saelens et al., 2003; Frank et al., 2004; Vernez-Moudon, 2005; Coogan and Coogan, 2004). Yet most empirical analyses to date still use separate models depending on outcomes, without much actual integration of frameworks.

2.1.1 The built environment

Cities are built and evolve incrementally over time. Population, commercial areas, employment, civic uses and green areas are rarely distributed evenly across space. Transportation networks further unite spaces, and divide others, giving structure to a regional ensemble. Within a region, distinct areas may be described as **neighborhoods**. Depending on definitions, neighborhood boundaries may vary. Boundaries can be defined politically (e.g. electoral districts, wards), based on service areas and utility distribution, through an areas historical development or common look and feel, or as perceived by individual residents. In this section, I present a brief discussion of the built environment, the quantitative measures used to define spatial features and the concepts and measurement used in research.

Post-World War II America has largely adopted a suburbanization model promoting single family housing on larger lots, connected by discontinuous street networks, with strong separation of land uses (Frumkin et al., 2004). This era marks a break from the traditional forms of development that are found today in central urban areas that have not been subject to massive redevelopment schemes. Such areas typically host multifamily housing, more diverse land use, smaller lots and a grid-like street network. Since the early 1990s, architects and urban designers have promoted a return to this type of traditional design, believing it to be more adapted to city dwellers' needs. Neo-traditional neighborhood design ideas have gained considerable momentum, especially with the work of Peter Calthorpe (1993) on "New Urbanism." Returning to denser, mixed use, smaller, peopleoriented designs is thought to create a sense of community, reduce automobile use, ease travel by foot, and create places that enable a better quality of life. The geographic scale of the built environment is seen as a central element of such designs. Neighborhoods are conceptualized as having a small-town feel and are built at a village scale, providing vibrant public spaces for gatherings and community activities. Streets are lined with sidewalks and most basic services can be access within a five-minute walk (Calthorpe, 1993). While much theorizing has been done on the neighborhood, starting with the work of Clarence Perry in the 1920's, there are still serious limitations to our ability to appropriately measure constructs and their appropriate scales of measurement (Vernez-Moudon et al., 2006). One difficulty is to identify functional neighborhood boundaries.

When studying human behavior in urban environment, the neighborhood is the most intuitive setting. A behavioral setting may be conceived of as the "small localities bounded in time and space within which there is some stable pattern of purposeful human behavior" (Lynch, 1971 p. 13). This description gives little in the way of defining what we need to know to identify the size and boundaries of a proper setting. Lynch does go on to suggest that we need to know the pattern of activity within the site and on its borders, the access to destinations outside the site, and the general circulation system provided by footpaths, sidewalks, roads, highways, railroads and transit lines (Lynch, 1971) that allow circulation within and in and out of the setting.

Conceptualization of the environmental factors that affect physical activity and travel patterns as human behaviors is a relatively new field of inquiry. While transportation research has developed concepts and measures, the larger scale of the built environment used to study auto travel is not appropriate for the study of non-motorized transportation and physical activity. Developing adequate quantitative measurement has proven to be a complex and persistent problem. The Transportation Research Boards' report on physical activity and the built environment (2005) identified the following questions:

- What are the settings where walking takes place?
- What setting area matters and at what scale should it be measured?
- What concepts should be measured to define neighborhoods?

It is this complex array of locations, scales and neighborhood features that we attempt to account for when we measure the built environment. Neighborhood scale can be defined using administrative area boundaries, such as census tracts, or block groups, or be defined using a threshold distance from a person's home. Measures should be designed to use existing available information whose evolution can preferably be followed over time, and be sensitive to observable changes. Finally that can be associated with policy issues and levers.

Urban form, or neighborhood type, has been measured qualitatively, by field description, and quantitatively, by compiling measures of different land use indicators (Pikora et al., 2003). Quantitative measures of neighborhood features are inspired by qualitative assessments of residents' perception of their neighborhood. Studies usually rely on descriptive and inferential statistics to evaluate the relevance of certain factors (independent variables) to the differences measured in specific human outcomes (dependent variables). Multivariate analyses enable researchers to control for potential confounding factors, often related to household or individual characteristics.

2.1.1.1 Measuring the built environment

Geographical information systems (GIS) have been an important tool for research on the built environment and its relationship with human behavior. Geographical Information Systems are now commonly used for the spatial analysis of land use, transportation networks, and other physical features (Forsyth et al., 2006b). Spatial analysis is the study of relationships between features as they coexist in space in terms of distance to other features, network access points, co-presence of other features in space, adjacent presence and other physically relevant factors (Forsyth et al., 2006b). These tools can be used to develop measures of theoretically derived neighborhood features of importance. Spatial information is contained in layers that can be overlaid, linked, and serve to develop composite measures through various procedures available in commercial software. For example, one may identify points contained within areas, or lines passing through areas (intersecting) or calculate areas of different types within a study area (e.g. calculating the sum of areas of parcels within a zone based on parcel type – residential or commercial for example). Calculated features may then be attributed to the area of analysis. For example, data pertaining to a census tract can be associated to its physical area, and data pertaining to a specific individual can be associated to the address of its place of residence or to an area surrounding the residence. Measures developed from an area may also be attributed to a point representing a specific location (such as street address), a household or an individual.

Government agencies increasingly rely on geocoded inventories of assets and infrastructures. **Geocoding** refers to associating a feature and its characteristics to a spatial location, through the assignment of latitudes and longitudes to an individual point line or polygon. At the city level, a plethora of information on terrain, road networks, land parcels and urban infrastructures is available in some but not all jurisdiction. Provided individual survey or other forms of data on human activity can be associated with areas, or point locations in geographic space (through geocoding), individual and household information may be combined with physical environment features.

Density of population or employment, land-use mix, connectivity of road networks, street scale design and aesthetics qualities are all elements that are theorized to be associated with travel behavior and physical activity. They also usefully relate to policy levers that planners can influence. These concepts are summarized in Table 2.2.

Table 2.2 Design elements of the built environment and their description

Concepts	Description and relevance for walking and travel
Density	Density represents the amount of activity in an area. It is calculated as a number of units per area. Units can be population, employment and commercial densities. Density captures agglomerations that increase service proximity in an area.
Retail floor-area ratio	Floor-area ratio, another indicator of density, expresses the ratio between commercial building floor space on a parcel and the size of the parcel itself. It serves to indicate if the commercial area has lots of parking space.
Land use mix	Neighborhoods have different primary functions that are reflected in the distribution of land uses. Some areas are developed for single use and others combine multiple land uses. The relative proximity and diversity of land uses in an area may affect access to the services by different modes. Land use mix therefore captures the ease of getting from one destination to another by walking.
Street connectivity	Represents the directness of routes, the availability of alternative routes and the patterns of development and movement in an area. It is often measured as the density of intersections in an area. The presence of Freeways and highways may block connectivity for pedestrians and increase connectivity for cars, while paths, trails and traffic calming may improve connectivity for pedestrians. Low connectivity may reduce access to possible destinations within a specific distance in all directions, and increase travel distance between destinations.
Street scale design	Captures the three-dimensional space on and along a street. In effect, it represents the "pedestrian friendliness", or ease of walking of an area. Building setback, street width, a ratio between building heights and street widths, the presence of sidewalks, medians and pedestrian islands reflects street scale design.
Aesthetics qualities	The qualities that contribute to the appeal and attractiveness of a place, from street furniture (lighting, benches, garbage cans) to landscaping of buildings, to the size, diversity, materials and orientation of windows on buildings along the streets. Although approaches to measuring them exist, they are not discussed here.

Source: adapted from Ewing and Cervero, 2001; Handy et al., 2002; Krizek, 2003; Frank et al., 2003; Frumkin et al., 2004; Lee and Moudon, 2004.

The way in which these concepts are measured can have considerable impact on the distribution of values in a region, and on the sensitivity of the studied outcome to changes in the built environment variable. Built environment concepts are now presented in greater detail.

Density. Density may be conceived of in two different ways. One may choose to assess the density of a feature over a total land area (gross density) or over the area specifically attributed to that use. Net residential density is measured as number of households per residential acre within an area, whereas gross residential density is measured as the number of households per total area. Measures can also make use of population counts instead of number of households, dwellings or families. The same goes for employment or commercial density. A low-density neighborhood is typically difficult to serve by transit (TRB, 2001). This reveals a difficult issue that is seldom mentioned and that has yet to be resolved in most studies. The area of a parcel or the footprint of a building may not fully reveal its actual content since tower development result in much higher densities and mixed land uses within the same parcel. Multi-story buildings with residential and commercial use render this problem even more complex since it becomes difficult to obtain and properly account for the actual areas dedicated to specific uses. "In the future, as activities increase, we may turn to measures of cubic density: intensities per unit of volume" (Lynch, 1971 p.33).

Floor area ratio. The retail floor area ratio (FAR) is another indicator of neighborhood design that reflects density of commercial uses in an area. It represents the ratio of the surface of a store area to the surface of the parcel in which it is located. The FAR therefore accounts for the size of parking space on the parcel, thereby distinguishing between neighborhood type stores, with little parking space, and "big box", or commercial centers.

Land use mix. Land use zoning was originally created to separate industrial uses from residential areas, as a public health measure designed to prevent residents' exposure to industrial fumes (Frumkin et al., 2004). Today's service economies have allowed the multiplication of uses that can coexist beneficially with residential land uses. Indeed, many commercial and service uses are compatible with residential uses and may enhance the quality of life in a neighborhood by bringing activities closer to one another and reducing time required to access them. Land use mix is a measure of the proportion of different types of land uses in an area. Uses are typically expressed in a number of levels of hierarchical classification. Residential, commercial, retail, office, industrial, and public services are only some of the highest order classification available. Retail areas, for example, could encompass sub-categories such as food stores, clothing or restaurants. Land use mix is commonly measured using the normalized entropy index (Cervero, 2001; Ewing and Cervero, 2001; Krizek, 2003; Frank et al., 2004a; Frank and Pivo, 1994; Cerin et al., 2007) and takes the following mathematical form:

$$LUM_z = -\sum_{i=1}^{n}\left(p_i * \ln p_i\right) / \ln n$$

Where p_i is the proportion of land area or building square footage attributed to land use *i*, and *n* is the number of land uses in the zone *z*. This general formula allows researchers to account for the different number of land use types that may be found in a given area (Frank et al., 2004). A more specific formulation may only test the relevance of a determined number and types of land uses present within the area. The values of the index theoretically range from 0 (single use) to 1 (equal mix of all land use type available inside the buffer). Other ways to measure land use mix have been proposed (Guo and Bhat, 2007; Eid et al., 2007) but the entropy formulation seems to have gained popularity in multiple fields of inquiry.

Street connectivity. The third concept, street connectivity, is a transportation specific measure and refers to the relative ease and presence of options for getting from one point to another. It is frequently measured by the number of intersections per square kilometers in the area or sometimes by the block size. Higher intersection density reflects a grid shaped neighborhood that allows more route options, and more direct routes form origins to destinations. This may be beneficial to travel, both motorized and non-motorized, albeit at different scales. However, the characteristics of the built environment are likely to have collective and interactive effects on the availability and use of certain modes (Ewing and Cervero, 2001). Higher density, higher land use mix and higher connectivity in the neighborhood of residence are often linked to more walking (Frank et al., 2005; Chapman and Frank, 2004), supporting the interaction hypothesis. This however raises the analytical problem presented below.

Walkability index. To evaluate relationships between the built environment, travel, and physical activity, land use measures may be assessed individually, or be combined into a composite measure. Because these concepts occur jointly in space and are often highly correlated, the creation of an index may be more appropriate. Residential density and intersection density are often strongly correlated with each other, and land use mix also tends to be associated with population density. These associations may theoretically bias coefficient estimates in regression models. The walkability index is an example of a composite measure (Frank et al., 2004; Frank et al., 2005; Frank et al., 2009) and was designed to reduce problems related to multicollinearity (Frank et al., 2004). The walkability index combines four measurements aggregated at the 1 km network buffer level: intersection density per square mile, net residential density, land use mix and retail floor area ratio. Each value is individually normalized and they are added together to form a continuous measure. Higher values signify greater walkability. Independent associations between individual factors are however lost.

Research has identified associations between numerous characteristics of the built environment and different forms of physical activity. Many reviews of these existing studies are available (Frank et al, 2003; Dannenberg et al., 2003; Saelens et al., 2003; Lee and Moudon, 2004; Sallis et al., 2004; TRB, 2005) and generally attribute some degree of confidence to the relationships while pointing out the needed disentanglement of causation from self-selection effect. The problem of self-selection will be described later.

2.1.2 Measuring walking and other physical activities

Physical activity, human kinetics and recreation researchers, seeing the limited success of exercise programs to gain high numbers of adherent, have turned their attention to promoting more moderate forms of physical activity including the practice of walking (Frank et al., 2003). Walking is the most common of all forms of physical activity since it requires no equipment and can be integrated into everyday life both as a form of leisure, and as a form of transportation.

Numerous methods are used to measure physical activity. I limit the present discussion to those used to measure walking, both utilitarian and leisure-related. Three reasons outline this choice. First, surveys frequently report walking as the primary form of physical activity. Second, the bulk of literature on the relationship between physical activity and the built environment aims at measuring walking (TRB, 2005). Third, with a few exceptions, these approaches may also be used to measure cycling, another form of physical activity and transportation. Various techniques used to measure walking and their advantages and limitations are presented in Table 2.3.

Table 2.3 Measuring walking: description, limitations and advantages of approaches

Technique	**Description and example**	**Advantage**	**Limitation**
Self-report in diary logs or in recall surveys	In diary logs, respondents report activities in a table. Each activity is a row. Duration, activity type and co-presence are typical attributes. In other cases, average values over a month are reported	Commonly used since they are easy to administer, inexpensive and acceptable to study participants. Recall surveys are simpler to fill up because they are more targeted. Diary logs are more time consuming, but may be used for more diverse research purposes.	*Accuracy:* Vigorous activity is often more accurately reported, whereas moderate activities are sometimes less defined and sporadic, and it may be unclear to the respondent as how to define what counts as physical activity, and what doesn't. *Bias:* Subject to recall bias and to the sampling of a non-representative period of recall or group. It also tends to overstate actual physical activity. *Misrepresentation:* Survey respondents may give socially desirable instead of completely truthful answers.
Behavioral observation	Using qualitative ethnographic style observation practice in a specific setting.	This qualitative method may be used to enhance theoretical constructs and identify the diversified situations that may arise when walking for leisure or travel within a city.	Behavioral observations are rare in the literature since they are so time and labor intensive. Examples are mostly found in earlier writings such as Lynch (1971) and Appleyard (1981).
Mechanical or electronic devices such as pedometers or accelerometers (step counters)	Worn on the hip. Using inertial or mechanical sensors. Used to detect and measure the wearer's motion and vibration as a proxy for physical activity.	Mechanical devices are increasingly becoming popular, because their accuracy levels can be measured and since they provide an objective measure that is less subject to recall bias or to faulty representation. Also requires smaller commitment from respondent.	Devices are expensive, and still experience difficulties in accurate measurement. May encumber the user or the user may forget to wear it. Accurately measures physical activity levels but not what kind, for what purpose, or where the activity is made. Still requires information from the individual in the form of a survey.

Technique	Description and example	Advantage	Limitation
Electronic devices such as Global Positioning System (GPS).	Device using remote sensing to identify and record distance, speed and trajectory. Based on positioning on earth surface with respect to at least three GPS satellite signals.	Very accurate account of origins, destinations, trajectories and travel speeds. GPS requires very little input from the participant and accounts for all the movements within a given day. Devices are becoming more and more compact and can be joined to other instruments.	GPS technology still has limited ability to measure movement inside buildings or in highly dense areas where satellite signals may be blocked by infrastructure. GPS is so accurate that it may pose privacy concerns for respondents. It also requires a considerable amount of post-treatment to identify travel modes. Still requires information from the individual in the form of a survey or diary.
Indirect measures (often in laboratories) of actual physiological responses.	Measures such as maximal oxygen intake; heart rates, etc.	Allows to link physical activity directly to physiological processes	Lab measures can only be done for small samples (expensive and high human resources). Subject to long and complex ethical reviews. Unnecessarily complex for understanding the relationship between the built environment and physical activity.

Source: compiled from TRB, 2005

Although the tendency is to move away from self-reports and to make more frequent use of objective measures of physical activity, a combination of both objective and subjective measures may be complementary. First, while objective measures may provide more accurate details on the location of walking and the distance traveled (in the case of GPS data) or activity time and intensity (accelerometers), they lack the ability to record the purpose of activity. Second, both types of measures may be compared for validity, reliability and discrepancies (Gorman et al., 2009).

2.1.3 Public transit use and active transportation: existing evidence.

Active transportation can be a considerable source of physical activity, especially for inactive population (Giles-Corti and Donovan, 2002). Increasing the proportion of purposeful trips made by walking is considered a feasible way to increase levels of moderate physical activity (Sallis et al., 2006). For many inactive people, walking is the most feasible means of harnessing the benefits of a physically active lifestyle. This incursion into the physical activity/transportation connection has influenced the more specific study of public transportation use. The literature on the relationship between using public transportation and walking is still scarce and much remains to be explored.

Evidence suggests that using transit indirectly supports walking, since trips to access a transit stop or station and trips from public transit to a destination are frequently walked (Frank, 2004). Besser and Dannenberg (2005) found that 29% of American transit users met physical activity guidelines solely by walking to and from transit stops or stations. Transit use has also been associated more broadly with meeting physical activity guidelines as measured over a full week (Vernez-Moudon et al., 2007). One study to date has used a pre-post design to assess relationships between transit use and physical activity. The addition of a light rail transit station in a neighborhood resulted in the new transit users walking more than they previously did (Brown and Werner, 2007).

When comparing transit commuters to car commuters in New York, Wener and Evans (2007) found that transit users walked more than car commuters and were 4 times more likely to reach 10,000 steps per day (measured by pedometers). Similar results were found when looking at a sample of Australian University students' commuting and walking patterns (Villanueva et al., 2009). Those using public transit to get to University were more likely to reach the 10,000 steps necessary to meet physical activity guidelines. Lachapelle and Frank (2009) also found that additional transit trips reported in trip diaries were positively associated with meeting physical activity guidelines of 30 minutes a day (Odds ratio 3.42) (walking was measured as a path distance between reported origins and destinations and categorized to insufficient and sufficient walkers), but that additional car trips were negatively associated with such outcomes.

This evidence provides a solid starting point to the analyses presented in this thesis. Much remains to be explicitly addressed in order to better understand the mechanisms responsible for associations between transit use and physical activity. A few of these concepts are presented in the thesis.

2.2 Time use

In order to appropriately study travel-related behavior and participation in physical activity, the concept of time and time use must also be considered. According to Hagerstrand's model, travel occurs in space and requires a certain amount of time. Both are strongly intertwined. "Time use occurs within parameters of space, and the need to move through space prioritizes the use of time. Conversely, different locations in space are related to each other within limitations of time" (Michelson, 2005, p.156). With his proposed law of constant travel time, Hupkes (1982) suggested that individuals allocate a certain amount of their time budget to travel. If travel times were reduced, the available time would be used to travel farther, or using slower modes. Inversely, longer travel time by the most popular mode, may reduce the potential allocation of time to other modes of transportation.

Time use analysis enables an understanding of the ways in which we use the spaces that surround us. Activities take place in different settings that need to be accessed, and only a limited amount of time is available to carry out daily activities. It is therefore understandable that people value quick and easy access. Travel time is distributed between time spent at the place of residence, travel time and time spent in exterior environments. The distance between locations and the efficiency of transportation modes affording access to each location can have an important effect on the availability of time remaining to undertake other activities. Much of our daily time is already committed to essential or high priority activities: sleeping, eating, childcare and working for sustenance. These may generate non-discretionary travel. We then make tradeoffs between different activities with the remaining fixed amount of "free time" and prioritize necessary over desired activities (Michelson, 2005). This discretionary time will be used to partake in active and sedentary forms of leisure (Pratt et al., 2004). It may also be used for discretionary travel.

Together, time and space present three major constraints on travel. First, one can only go so far and has only so much time available in a day. Second, one may require the proximity of a sufficient number of people in order to carry out an activity within a specific time frame (this is referred to as coupling constraints and is less important to the discussion in this thesis). Finally, time and space are constrained by human authority: laws, legislations, policies and private decisions that manage the availability of activities (e.g., store opening hours, curfew, congestion, transit service span during a day) (Michelson, 2005). Time use is a matter of making personal choices within this set of constraints. Its study allows researchers to better understand the tradeoffs made in everyday life. Time use data can tell us a lot more than how people use their time and can help us understand the society, political system and infrastructure in which individuals live (Michelson, 2005). In the context of research on walking, time use can capture both travel behavior and physical activity behavior better than travel (Kitamura et al., 1997) or physical activity surveys (Godbey, 2005).

The SLOTH model, which takes into consideration Sleep, Leisure, Occupation, Travel and Home maintenance activities, provides a framework to understand tradeoffs in daily activities and the policies required to influence specific activities (Pratt et al., 2004; Frank, 2004).

Because travel is largely understood as a demand derived from the demand for other activities that require traveling to, the trip based approach to travel surveys is now being surpassed by activity-based travel surveys, which record total time spent during a day, participation in activities and travel between activities (Kitamura, 2005). In a study conducted in Australia using the National Time Use Survey, Tudor-Locke and colleagues (2005) set out to examine the patterns and relative contributions of the two types of walking (walking for transport and walking for exercise) to achieving recommended levels of physical activity (30 minutes of brisk walking, on a daily basis). Those who walked for exercise reported longer bouts of exercise, but a higher percentage of participants walked for transport. Authors concluded that planning interventions that favor walking for transport could reach populations that rarely exercise. When analyzing only the subset of people who walks only for transportation, the “doers”, Tudor-Locke and colleagues (2005) found that accumulated durations (≈28 mins/day) approximate public health guidelines. Lower income populations walked more than higher income populations for utilitarian purposes. This points to their limited access to private and public motorized transportation. They also walked less for leisure, suggesting that they either lacked time or interest for leisure or lived in areas where leisure activity was inhibited by lack of infrastructures like parks and trails. This research was however not directly linked to measures of the built environment, nor did they evaluate the question of activity displacement.

2.2.1 Activity displacement

Within a limited time budget, the trade-offs made between activities may involve **displacement** between different forms of travel (mode and distance), between different form of activity, and between leisure- or transportation-related walking. It is however likely that some travel may serve its own purpose; that is, some people enjoy driving around for the sake of driving, others enjoy walking or cycling as forms of physical activities (to the extent that they are practiced along the road network, they may be considered as travel. After all, even a walk in the park requires traveling to the park). Some people may purposefully engage in more driving or walking then they *need* to. A person may also walk not only to get to a destination, but also for the mere pleasure of enjoying walking or strolling. This second set of people may later decide to forego a session in the swimming pool, having already completed a physical activity session. Walking trips can advantageously substitute for car trips when distances allow it. However, a careful researcher must ask whether the walking accomplished for utilitarian purposes is traded-off against other physical activities usually programmed into a person's daily life.

Both transportation and health perspectives can gain from understanding the phenomena of activity displacement. From a transportation planning perspective, it is important to understand whether car trips are really substituted by walk trips, or if additional walk trips are added to a person's overall travel. For public health research, it is the overall amount of physical activity being done that counts. If someone foregoes a jogging session at night for a considerable walk during lunchtime, taken to save time, a displacement phenomenon is at play and total levels of physical activity are modestly changed. With a limited time budget, people may feel they do not have the necessary time to engage in physical activity. Accordingly, some would choose to displace other physical activities with leisure walking near their place of residence, since it is a much less time and equipment intensive activity. Additionally, they may choose to substitute leisure walking for utilitarian walking to save even more time. Accordingly, a person would choose to walk to different errands to pursue useful activities while at the same time spending time being active. Walking as a mode of transportation to work or for other utilitarian purposes has declined over time, but in many instances, walking may be increasing for leisure and recreational purposes (TRB, 2005).

2.3 Transportation framework

The transportation framework is inspired by economic theories of consumer choices and is grounded in the fulfillment of individual liberties and the maximization of utility. **Utility** is a concept that reflects individual preferences. Individuals make choices to maximize their preferences. Utility, in its basic form, is considered a function of mode-specific pecuniary costs (e.g. tolls, fuel, fare and taxes), as well as non-pecuniary costs such as travel time and distance traveled. Furthermore, pecuniary cost may vary in their form. Costs may be sunk (already expended), or marginal (out of pocket at the time of the trip), and this may influence how they are perceived. With the influence of theories in psychology, individual preferences and attitudes are now being integrated to the utility function (McFadden, 2007). Like the ecological model, the transportation demand framework considers the impact of many factors, ranging from individual socio-demographic characteristics and attitudes, to environmental and policy incentives that may alter an individual's desires and choice of transportation. "Travel is the outcome of a grand confluence of human and other factors, many systematic, and many others not. It will never be fully understood" (Boarnet and Crane, 2001 p.3). Indeed, decisions as to traveling depend on the opportunities available, and opportunities depend in turn on the characteristics, resources, preferences, values and circumstances of an individual. Circumstances are shaped by long, medium and short-term considerations that are intertwined in a complex web of decision-making. "Each commute reflects choices of where to live, where to work, when to work, when to go home, how to get from home to work, and what side trips to make along the way" (Boarnet and Crane, 2001 p.3). As these travel choices may be influenced by how surrounding environments are shaped, Cervero (2002) formalized the integration of built environment characteristics in the utility function of travel modes.

The basic objective of transportation is “to provide access and mobility to residents of an area” (TRB, 2005 p.112). Mobility is most commonly defined as a measure of the performance of a system or mode, in terms of time and speed. Access implies the ability to travel and to reach desired or required destinations. The TRB defines it as the proximity (distance) or convenience of many destination or facilities (TRB, 2005 p.75). While transportation research was traditionally focused on automobile travel, reducing motorized travel has become a central objective of many transportation policies. Furthermore, research is increasingly turning to the analysis of **multimodal networks**, travel networks that unite the use of multiple modes of transportation to take advantage of the qualities of each one in specific circumstances (Meyer and Miller, 2001) and to combine them when possible.

2.3.1 Travel Demand Management (TDM)

Transportation experts are increasingly shifting from an approach based on providing supply to an approach based on managing demand for travel (Meyer, 1999). A number of travel demand management (TDM) initiatives have been used to promote a shift from use of single occupancy vehicles to public transit use and non-motorized transportation (walking and cycling). TDM initiatives can involve modifying the built environment in order to support the use of specific modes of transportation, changing the price of different modes of transportation and using social marketing techniques to promote and stimulate the use of specific modes (Meyer, 1999; Ferguson, 1998; Ferguson, 1999; Potter et al., 2006).

As with the study of physical activity and the built environment, much attention has been given in the past 20 years to the relationships between travel behavior and the built environment. Pioneers include Pushkarev and Zupan (1977) and Frank and Pivo (1994). From an initial almost exclusive concern for automobile, travel surveys have moved to including more diverse modes of transportation with non-motorized travel appearing in the ’80 s. While the rich research produced in this field has garnered much attention, it is still unclear which policies will allow the greater changes in travel behavior and a net reduction in driving (Boarnet and Crane, 2001; TRB, 2005). The process of modifying the built environment is a long and arduous one. Changing the built environment to render automobile use less attractive and provide more destinations within walking and public transit reach is potentially important in shifting current travel patterns and promoting physical activity.

2.3.2 Mode choice

The leading edge of travel behavior research draws on the work of Daniel McFadden, Nobel Prize winner for the development of discrete choice models. These econometric models provide a stronger theoretical approach to travel behavior and transportation planning. According to this theory, individuals make decisions in their own self-interest, when they have the option to do so. Choices about traveling or any other form of consumption are made on the basis of feasibility and relative costs and benefits of various modes. Demand theory is believed to have the ability to explain the effect of multiple external circumstances on complex behavior. According to the demand theory, in order to understand travel, one needs to know the attributes of travel alternatives, individuals' perceptions and attitudes, socio-demographics and household characteristics that may affect travel decisions. Furthermore the balance between short term travel choices and long-term decisions on car ownership, location of residence and employment location can all increase the complexity of such analysis. The demand framework typically relies on three key determinants of the choice to travel. The first is the time it takes to get to a destination. The second is the cost of a specific trip and mode, and the third is the comfort levels afforded by specific modes. For the demand framework to adequately reflect the choice to walk or cycle, models would need to integrate factors more typical of these modes, such as adverse terrain (e.g. wide street crossings) or favorable infrastructure (e.g. traffic calming), presence of nearby destinations (land use mix and density) topography, fear of accidents and weather extremes (wind rain and snow). Empirical analyses typically only explore a limited set of these potential effects.

For example, Cervero and Duncan (2003) developed a discrete-choice model of walking and cycling for trips under 5 miles in the San Francisco Bay area. The discrete choice model evaluates the probability that individual *n* choose mode *i* to travel between origin *o* and destination *d*. The discrete-choice model is therefore specified according to individual characteristics, transport mode used and their specific impedance factors (pecuniary or not), as well as characteristics of the zones of origin and destination.

Because the survey instrument used in this thesis did not include trip diaries, simpler mode choice models are used. In choice models, the dependent variable can be mode share within an area, mode share for an individual's overall travel, or a binary choice model for a specific mode. These dependent variables can be regressed over the physical, infrastructure, costs and socio-demographic characteristics.

2.3.3 Trip types and purpose

Most trips are made with the intention of fulfilling one or more activities – hence, the economic conceptualization of travel as a demand largely derived from the demand for other activities (Meyer and Miller, 1984; Boarnet and Crane, 2001). Traditional transportation planning focused mostly on the journey to work because it is was believed to be one of the most common trips taken, and because most work trips occur at non-flexible hours during week days in the morning and at night, causing peak hour congestion (Shrank and Lomax, 2004). In order to alleviate congestion, understanding trips to work is of primary importance. However, changing travel patterns linked to greater leisure time have increased leisure trips' share of total trips. Travel surveys now record purposes of trips in multiple categories. These can be grouped into categories such as shopping, driving someone, going out to eat, traveling to recreational events, to school, to child care or for leisure (Cerin et al., 2007; Chapman and Frank, 2004). While most trips are transportation-related, a leisure trip can occur without any specific destination in mind. This may be the case for strolling, or "going for a drive". Trips have been analyzed by grouping them into transportation related, or leisure and fitness related trips (Corti and Donovan, 2002), discretionary and non-discretionary walking trips (Frank et al., 2007) and work and non-work related trips, maintenance and leisure trips (Krizek, 2003). Different types of trips may be influenced by different conditions, depending on the modes used. For example, work trips are much less flexible since they are a non-discretionary form of travel. However, given that employment is often a longer-term situation, a person may have chosen to live in a place based on travel time and distance to work. On the other hand, trips to a cinema or restaurant are made under much looser travel restrictions. There are many possible restaurants to go to and one may decide to have dinner at home based on exterior circumstances. Additionally, these non-discretionary trips may be taken at times when public transit service is much less frequent and therefore less appealing.

The survey instrument employed in this thesis did not include trip diaries, but rather count values of transit trips over a month. This precludes the analysis of discrete choices associated with specific trips. However, the choice model and utility maximization framework can nonetheless be applied to the analysis of transit use over a month as a dichotomized variable. Such approach is used in chapter 4.

2.3.4 Public transit networks and transit quality of service

The Transportation Research Board in the United States commissioned the preparation of a *Transit Capacity and Quality of Service Manual* that serves as a standard in the industry (TCQSM, 2003). The TCQSM reviews studies and practices and offers methods for transit agencies to assess the state of their network and plan for future use. In this section, I review its most important concepts, availability, comfort and convenience.

Transit agencies rely on a number of performance measures that can reflect broader agency management and financial goals. Among them, concepts such as quality of service in public transportation planning reflect the passenger's perception of overall transit performance (TCQSM, 2003). Understanding passengers' perception is required to make decisions about where transit service should be provided, what kind of service is needed, how often service should be supplied and for what daily period it should be provided. By measuring quality of service, a transit agency can gauge its success in providing service to its customers. On a national basis, the two main components of quality of service that are found to be the most important to passengers are availability and comfort and convenience (TCQSM, 2003). If a transit service is considered not available for one user, then comfort and convenience will not be relevant. Once available, the comfort and convenience of a trip will determine the user's overall experience with the system. Hence, these concepts are relative to individual users. What is comfortable for one may not necessarily be for another. Similarly, walking 500 meters to a transit stop may be considered much more burdensome to some users.

Quality of service measures are required at various levels of a transit system. Indeed, performance measures at the level of individual transit stops can vary considerably from location to location. Measures may also be developed at the level of a route segment or for multiple routes along corridors. There will likely be less variation in quality of service over the route segment than over the corridor. Other measures can be applied to the whole system. Only through the combination of these measures can we provide a complete picture of transit quality of service. The TCQSM manual provides a framework for quality of service based on two performance measure sets and three transit system levels. Matrix cells in Table 2.4 represent the most commonly used measures.

Table 2.4 Quality of service matrix

	Transit stop	**Route segment**	**System**
Availability	Frequency and scheduling	Hours of service (span)	Service coverage
Comfort and convenience	Passenger load and capacity	Reliability	Transit–Auto travel time

Source: TCQSM, 2003

While quality of service can be assessed from the standpoint of individual users, it is also important to assess transit’s ability to meet broader community objectives. This implies an analysis of consistency between present transit service and stated community or regional goals. A more detail description of quality of service factors follows.

2.3.5 Availability

Availability measures how easily potential passengers can use transit for a given trip and purpose. This implies multiple considerations.

> Transit service is only an option for a trip when service is available at or near the locations and times that one wants to travel, when one can get to and from the transit

> stops, when sufficient capacity is available to make the trip at the desired time, and when one knows how to use the service. If any one of these factors is not satisfied for a particular trip, transit will not be an option for that trip—either a different mode will be used, the trip will be taken at a less convenient time, or the trip will not be made at all (TCQSM, 2003 p.3-6).

Five components are included in the concept of availability: spatial availability (at origin and destination), temporal availability, information availability and capacity availability. If all of the factors are met positively, an individual may weight the benefits of using transit against other modes, given their availability and given the quality of the transit service for a particular trip. Considerations pertaining to comfort and convenience may then be appraised. These will likely differ considerably from user to user, given personal characteristics, values and preferences. For example, a long walk for one individual may be perceived as a relaxing stroll by another. Availability may also differ according to trip purpose, destination and time of day. Some travel decisions are made every time a trip is taken. Additionally, other decisions are much more infrequent but may bear strongly on perceived availability of public transit. The decisions pertaining to home location, to the purchase of a second vehicle or to accept a job in a specific location are long term decisions that will determine to a certain extent the general availability of transit for an individual and his household. The Transit Capacity and Quality of Service Manual (TCQSM) (TRB, 2003) measures availability with four separate constructs:

- Service frequency and scheduling;
- Hours of service or service span;
- Spatial service coverage;
- Information availability.

2.3.5.1 Frequency and schedules

How often a service is provided and the span of time when the service is provided during a day may influence the decision to use transit for a given trip. Frequent service equates with short wait times and flexible travel departure times. It also allows a user not to be reliant on schedules for planning trips ahead of time. A ten to fifteen minute headway seems to be the threshold below which users no longer rely on schedules and simply show up at stops. The service span throughout a day brings additional potential to a transit line since trips with other purposes than peak hours work trips can be made using transit (TCQSM, 2003). Heavy and light rail systems are often designed as frequent transit service with a broad service span and high frequency through the day. Commuter rail that only provides service to the Central Business District (CBD) in the morning and back home at night, while being effective for work trips, is not supportive of off-peak, discretionary travel because of its short span and irregular frequency (most offer only a few in-bound trip in the morning and out-bound trips at night).

2.3.5.2 Service coverage

Service coverage considers the links between the origin and destination of a trip. Service coverage is often measured using GIS to identify areas within which transit use is an option. Coverage may simply represent the extent of the transit network itself over a region, or may take the form of time dependent accessibility measures (i.e., from a given stop, what area of the network can be reached within 15, 30 or 45 minutes). Distance to transit is central to the issue of coverage since it will determine the area from which transit can be accessed, especially at egress point where walking is the most typical means of completing the journey. Coverage can therefore be viewed as the transit network and the areas accessible within a given walking time or distance from each transit stop. Transit systems may be reached by walking, cycling or driving. Hence, coverage involves actual transit network measures, surrounding land use, pedestrian and cycling network design as well as park-and-ride facilities. If an individual can access a transit stop from their home by park-and-ride or using a bicycle, on the other hand the options for getting from a transit egress point to a destination are often much more limited since a vehicle is seldom available at the destination end of the transit trip.

2.3.5.3 Walking distance

Research shows that 75 to 80 percent of passengers are willing to walk 400 meters or less to a transit stop, which, at an average walking speed of 5km/h is equivalent to a maximum walking time of 5 minutes (TCQSM, 2003). For rail transit, very frequent bus transit and express lines, evidence points towards a doubling of the distance people are willing to walk to access stations. This suggests that individuals may be willing to walk greater distances to access higher quality service. Walking speed and acceptable walking distance may vary according to age groups, hilliness of an area and other walking environment features. The elderly do not walk as fast as young adults, and above a 5% slope grade, the distance that they can travel within a given time diminishes. Additionally, lack of sidewalks or poor quality sidewalks, poor street lighting, wide and busy streets without crosswalks can all affect one’s desire or ability to reach a station or stop by walking. The street pattern in a given location can make traveling distances longer and may affect the number of residents and services within 400 meters of a transit stop or station. A grid pattern may offer more direct routes to a stop and often accommodates competing routes on parallel streets (TCQSM, 2003).

Access to transit by bicycle may allow cyclists to make longer trips and may expand the catchment area of a transit network. Bicycle connections to stops and stations, bike parking at stops and on-vehicle bicycle carrying facilities are the three components that link cycling and transit (TCQSM, 2003). Since cycling speeds are up to 4 or 5 times higher than walking, a 5 minute cycling trip to a transit stop may allow the cyclist to access a transit stop 1.6 to 2 km away, therefore expanding the coverage area of a stop by up to 25 times that of walk trips (TCQSM, 2003). On-vehicle bicycle carrying facilities may also broaden the transit catchment at the trip end.

Walking and cycling are not the only means of accessing transit stops and stations. In fact, in the United States, commuter rail stations are primarily accessed by cars using park-and-ride lots (Cervero, 2001). While these facilities support access to transit in low-density areas by focusing transit boarding in a number of focal points, they are prone to criticism because faster access to the city core from outlying areas is thought to promote sprawling development, while supporting a lifestyle largely dependent on automobiles for all other travel. Park-and-riders mostly access CBD during weekday rush hour periods, and use transit to avoid the high cost of parking at their destination and the congestion along the way. Park-and-riders are likely to have favorable transit-auto travel time ratios or highly prohibitive parking cost at the workplace.

2.3.5.4 Information availability

Finally, the availability of information can impact a user's decision to board a given transit service. This is of particular importance for new users, infrequent users, tourists, and transit users going to a new destination. Information on lines, fares, transferring scheme and destination stops are all required to complete a trip. Multiple forms of information provision can be used by transit agencies to help users get to their destination with ease: printed information such as paper schedules, internet and phone information, on-site information such as network maps posted in a station, visual displays such as real-time headway information, audible on-board announcements, and transit hub physical infrastructure such as way-finding information (e.g., exit signs, circulation arrow, color coded schemes for different lines) may all help users understand and navigate the system more easily.

2.3.6 Comfort and convenience factors

There are a number of factors that may impact a passenger's perception of the comfort provided by a specific transit service. First and foremost is the passenger loads. Capacity of service may be the last hurdle perceptible to the users once a vehicle arrives. Standing for a long period of time on highly crowded buses or trains makes a transit trip much less attractive. Crowding also complicates entering and exiting a vehicle, which in turn slows down the average speed of the vehicle. As loads of passengers on transit may vary according to times of day, lines, and days of trips, it may be difficult for a user to foresee capacity problems and adjust his travel. Capacity issues will vary according to the position of the stop along the line, with busses arriving at last stops before major destinations having a greater probability of being full. There are different thresholds of bus capacity that may be perceived by the users. A fuller bus with seating left may mean that a user will be required to sit next to someone. The user may have to stand up with adequate space or be crowded among other standing users. In the worst cases, a bus might pass without stopping if capacity has reached its limit. This is a strong deterrent to using transit, which is unacceptable from a user's standpoint.

System reliability affects wait time at transit access points, the total trip time and the consistency of a passenger's arrival time at destination. Passengers that are not confident the service will be provided may choose to board an earlier departure to ensure arriving on time, therefore reducing the time they may allocate to other activities. Reliability issues in a system may lead to bunching of arrivals, a negatively perceived factor from the passenger's perspective, since more riders will have to wait a longer period for the first bus to pass, and very few riders will be advantaged by the early or on-time arrival of the next bus (Rietveld, 2005). Reliability can be influenced by a number of factors, only some of which may be controlled by a transit agency. External factors are road construction and maintenance, traffic conditions and transit preferential treatment in traffic (such as High Occupancy Vehicle lanes and signal timing). Policies, land use and regional transportation planning may be burdensome or supportive of transit. Careful regional planning and inter-agency collaboration is paramount in supporting a public transit network. Possibly the most important convenience factor, and certainly the dearest to economists, is the issue of travel time. For individuals with the option to use a car, transit-automobile travel time ratio will determine to a large extent the final decision to use transit or not. Transit service reliability issues may extend actual or perceived travel time.

Additionally, Chu (2004) identified a number of factors that may be recorded as dichotomous or categorical values to assess the convenience and comfort of a transit system's characteristics: service type (rail, commuter line, bus, express bus), transfers (main line or not), presence or absence of a shelter, bench, garbage, schedules, lighting, and universal accessibility at a given stop. Cervero (2001) also use a value that distinguishes feeder bus lines that connect to the subway system from other local bus lines. Variables that reflect the presence or absence of traffic lights, street crossing delays, sidewalks and streetlights may all affect perceived accessibility to stops (Chu, 2004). Variables can represent attributes of the actual stop, features supporting walking along the road of the stop and features supporting road crossing for pedestrians.

2.3.7 Transit level of service

Measures of all of these previously discussed concepts are often converted into values that ease analysis and comparison. **Level of Service** (LOS) measures are designated ranges of values for a particular service component. Typically, as in the TCQSM (2003), LOS is represented by letters ranging from “A” (highest) to “F” (lowest), mimicking similar highway measures. The gradation is designed to reflect changes in service quality perceived by passengers at each LOS threshold (TCQSM, 2003). Measures may be made for each concept reviewed and composite measures may be developed. The programming of needs on a new route may then be assigned targeted values that can be compared to other parts of the network. Typically, LOS measures are used by agencies to assess performance, set standards and identify gaps. Research often preserves the richness of information by keeping discrete, continuous, categorical and dichotomous variables in their initial disaggregate form. The term LOS is nonetheless used by many.

As may be seen in the vocabularies used by different sources to define LOS, accessibility and availability, there is no strict agreement on the definition of specific measures and often a few simple available measures will be used as proxies of transit system performance. Considerable information is required to understand the complex picture of what factors bear the most importance in supporting existing transit use and in making transit a viable option to new passengers. Since a systematic comparison of these measures has yet to be reviewed in the literature, there is still little agreement on which measures best represents passengers’ perception and which are most likely to affect their use of the system. In the next section, I discuss transit use from the perspective of individuals.

2.3.8 Individual and household characteristics

Along with transit network and land use accessibility factors, several population characteristics have been linked to general travel behavior and public transit use. Men and women have different travel patterns (women traditionally have lower car ownership rates), age groups experience traveling differently, and income is a major factor creating additional differences between groups with respect to travel behavior (Lucas, 2006). In the US, the spatial mismatch hypothesis has generated a number of studies on racial disparities in access to employment (Sanchez, 1999; Cervero et al., 2002). Household attributes (such as number of persons in the household and presence of children) and responsibilities further constrain individual travel behavior.

Transit users have traditionally been described as individuals not able to afford a car. Recent research efforts have described more complex processes and differing relationships to public transit based on individual and household attributes. Three groups, along with their typical characteristics, are described next: transit-dependent riders, automobile dependent population and choice users of transit.

2.3.8.1 Transit dependence

Public transit use in the United States and elsewhere has consistently fallen since WWII (TRB, 2001; Lucas, 2006). In the minds of many, transit has come to be considered a lesser form of mobility, second to car ownership and car use (Deka, 2002). Transit-dependent populations are often narrowly described as members of households without a car (Vandersmissen et al., 2004). Since car ownership depends to a great extent on income, household income is often used as a proxy of transit dependence. Indeed, an important correlation has been found between income and car ownership both at the individual level and at the census tract level (Deka, 2002). Yet conceptualizing transit dependence solely based on these factors may produce less than accurate estimations. Younger people under the driving age and seniors may not be able or willing to drive, and disabilities and language difficulties may prevent others from driving.

Car owning households, which often share a vehicle among many household members, offer a specific case of interest that displays the complexity of the phenomena. Travel is time sensitive; that is, travel may be required at specific times, and the availability of a car at the time of a trip can be restrictive to certain members of a family. In order to address this issue more closely, Vandersmissen and colleagues (2004) used a trip level activity-based survey that included time of trip departure. For every trip starting from the home end, a series of logical questions were asked to determine actual availability of car: Does the household own a car? Does the individual hold a valid driver's license? Is the car at home at the time of the trip? Is there a person available to drive the individual? For a car owning household, individuals with a driver license and a car available at the time of the trip will have actual car access and be deemed choice riders, should they take a trip by transit. In the same situation, where the individual does not have a driver's license, a trip taken by car will depend on the availability of another driver. For households without a car, or individuals without licenses and without someone to drive them, a transit trip will be made in a temporary condition of captivity.

This categorization broadens the potential transit market by identifying time specific captive riders among car owning households. Individuals in this situation may decide not to take a specific non-mandatory (or discretionary) trip for lack of convenience, or to make this trip in an area that can be walked to, assuming a location for the activity is available close by. An example is the choice to walk to a nearby restaurant instead of driving or taking transit to a restaurant out of walking reach. Non-discretionary activities are however more restrictive because of time sensitivity.

2.3.8.2 Automobile dependence

Given that public transit is not available everywhere in a city, the concept of **auto dependence** reflects a second reality that requires consideration. The concept of auto dependence can be traced back to Newman and Kenworthy (1989). An automobile dependent individual is a person for whom public transit is not available within reasonable distance from home. For some, this concept extends to the preference for automobile use, and the disinterest in transit use, although the use of the term dependence is questionable. Furthermore, if a desired destination cannot be reached by transit, an individual will have to use other modes of transportation. The popularity of automobile use may make the term automobile dependence at odds with the growth in car use that occurred all over North America and Europe in past 60 years (TRB, 2001; Zhang, 2006; Deka, 2002). Indeed, most drivers are satisfied with their conditions and would not consider themselves trapped in a cycle automobile dependence. The concept is nevertheless important in designing policies to reduce automobile use. Zhang (2006) reviews dimensions of auto dependence as a process and the varying conclusions and recommendations included in studies (Table 2.5).

Table 2.5 Automobile dependence process and recommendations for change

Dimension	Recommendation
At a macro level, auto dependence is characterized as: dominant modal share of driving, high level of per capita automobile travel, large amount of gasoline consumption.	When urban densities exceed 30 person/ hectare, auto use declines rapidly. Urban densification is the main solution.
Auto dependence does not reflect true consumer choice since market distortions in land use and transportation development encourages excessive motor vehicle use.	Development favorable to auto travel is dominant. Land use change is the key strategy
Growth of auto dependence is attributed to: change in the composition of the workforce, age structure of the population, and the rise in income.	Policies have limited impact in changing social patterns. Response strategies are needed. Improve vehicle technology, higher fuel efficiency, and expand highway networks.
Adult lifestyle and influence of parents are important formative factors that shape young people's long-term travel behavior.	Education to children and youth about alternative transportation must be undertaken.
Process of dynamic acceleration of auto dependence. People buy automobiles for convenience reason (carrying things, saving time, and taking children to school) and then begin making use of it when it is not necessary.	Ownership and use must be controlled through policies that discourage the purchase of additional cars, tolling and parking control.
There are two main strategy types: "Push" measures such as charging for access displaces old, poor and urban residents. "Pull" measures direct drivers away from automobile by increasing attractiveness of alternatives.	Focus on pull measures: Diversify vehicle types and access to vehicles (e.g. car share). Favor alternative forms of transportation such as transit. Modify the built environment.

Source: Compiled from Zhang, 2006

The lack of considerable and sustained investments in transit provisions that differentiate the United States from Western Europe is thought to have contributed to the growing desire for car ownership (TRB, 2001). Low-income populations that typically have the lowest car ownership rates are increasingly purchasing cars, which brings Deka (2002) to ask whether transit actually provides the service they need. From the traveler's perspective, the demand side of driving, auto dependence is a dynamic social and individual behavioral process that forms and develops over time. Travel purpose, complexity of multi-journey trips, length and cost of travel and household income may all influence the choice to own a car. Once a car is owned, a cycle of dependence is triggered. The process of automobile dependence can also be linked to broader policy variables such as gasoline price, transportation technology, and government subsidies of public transportation or highways.

Many definitions are unclear as to whether auto dependence is indicated by the absence of choice or will or the actual extent of auto usage. The latter may not be indicative of dependence in itself. In order to accurately account for automobile dependence, researchers need to distinguish between automobile dependent trips, places and people since some trips cannot be accomplished by public transit (e.g. heavy item shopping) and some destinations are out of transit reach (absence of choice), and some individuals negatively perceive transit use (absence of will).

Zhang (2006) sought to clarify this issue and defined automobile dependence as “the probability that driving is the only element in a traveler’s feasible choice set of travel modes” (p.312). This definition entails two parts: choice set formation, the perceived modes available, and mode choice decision, the actual trip based choice. His analysis reveals that 30 percent of Bostonians are effectively automobile captive since they lack any viable alternative to auto travel. A more detailed discussion of choice follows.

2.3.8.3 Choice transit riders

Not all transit users are limited to using public transit. A **choice rider** is a person who chooses to use transit when other options are available. Properly defining and accounting for choice riders is also problematic since until recently, very few travel surveys directly address preference for modes. Instead, researchers must rely on other attributes to assess choice. Car availability is considered the strongest predictor of not using transit (Deka, 2002). Even if the initial goal of car purchase is not to stop using transit, a process of habituation is at play and a person may in the long run even stop considering the use of other modes as alternatives. A crude estimation of choice use is then related to car ownership and driving license. As mentioned earlier, travel decisions may also reflect a person’s lifestyle choices and household constraints.

For transit to always be a viable option, it needs to be considered available both at discretionary and non-discretionary activity destinations. If transit is available at the destination but not at the origin, a person may choose to use park-and-ride facilities and combine modes. This choice is closely tied to the level of congestion on automobile corridors, the travel time difference between using transit and automobile, and the availability and cost of parking at the destination (TCQSM, 2003). From an economic perspective, trade-offs will be made between the time costs related to both modes and the out-of-pocket cost related to transit fares and parking fees.

Some individuals may not have the opportunities afforded to others and may find themselves in a situation of restricted choice. Such is the case for transit-dependent riders, who don't have access to car travel, and automobile dependent travelers, who don't have access to public transit. Conventional mode choice models assume a deterministic choice set combining all the different modes, thereby omitting the existence of the three aforementioned groups, transit-dependent, automobile dependent and choice transit rider. To account for restricted choice, Zhang (2006) applies a two-stage discrete-choice model, evaluating probabilistic choice set formation prior to mode choice modeling. Choice set formation refers to the actual combination of modes available for a given trip; the number of different possibilities may be expressed as $2^m - 1$, where *m* is the number of modes. For example, for the three modes, car driver/passenger, walk/cycle, and public transit, seven possible choice sets exist. When omitting individuals with disabilities and the young and elderly who may have restrictions on their ability to walk, walking is technically available (although not necessarily suitable) for everyone, which leads to three different choice sets that refer to the groupings discussed above:

- car, walking and transit for the choice riders;
- car and walking for the car captive;
- and walking and transit for the transit-dependent.

Obviously, this classification entails that the transit captive riders actually have resources to cover fare costs, an assumption that should be verified through survey design. A simpler categorization approach is used in chapter 6. Details are presented below.

In summary, three differing relationships to public transit were discussed in this section. The factors that may be measured to estimate the prevalence of these groups in a region, a city or a specific area are presented in Table 2.6. As can be seen from the table, some factors (marked with a ⇔) may encourage public transit use for some and discourage it for others.

Table 2.6 Relationship to public transit and reasons

Groups and factors	Reason
Captive riders	
Age	
Under 16 years of age	Unable by law to operate a motor vehicle
Senior citizens	Unwilling or unable to operate a motor vehicle. ⇔ Senior citizens might drive and find the additional walking related to transit burdensome.
Income	
Low income	Income constraints prevent car ownership.
Language difficulties	
Migrants	Unlicensed or unwilling to drive.
Overseas visitors	⇔ Lack of language skills may be a barrier to driving AND using public transport.
Single or no car household	
Multiple adult household Couple with families	Demands on having at most one vehicle is incompatible. Car is shared and not always available at time of trip.
Disability	
General disability, physical ill	Unable to drive.
Choice riders	
Social/personal inclination	
Perception of system	Social stigma of transit use
Efficiency of modes	Preference driven by availability of information on public transit.
Presence of park-and-ride lots	Opportunity to reduce trip time or to avoid parking fees.
Previous experience	
Migrants	Use of public transit in previous country may make a person more inclined to use transit. ⇔ Or vice-versa.
Travel incentives	Tax refunds on transit passes, employer sponsored transit passes, etc.
Transit-auto travel time ratio	The difference between the complete journey by transit and by car either favors transit or compares equally.
Auto-dependent users	
Social/personal inclination Perception of system	Social stigma of transit use.
Home	Not within transit catchment area, poor service quality
Work place	Not within transit catchment area, poor service quality
Common destination	Not within transit catchment area, poor service quality
Single parent	Transit may be unable to allow the required flexibility
Mandatory car users	Car required for work, frequent interregional travel, multiple destination outside network, etc.) Leads to dynamic acceleration of car use.

Compiled and adapted from Murray and Davis, 2001

A combination of all the factors presented in the previous pages may be analyzed by transit agencies to understand and predict the usage of transit networks based on population composition and distribution over an urban area. Since transit agencies are often cash strapped, careful evaluation of these factors and their interaction may help distribute service equitably, and identify cost effective measures of improvements.

2.3.9 Neighborhood location preference, travel preference and causation

The following section considers this question: What if the relationship between walking behavior and the built environment is largely the product of people's decision to locate in areas that are more conducive to the lifestyles and behavior they prefer? In such a case, the identified relationships could be considered spurious because they present a plausible but potentially false argument. This theoretical conundrum has caused recent debate in the literature on the relationship between environment, travel behavior and health. It is referred to as the self-selection bias. The term self-selection suggests that individuals may choose to live in places that allow them to practice the lifestyle they desire. Accordingly, people wishing to walk to access shops, work and other utilitarian locations in their daily lives would place this criterion high on their list when seeking housing. Observably high levels of walking in this environment would therefore be likely a product of the lifestyle and location choices of a person, rather than the effect of existing built environment. In its simplest form, Boarnet and Crane (2001 p.30) outline the root of the debate: "Attempts to engineer social change through neighborhood building must acknowledge that human behavior is not a simple reflection of the neighborhood." Researchers should ask themselves: do people walk more because they live in an aesthetically pleasing neighborhoods with plenty of shops, parks and other destinations, or do people chose to live in or frequent these areas because they enjoy walking? The self-selection bias limits our ability to draw causal inferences about the built environment as a cause and walking as an effect, acknowledging that residential and travel preferences may be considerably strong predictors of residential location. Approaches exist to formally account for this bias. A few examples are presented below.

2.3.10 The importance of housing location

For businesses, location means proximity to potential customers and easy access for customers (Jones and Simmons, 1993). Depending on the nature of the goods being traded (lumberyards are seldom found in dense urban areas for example) and economic feasibility (the space requirement of a lumber yard makes downtown land values prohibitive to locating there), some locations may be favored by a business. These are all important considerations in a business' choice of location. Certain locations in the city may be more valuable than others and provide more "bang for the buck" to developers, industries or restaurant chains. For example, a fish processing plant is more likely to be found near a harbor, thereby reducing its boat-to-plant transportation costs. Expensive jewelry stores are more likely to locate in business districts or high-end neighborhoods where their potential customers live. Industries may also choose to locate near places where many potential employees reside, giving them access to a wide human resource base. According to the work of early location theorist William Alonso, land values decrease as distance to central business district increases (Schaffer and Sclar, 1980). This is true for commercial, industrial and residential land uses.

Just like industries, households are engaged in their own production of livelihood. At a much smaller scale, they require inputs in goods, such as clothing, food, fuel, electricity and the ability to access other locations where they make purchases, spend leisure time and earn their income. It is reasonable to think that homebuyers' decisions may be influenced by these factors. Hedonic modeling approaches have been designed to estimate the contribution of different characteristics of a house and its surrounding in influencing the retail value of houses (El-Geneidy and Levinson, 2006), while discrete choice modeling assesses the factors related to the choice to buy a house (Guo and Bhat, 2007). In recent years, research has begun to target the added value of neighborhood attributes and distance to centers, as factors external to a house's attributes that may bear on its value or utility (El-Geneidy and Levinson, 2004).

In this theoretical framework, people may chose to select neighborhoods based, amongst other things on their liking of a park, a trail, or a series of nearby stores. This body of knowledge presents considerable research challenge. Do individual preferences interfere with our ability to measure the true effect of the built environment on walking? To what degree walking reflects attitudes and lifestyles, and to what degree it reflects the effects of living in a neo-traditional neighborhood? Likewise, people may also have personal preferences about traveling. These preferences may however be difficult to disentangle from individual responsibilities and commitments, as well as from the effects of their personal knowledge and experience of alternatives to certain travel behaviors.

The previously described theoretical frameworks, both health and transportation related identify a number of factors that may affect active transportation, as a travel mode and as a form of physical activity:

- Individual characteristics;
- Attitudes, preferences, motivations, energy and skills related to the behavior;
- Opportunities or constraints that make the behavior easier or more difficult to perform;
- Incentives or disincentives that encourage or discourage the desired behavior relative to competing activities;
- Personal reasons (state of personal health, injuries, health impairments and physical disability, lack of self-esteem);
- Time constraints (lack of time may limit ones ability to engage in physical activity);
- Environmental impediment (inconvenience of destinations based on their, limited travel choices, weather);
- Concerns for safety and security (TRB, 2005).

Theorizing about the relationship between transit use and active transportation should be done with three purposes in mind: promoting physical activity and supporting a mode shift from single occupancy vehicles to transit use and non-motorized transportation, and enhancing access of transportation disadvantaged populations. Active transportation combines the accumulation of reasonable levels of physical activity and the fulfillment of transportation needs. Combined with public transit use, it can enable both local and regional access to destination in the absence of a car. Researchers should consider whether neighborhoods are really consciously chosen for the travel choices they allow (for example, the ability to walk to a destination, or the ability to use public transit), and whether all residents are able to locate according to their travel and lifestyle preferences.

2.4 Formulating the research problem

In this thesis, theoretical frameworks are drawn from the fields of transportation, public health and other behavioral science to address the intertwined outcomes of access to public transit, use of transit and associated active transportation. Promoting the use of public transit is perceived as an important response to challenges such as climate change, traffic congestion and urban air pollution (TRB, 2001; Frumkin et al., 2004). Can the practice of physical activity in the population be increased while contributing to other social and environmental goals? How can a health perspective to non-motorized travel contribute to transportation research? Understanding *how* transit use is associated with active transportation is the central aim of this thesis.

2.4.1 A potential catalyst?

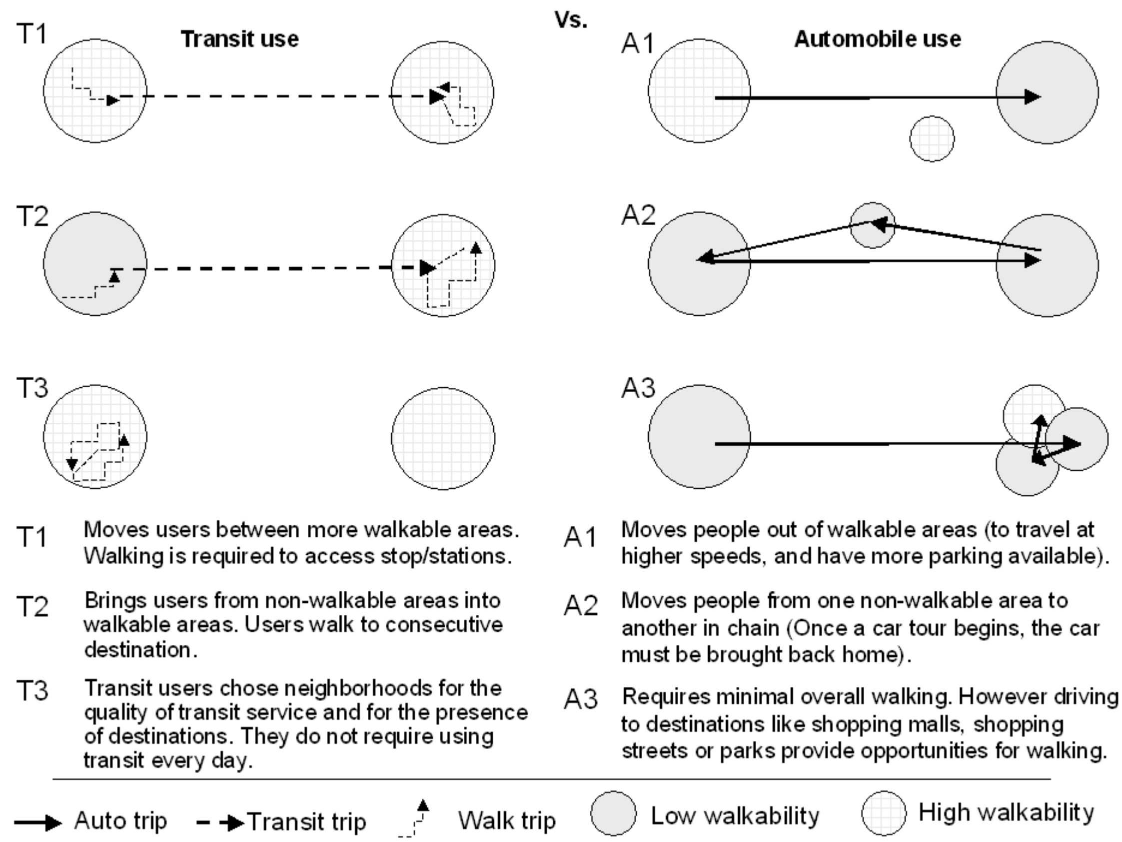
What are the mechanisms through which public transit use is associated with active transportation? How do these relationships vary by income, age, gender, auto ownership and availability, or for types of built environments? A theoretical interpretation of the association between public transit and active transportation is formulated using the concept of catalyst presented in the introduction. I posit that public transit use can favor an active lifestyle through a variety of mechanisms, some supportive of the catalyst effect, and some to its detriment (Table 2.7). Also included in the table is the chapter where each potential mechanism is specifically addressed.

Table 2.7 Potential mechanisms supportive or deterrent to the catalyst effect

Mechanism	Chapter 4	5	6
Supportive of catalyst effect			
Transit users have to walk to access transit stops and stations.		X	X
Transit service and walkability are associated. Transit service tends to be better in places with high walkability. Ridership is also higher.	X		
Transit users may be predisposed to walking through their housing location choice They may choose to live in high walkability areas with good transit service so as to enable short walk trips.	X		
Neighborhood walkability is positively associated with satisfaction with transit service because it captures how easy and pleasant the pedestrian part of the transit journey is.	X		
Transit users walk to access shops and services near home and avoid long-distance regional trips whenever they can.		X	
Transit users travel to areas that are denser and near more services where they can walk.		X	
Transit-dependent riders have limited alternatives for transportation other than walking, cycling and using transit.			X
Deterrent or potentially confounding the catalyst effect			
Enjoyment of physical activity for transit users does not confound relationship between transit use and walking.		X	
Transit users, choice or dependent, do not make lifestyle adjustment that reduce their level of leisure physical activity (displacement).			X
Lack of time of transit users, choice or dependent, does not reduce their levels of active transportation or leisure physical activity.			X

By requiring walking to access transit and by typically bringing users to central areas with higher densities and a mix of services accessible within walking distance, transit use may further support active transportation and act as a catalyst for an active lifestyle. Transit users and automobile users can be compared with respect to where they live, where they go, and their non-motorized travel patterns (Figure2.2).

Figure 2.2: Mechanisms by which transit use and automobile use are associated with active transportation

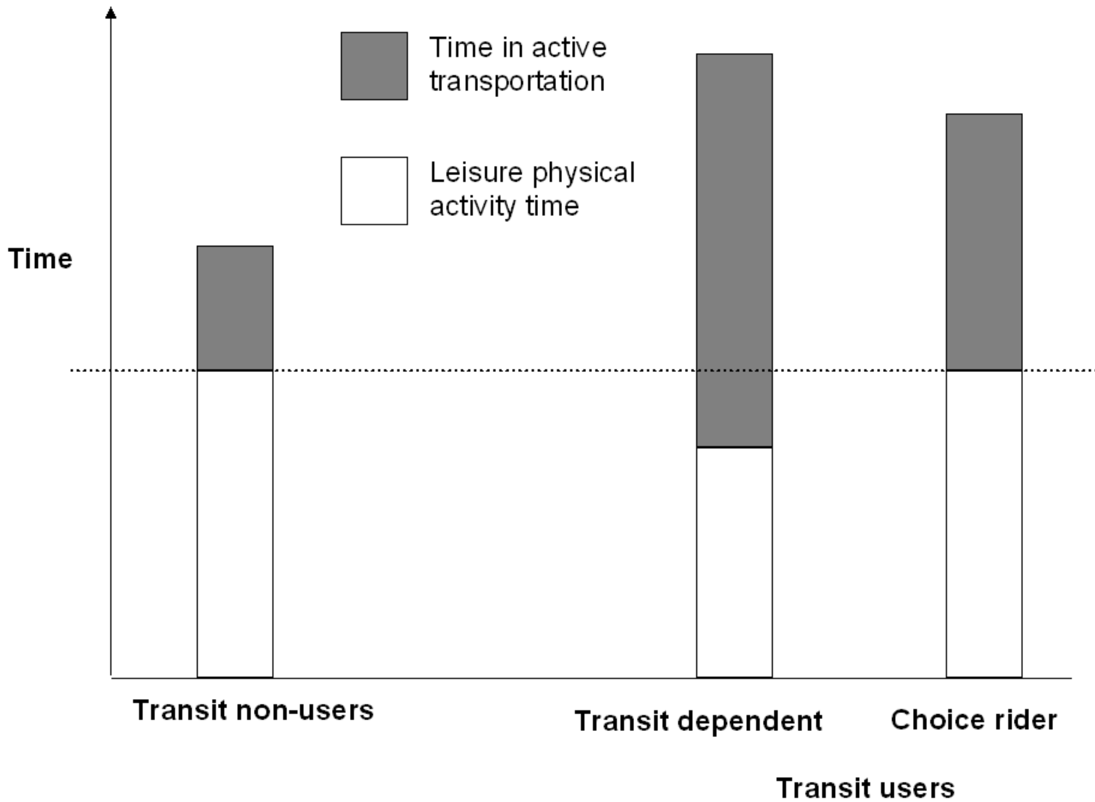


The contribution of public transit use in shaping the relationship between active transportation and different built environments has been largely overlooked. Because the relationship between the built environment and the share of transit users is well documented (Ewing and Cervero, 2001), assessing associations between public transit use and active transportation across neighborhood walkability should clarify the relationship between built environment, travel patterns and physical activity behavior. Furthermore, because a greater share of public transit patrons earn on average less than non-users (Cambridge Systematics, 2007), assessing these associations across neighborhood income may also provide interesting insights. The Neighborhood Quality of Life Study (NQLS), through its sampling design, (described below) provides an interesting opportunity to study these relationships.

It is hypothesized in chapter 5 that public transit use moderates the relationship between the built environment and active transportation. Higher proportions of transit users reside in high walkability neighborhoods. Likewise, a higher proportion of individuals in high walkability neighborhoods are more likely to practice active transportation regardless of whether they use transit or not. Transit users are expected to walk more than non-users. This calls for an assessment of the differences in physical activity between transit users and non-users residing in high and low walkability neighborhoods.

Activity displacement can be studied with a time use perspective (Michelson, 2005; Sturm, 2004). Humans must distribute needed and desired activities within a fixed time budget of 24 hours. The introduction of new activities in a daily schedule may displace other activities, which will take place for shorter periods of time or may be avoided altogether (Michelson, 2005). New activities may displace other previously practiced activities that have similar characteristics; in this study, active transportation may displace other forms of physical activity. The rationale behind this idea is that people may forego other forms of physical activity, being satisfied with the amount of physical activity performed for transportation purposes. Alternatively, they may lack time to perform other physical activity because they spend more time on transportation. Such behavior would dismiss the claim that transit may be a catalyst for active transportation. A hypothetical data distribution (Figure 2.3) clarifies the study of displacement in this thesis. In it, transit users walk considerably more for transportation, but only perform slightly more physical activity (leisure and transportation combined). This is because both choice and dependent transit riders would potentially report more active transportation than the non-users, but each of the three groups would report similar mean levels of leisure physical activity. The figure however shows transit-dependent riders to have slightly lower level of leisure physical activity than the two others. If actual empirical results were similar to the hypothetical example presented below, they would favor the catalyst hypothesis. If transit users' leisure physical activity levels were lower, as is the hypothetical case presented here, the catalyst hypothesis could only be dismissed if this was not compensated by more active transportation. This topic is addressed in Chapter 6.

Figure 2.3 Activity displacement: hypothetical distribution of active transportation and leisure physical activity



2.4.2 Transit quality of service and public transit use

Emerging impetus to reduce automobile use has spurred increasing interest in understanding what will get people to use transit (TRB, 2001). Many of the indicators of transit use are reflective of supplier side requirements (Rietveld, 2005; TRB, 2003). The industry is turning to the development of measures portraying a passenger's perspective on transit use. For this purpose, individual behavior, their perceived environment and satisfaction with the transit system can be assessed using survey information, and matched to information on the availability and quality of transit service near surveyed individuals.

Most empirical research and analysis on active transportation has used the distance to transit stops as an indicator of the presence and quality of transit service. The most common measures used are the straight line (Euclidean), or the shortest path (network) distance to the nearest transit stop (Forsyth et al., 2004). Differentiation between transit technology or service type (e.g. rail, bus) has also been used (Besser and Dannenberg, 2005; Ming Wen and Rissel, 2007). This restricted approach has the benefit of only requiring information on transit stops and not on the actual lines or schedules. In physical activity research, the measures have been typically self-reported through an approximation of distance or time. However, this measure tells us nothing about where the system actually goes or just how good the service is.

The field of public transportation studies has developed more elaborate sets of measures to describe transit service, based on information they often routinely gather to manage operations, prepare scheduling, and plan future expenditure programs. As discussed earlier, the Transit Capacity and Quality of Service Manual (TCQSM) (TRB, 2003) has compiled much of the literature in this field. Focus on the service side has meant that much fewer research has been devoted to exploring a user's perspective through fine scale, detailed measures of public transit quality of service that include the pedestrian realm at both ends of a trip.

Transit users are interested in a transit service that is near their home, fast, efficient, comfortable, punctual, and that serves the destinations where a person needs to go (TRB, 2003). In other words, transit users want a system that maximizes access to destinations, or to opportunities, and that minimizes inaccessible places and destinations. This requires a built environment that is supportive of active transportation and that provides opportunities within reasonable distances to actual destinations once a person is out of transit (Krygsman et al., 2004). An ideal transit system, from an individual's perspective, is one where multiple facilities and services are found both near home and frequent destinations. Transit users are expected to use these services along their paths, thereby generating more walking. Behavioral evidence of this relationship is presented in chapter 4. Because the survey data used did not include trip diaries, it was impossible to retrieve information how trips to facilities and services were tied to transit trips.

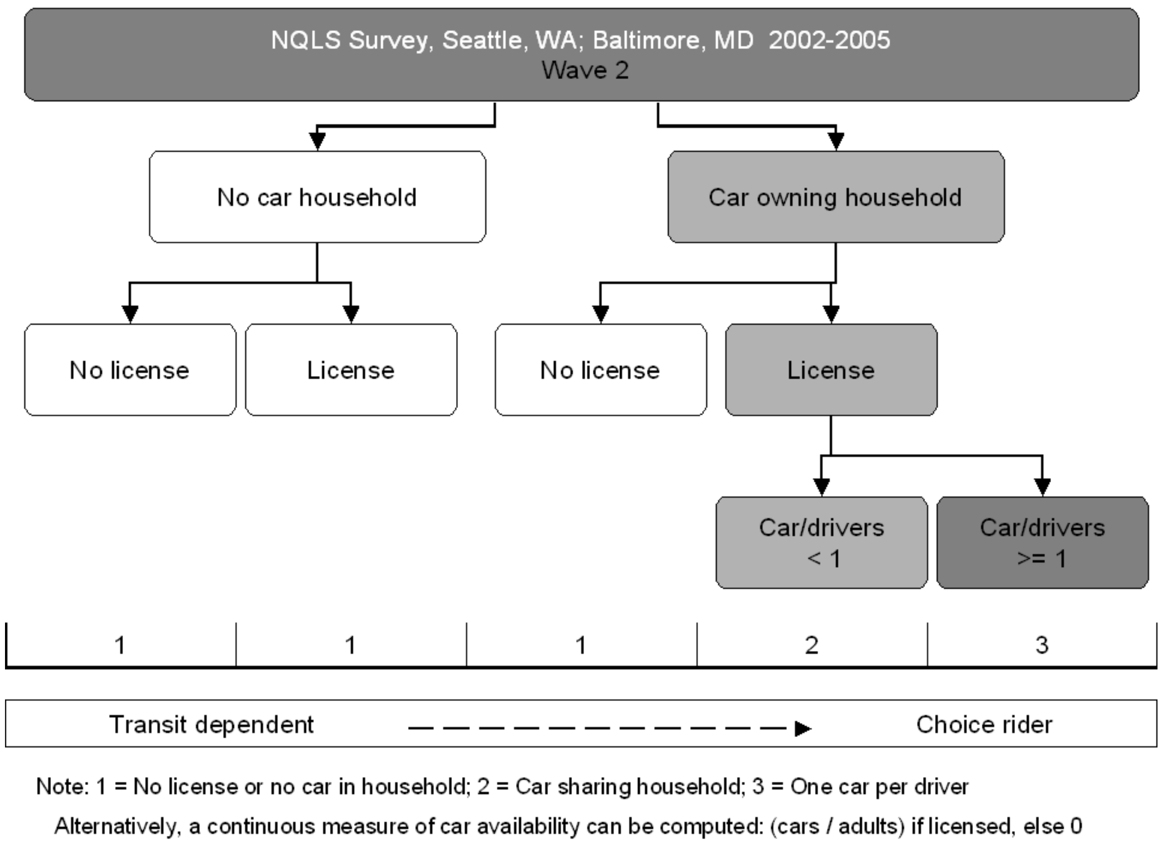
2.4.3 Travel disadvantage and transit dependence

I have so far focused this discussion on the relationships between transit use and active transportation. However, central to this analysis is the question of access to public transit, and the choice, or lack of choice, for using it. Access to spaces, to opportunities, and to mobility are some of the central concerns of equity planning (Krumholz, 2001). In the field of transportation, access has been largely theorized through the concepts of travel disadvantage in the UK (Lucas, 2004), and transit dependence in North America (Bullard et al., 2004; Litman, 2002) yet only limited empirical applications are found (Thompson, 1998; Talen, 1998; 2003; Zhang, 2006). There is much space to expand the discussion and evidence on this matter. Two aspects of travel disadvantage are discussed in this thesis: access to transit service with respect to housing location choices, and the lifestyle issues associated with transit dependence.

Transit dependence can be defined in many ways: from the identification of households with no car, to more detailed classifications involving constraints associated with time, space, and household structure and characteristics (Murray and Wu, 2003; Deka, 2002; Sanchez, 1999; Vandersmissen et al., 2004). There may be, in fact, various categories, or degrees, of transit dependence having each their own distinct implications. A person in a favorable situation for using transit (living in a central area well served by transit) can forego car ownership and the high cost of parking in these areas, and be considered transit-dependent. This person may have been financially restricted to only using transit, or may have chosen this carless situation, thereby blurring the boundaries of transit dependence.

There is space for much exploration on this topic, but the limited sample of transit users in this survey commands a simpler classification. Based on the number of vehicles in a household, if a person had a driver license and the number of adults in a household, five categories of relationships to car availability can be created, with four of them considered as degrees of transit dependence (Figure 2.4) and a final category that has complete and unrestricted access to a car at all time. For lack of adequate sample size, chapter 6 uses a three-category classification shown at the bottom of the figure. The classification is used to analyses walking and physical activity behavior as well as associations with attitudinal variables.

Figure 2.4 Car ownership-based classification of transit dependence



Transit service is never equally distributed across a city and the quality of service varies between areas. Individuals may choose to reside in neighborhoods that suit their own preference for a certain lifestyle. Using public transit on a regular basis, for the commute or other activities requires that a person live close to good quality transit service. Whether the characteristics of the transit service and the neighborhood of residence are associated with transit use or whether a person was predisposed to use transit and therefore chose to locate in places with good transit is known as a problem of self-selection. Transit users are likely predisposed to locate in places where the transit system can serve their needs. However, greater transit accessibility is mostly achieved in urban core areas where land, and rent value is higher (Murray and Wu, 2003). Hence, some lower-income transit users, often dependent on transit, may have greater difficulty locating in such areas.

Whether a person is able to locate near good access to transit service or not is the first step towards its use and towards the studied relationship with physical activity. Deka (2002) suggest that many competing objectives have been imposed on public transit provision in recent years. On the one hand, rail projects are often developed to attract wealthier car commuters to transit. While this may provide the potential advantage of reducing overall greenhouse gas emissions from the transportation sector, its does little to increase mobility. On the other hand, public transit agencies are still required to fulfill the objective of providing transit to the less well-off to increase their level of mobility. Increasing access to transit in places where low income population reside and providing opportunities for lower income housing in wealthier places with good transit service may be two important strategies to increase access to transit for all.

The health and transportation research frameworks have been presented in greater details throughout this chapter, preparing the reader for the analysis of the complex pathways between housing choices, transit access, transit use and active transportation. The sources of data used in empirical chapters as well as the statistical approaches presented will be explored in the next chapter.

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Chapter 3 Data and methodology

The objective of this chapter is to present the survey instrument and the data used to create transit service measures, and present the statistical concepts and models used in the empirical chapters of the thesis.

3.1 Survey data: Neighborhood Quality of Life Study (NQLS)

The work proposed as part of this PhD research project is carried out using a survey instrument assessing personal characteristics, attitudes, preferences, behaviors and perceived neighborhood environment. The Neighborhood Quality of Life Study (NQLS) uses self-reported and objective measures to study differences in multiple health outcomes across neighborhood walkability and income, with an emphasis on the practice of physical activity. Co-Primary investigators Jim Sallis, Brian Saelens and Lawrence Frank developed this survey instrument and the study's sampling framework, and carried out the data collection. Information on the survey, such as the survey period[1], sample size and research design, geography and matched land use measures developed as part of the larger NQLS project is presented in Table 3.1.

[1] A graphic of the dates surveys were received is included in Appendix 1, Figure A.2 for reference purpose.

Table 3.1 The Neighborhood Quality of Life Study (NQLS)

Year	2002-2005 (Two waves, 1=Prime; and 2=six month retention sample)
Sampling	Community based (32 neighborhoods)
Geography	**Seattle, WA** (King County); **Baltimore, MD** (Baltimore City and County, Howard County, Montgomery County, Prince George's County)
Design	Cross–sectional, observational study, quasi-experimental
Survey type	Self-reported health, quality of life and NEWS (Neighborhood environmental walkability scale) Accelerometer deployment on week prior to survey
Administered	Mail-in surveys; 2 waves (repeat and distinct measures)
N (returned)	**Seattle Wave 1: (1287); Wave 2: (1023)** **Baltimore Wave 1: (912); Wave 2: (722)**
Weighting	NA
Age range	20-65
Inclusion	Not residing in a group establishment (e.g. nursing home, dormitory), ability to complete survey in English, and absence of medical condition preventing from walking.
Duration	Accelerometer: 1 week for each wave; Self-reported physical activity: 1 week for each wave
Primary aim	Establish relationship between physical activity and the built environment
Funding agency	National Institute of Health (NIH) National Heart Lung and Blood Institute (NHLBI) HL67350
Land use measures	1km network buffers (household) neighborhood walkability (not used in empirical chapters), perceived built environment
Transit service measures	Perceived ease of access to transit from home and work, Self-reported time (categories) to walk to transit from home
Physical activity outcome	Self-reported: International Physical Activity Questionnaire (IPAQ)*2 Objective: 1 week accelerometer deployment during each of two waves
Other used outcomes	Satisfaction with access to public transit, Importance of access to public transit, Overall transit use over the month

Additional information on the survey methods and survey items can be found on-line (See: http://www.ipenproject.org/methods.htm, for methods and http://www.ipenproject.org/surveycore.htm, for the two waves of the survey, Accessed on February 17th, 2008). Frank and colleagues (2009) also published a paper describing at length the methodology and proposing that it be developed elsewhere for international comparison. The surveys are provided in appendix 2 and 3.

3.1.1 Survey design

The NQLS survey provides an important opportunity to study residents of different neighborhood types. The survey collected self-reported information on physical activity, travel behavior and perceived characteristics of places near home and work of individuals residing in 32 different neighborhoods in Seattle, WA (16) and Baltimore, MD (16) – see Figure 3.1 and 3.2. These two regions were selected for their known variability in walkability and for the availability of parcel-level land use information (Sallis et al., 2009). Furthermore, the regions are situated on opposite sides of the continent, and may, by their distinct socio-demographic composition and cultures, strengthen the theoretical relevance of the findings. The neighborhoods were selected based on median income for contiguous groups of census 2000 neighborhood block groups (deciles 2,3,4, for low income and 7,8,9 for high income) and mean walkability value (deciles 2,3,4, for low income and 7,8,9 for high income). More information on the creation of the walkability index can be found in chapter 2 and in (Frank et al., 2004; Chapman and Frank, 2004; Frank et al., 2009). The neighborhoods selected belong to one of four categories represented by a quadrant (Table 3.2). This study design allows comparing residents of different living environments. By maximizing variance between neighborhood types, the design allows for the assessment of associations, processes and mechanisms of active transportation, and to a certain extent, of transit use. As discussed in earlier sections these two variables (income and walkability) are highly relevant to the study of public transit.

Table 3.2 NQLS Study Design: walkability and income quadrants

	Low Walkability	**High Walkability**
Low Income	8 neighborhoods	8 neighborhoods
High Income	8 neighborhoods	8 neighborhoods

(Source: http://www.ipenproject.org/methneighborselnqls.htm Accessed on February 15th, 2008).

Figure 3.1 Map of the 16 King County study neighborhoods (Frank et al., 2009)

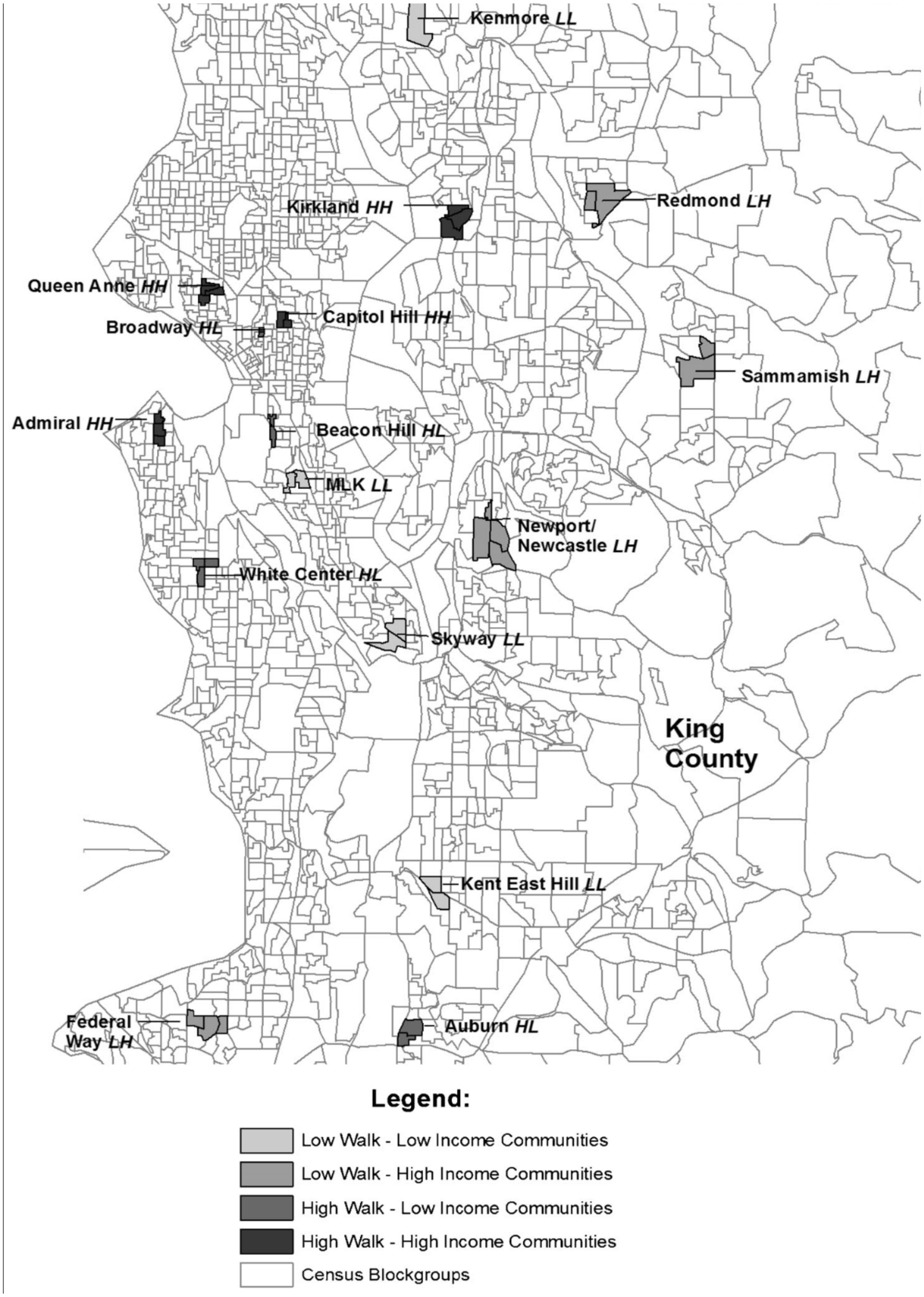
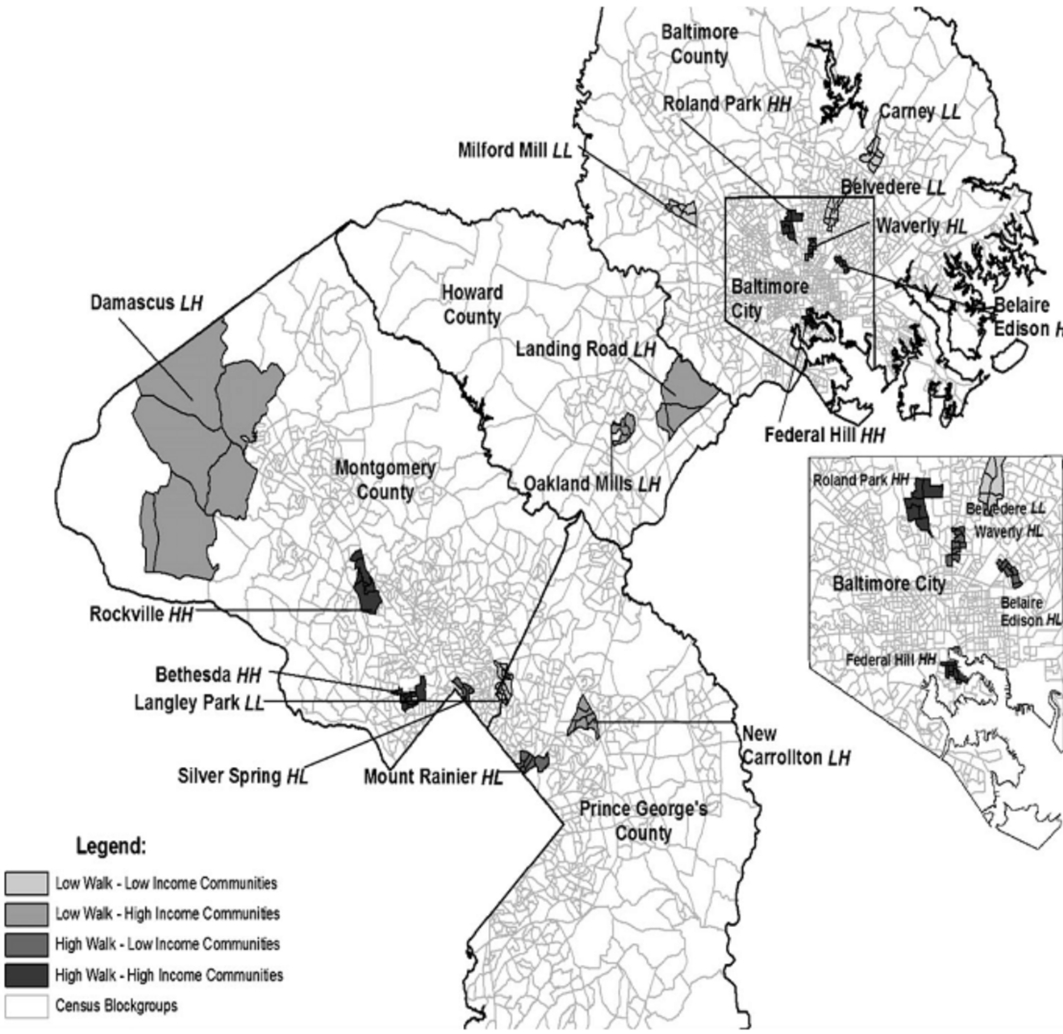


Figure 3.2 Map of the 16 Baltimore-Washington metropolitan region study neighborhoods (Frank et al., 2009)



Transit service data was only gathered and analyzed in the Seattle region. Spatial measures of transit are described in the next section and are analyzed in chapter 4. Measures were used to assess the relationships between neighborhood walkability and transit service. Analyses developed in chapter 5 and 6 were ran separately for Baltimore and Seattle (stratification), and pooled together by inserting a regional dummy variable. Some differences were noted between regions but overall the regions dichotomous variable was not significant in any of the relationships analyzed. Final analyses are pooled together. Pooling Baltimore and Seattle together is done under two main assumptions: the relationship between housing choices and transit use is not a function of the region of residence, and the relationship between transit use and physical activity does not differ between region.

3.1.2 Dependent variables and independent variables

Individual and household socio-demographic characteristics as well as questions on housing location choices were retrieved from wave 1 of the survey. All dependent variables used in this thesis, with the exception of housing location choice were retrieved from wave two of the survey, also referred to as the six-month retention sample. Self-reported data on active transportation and physical activity was assessed in both waves, and was augmented in both waves by objective measures of physical activity derived from accelerometer wear. Objective and subjective measures of physical activity used in the analyses were retrieved from the second wave of the survey.

The theoretical and conceptual frameworks presented in chapter 2 served to analyze the thesis outcomes (dependent variables) presented in Table 3.3. The chapter in which each outcome is analyzed and whether the dependent variable is also used as independent variable in some analyses is also presented. Seven dependent variables are used.

Table 3.3 Table of studied outcomes (and independent if applicable)

Chapter	4	5	6
Self-reported satisfaction with access to public transit	**D, I**		
Self-reported importance of proximity to transit in housing choice	**D, I**		
Monthly use of public transit	**D**		**I**
Frequency of commute by public transit		**I**	
Accelerometer measure of physical activity		**D**	
Walking trips to shops and services		**D**	
Self-reported active transportation (IPAQ)			**D**
Other categories of self-reported physical activity (IPAQ – leisure, household-based, work)			**D**

D = Dependent; I = Independent

The specific survey items of self-reported physical activity, attitudes variables and accelerometer measures used are presented in greater details in their respective papers. Suffice to briefly introduce them here.

3.1.3 Physical activity outcomes - IPAQ and accelerometer

Two distinct sets of measures of physical activity were available with the survey: Self-reported items using the IPAQ method are described in details in chapter 6 and will not be repeated here.

The other accelerometer-based measures are described in chapter 5 but a few additional precisions on raw accelerometer data scoring may be added here. Survey respondents were equipped with accelerometers that they were instructed to wear for a full week. Information on accelerometer data preparation is available on-line (Source: http://www.ipenproject.org/methneighborselnqls.htm Accessed on February 15th, 2008).

Accelerometers record information on movement of the person wearing the device. Information is recorded for set epoch, or time periods. In the case of the NQLS accelerometer deployment, epoch were set at one minutes. Based on the intensity of the movement captured by the device, activity can be categorized based on cut points. The cut points identified on the IPEN website were: 1-100 sedentary, 101-1952 light, 1953-5724 moderate, 5725-9498 hard, and 9499-10000 very hard activity. A default value was also given for no activity at all. For the NQLS study, participant were required to have at least 5 valid days for each time they wore the meter. In NQLS, a valid day for the purpose of scoring data was defined as a day containing at least 8 valid hours. A valid hour was one that did not contain a consecutive string of 30 or more zero values. If there was at least 66 valid hours over the course of the time that participants wore the meter, the data was accepted as complete. Total values were calculated by summing across wearing days the number of 1-minute periods that had a count in the specified range. The variable used in chapter 5 is the mean number of minutes of moderate to vigorous physical activity over the number of recorded days. Justification for using this variable is provided in the chapter.

3.1.4 Attitudinal traits

Attitudinal variables, the reasons for selecting the specific measures from the array of variables available, as well as description of their respective scales are described in their relevant chapters. Importance of closeness to public transit in choosing housing location, satisfaction with access to public transit, enjoyment of moderate physical activity and lack of time for physical activity are the four attitudinal variables that were deemed important in addressing the research questions specific to this thesis.

3.1.5 Transit use

Transit use was measured with two variables. One assessed specifically the commute to work by public transit over a month, and the other asked the number of times a person walked to transit over the past month, which is assumed to involve taking a transit trip. Both outcomes do not report on individual trips, but rather provide a portrait of travel over a month.

Sample sizes vary across each of the empirical chapters for a number of reasons. First, if the chapter only uses data from one region. In chapter 4, only the subset of Seattle respondents was used. Second, if the main independent variables used were only asked to certain respondents. In chapter 5, information on commute to work was only asked to respondents reporting working outside the home. In chapter 6, all respondents of wave 2 of the survey were asked about their general transit use and their practice of different types of physical activity. Furthermore, not all respondents sent back their accelerometer, and not all accelerometer records were kept (for example when not enough valid minutes or valid days of physical activity were recorded. Finally, some respondents did not answer all survey questions, as is often the case. Household income had the highest number of missing values, reflecting the more sensitive nature of this information.

There are a few limitations associated with using the NQLS survey:

- There are a limited number of public transit users in low walkability neighborhoods (potentially reducing the attainment of significant results);

- Transit use indicators reflect monthly use, while active transportation and accelerometer measures reflect weekly activity; and
- Active transportation measures are not directly matched to each transit trip (as would be the case in travel diaries).

Furthermore, the two time data capture seemingly has the properties of a cohort, or panel survey but could not be used in this thesis for this property since survey items on transit use were only administered on the second wave of the survey. Because there was no information on transit use in the first survey, it was impossible to assess changes in physical activity as a result of changes in transit use. It was also impossible to assess, in the context of this thesis, variations in transit use and physical activity according to seasonality, or weather variations because the dataset used only contained a variable on the date the survey was received.

3.2 Objective transit service measures: King County Metro

To augment survey data on attitudes towards transit, I created spatial measures of access to the public transit network and land use surrounding the surveyed individuals' home. These measures were developed using King County spatial information provided by King County GIS services. Geographical Information Systems (GIS) can help create measurements of the transit system's quality of service for specific location (e.g. households). I developed three sets of transit quality of service measures: quality of transit service within 500 meter and 1000 meter network buffers surrounding survey respondents' homes, and shortest network distance to nearest local transit service (nearest stop and nearest park-and-ride) and regional locations (neighborhood centers). These measures served to analyze the distribution of transit service across the four neighborhood types present in the survey, as well as to identify relationships with public transit use.

For the analysis of objective GIS-based indicators, I limit my assessment to the NQLS respondents from Metro Seattle. Multiple technologies (light rail, heavy rail, bus) and transit networks provide service to the four counties of the Baltimore area (Baltimore, Howard, Montgomery and Prince George), made the development of service measures comparable across both regions difficult. Furthermore, some sampled neighborhoods were Transit-Oriented Developments (TOD) serviced by the Washington DC subway (e.g. Silver Spring, Bethesda and Rockville). This restriction was agreed upon early on in the thesis development phase and agreed with by the supervisory committee during the prospectus defense.

The objective of this section is threefold: to describe the GIS dataset used to create the transit service measures, to present the measures developed and the steps required in the creation of the measures, and to present maps supporting this discussion.

The transit measures were used in analyses:

- To assess the distribution of quality of transit service for different groups of the population across neighborhood quadrant and a classification of travel disadvantage based on housing location choices;
- To identify associations between quality of the transit service and public transit use.

3.2.1 King County Metro transit data

Data required for the creation of the public transit measures were gathered directly from the region. King County GIS produces a data CD where the most accurate and up to date spatial information in King County is compiled (www.kingcounty.gov/gis). Their bi-yearly production of data CDs is supported by a number of departments who regularly submit updated data. This ensures accuracy and consistency in data description quality and format. Archived data sets were available through special request, and were accessed for August 2003 (the most recent update on the December 2003 edition of the data CD). This was deemed the most appropriate time point since most surveys were mailed back between the fall of 2002 and the fall of 2003. A description of the spatial information layers selected for this project, their source and purpose is presented in Table 3.4.

Table 3.4 Data used to create transit service variables and maps

Layers and tables	Source	Purpose and used attributes
Base		
Street network and Road table	King County Metro transit, GIS group	Network buffers, Shortest path calculations
Open water	King County Water and land resources	Mapping
Neighborhood centers	King County Metro transit, GIS group	Shortest path calculations
Transit service		
Revenue service (bus lines) and Revenue service table	King County Metro transit, GIS group	Transit service measures Segment ID, route ID, express service
Bus stops and Stop table	King County Metro transit, GIS group	Transit service measures Stop ID, Compass direction of vehicle passing at stops
Park-and-ride lot location	King County Metro transit, GIS group	Shortest path calculations
Point locations		
NQLS respondents	NQLS research team	Linking surveyed individuals to transit service
Example locations (12) and associated network buffers	Created	Testing measures, mapping

The open water layer was used to provide a geographical reference to situate King County maps. The street network was used for mapping backgrounds, and in procedures using the network analyst function of ArcGIS 9.3. Next, the transit service variables created and information on the variable creation process are presented.

3.2.2 Data transformation process

Multiple GIS procedures available in the academic license package of ArcGIS 9.3 were required to create three sets of measures. The network analyst tool allowed the computation of network buffers for respondents' home location, and the development of some of the transit service measures. The other service measures were created using the spatial join tool. Once the three sets of measures were built, they were associated to the survey respondents to analyze access and use of public transit.

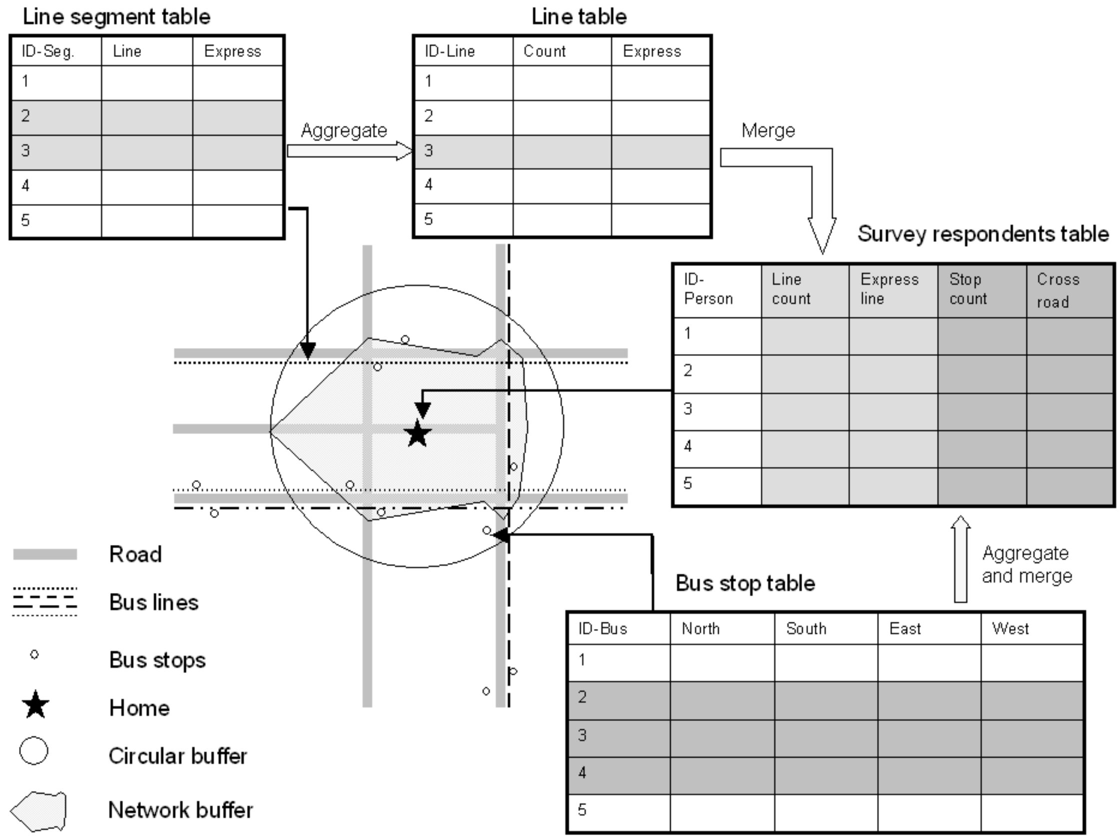
Two different procedures of the network analyst were used: the shortest path to nearest features, and the service areas. In both cases, the procedures used the street network to calculate geometrical distances, rather than direct lines (what is often referred to as crow fly). The service area procedure allowed the creation of a network buffer based on a set travel distance boundary on the street network. From a determined point, in this case the respondent's home location, the distance was calculated for each possible direction along the street network. The boundaries are then used to create an area, a polygon shape that reflects how far an individual can go in every direction using the street network. These boundaries, as they were used in this thesis, represent the expected pedestrian catchment area a person may walk to. These were used to identify proximate service as well as to calculate area level density measures.

3.2.2.1 Quality of transit service within 500 and 1000 meters from home

With the first set of measures, I seek to assess quality of service at one given location, using the survey individual household and workplace point. The TCQSM (TRB, 2003) suggests that a transit system requires accessible, fast, efficient and punctual service, comfortable, that minimizes transfers, and that serves desired and required destinations. I attempt to represent this set of characteristics by drawing a buffer area around home location point in which the presence and quantity of certain transit characteristics can be calculated.

This spatial information can be attributed to the individual by merging this information to survey responses using respondents' identification numbers as a link between survey database and the created spatial database. A visual description of the relationship between a household circular buffer and the data structure is presented in Figure 3.3. Information from the lines tables are aggregated and merged to the buffer, which is associated with individual survey respondents. The processes are described in more details below.

Figure 3.3 Associating quality of transit service measures to survey respondents



While the circular buffer is simpler to calculate, network buffers represent more accurately where individuals may actually walk. They always cover a smaller area than the circular buffers. Network buffers were set at 500 and 1000 meters for two reasons. First, according to the literature on public transit, people rarely walk more than 500 meters to reach a bus stop, and rarely more that 1 km to reach a faster system such as subways or express line (TRB, 2003; Morikawa and Ben-Akiva, 2002). Second, many studies use the 1000 meter buffer, giving it greater comparability to the body of literature assessing similar questions (e.g. Frank et al., 2004; Lee and Moudon, 2004).

Attributes of the lines and the stops were aggregated to the buffer, and associated back to survey respondents. Transit stops contained within each buffers were identified using a spatial join tool. The resulting many-to-one relationship was aggregated back to the individual. A bus count variable (number of stops) was added to the individual level file.

Additionally an indicator variable the presence of a transit crossroad within the buffer was created from the bus stop table. This would represent a location with greater regional accessibility. A transit crossroad was defined as a location where bus lines going to all cardinal directions would be found. For each stop, an attribute defined the compass direction of the vehicle with site access to a stop (North, South, East, West). The attributes were expanded into four dummies, dummies were summed during aggregation, and an indicator variable was attributed 1 if the sum of all dummies was above 0, else 0).

Bus routes intersecting (passing through) each buffer were also identified using the spatial join tool. The resulting one-to-many relationship produced a table of information that duplicated individual respondents and provided many cases for each bus lines. This is because transit routes are separated into segments that must be aggregated back to the route and re-associated to buffers to avoid double counting transit routes passing through. Two count variables (number of routes, number of express routes), as well as an indicator variable for express service (the procedure is the same as for transit crossroads) was created for each buffer.

Because network buffers vary in sizes depending on the characteristics of the road network, buffer areas were calculated and all count measures were normalized by areas.

3.2.2.2 Network distance measures

The last set of measures uses the network analyst to develop shortest path distance to the nearest facilities. For each survey respondents, three facilities were selected for their theoretical importance: bus stops, park-and-ride lots and neighborhood centers. For each destination, distance to the nearest features (3 for park-and ride lots and transit stops, 5 for neighborhood centers) was selected and the mean distance was calculated. Upon data observations, distance to nearest transit stop (meters), distance to nearest park and ride lot (kilometers), distance to nearest neighborhood center, and the mean network distance to 5 nearest neighborhood centers (km) were kept for analysis.

The measures developed to describe the public transit system for stops and for lines are presented in Table 3.5. It is typical procedure to develop a number of measures and identify and test the variables that present the highest relevance. The measures may be individually tested but sheer number of variables of potential significance and possibility of multicollinearity (see correlation Tables A.1 and A.2 in Appendix 1) suggests combining variables in an index. Factor analysis was used to combine multiple correlated measures into a smaller set of underlying constructs.

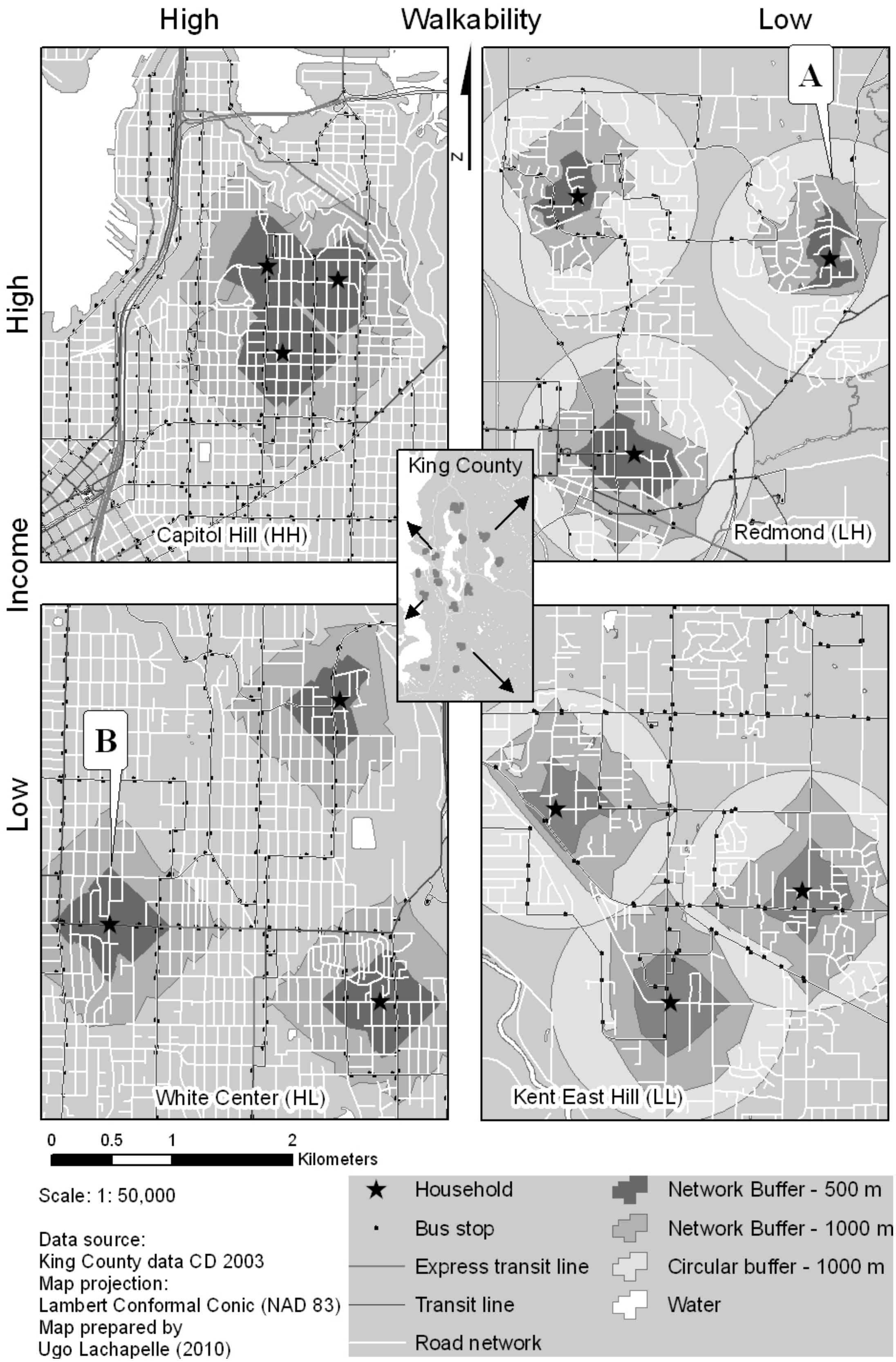
Table 3.5 Public transit service attributes

	Transit line measures
1	# of lines passing through buffer
2	Line density (# of lines/square km)
3	# of express lines
4	Presence of express lines
	Transit stop measures
5	# of stops in area
6	Stop density (# of stops/square km)
7	Presence of transit crossroad
	Network distance measures
8	Shortest network distance to nearest transit stop (m)
9	Shortest network distance to nearest park and ride (km)
10	Shortest network distance to nearest neighborhood center (km)
11	Mean network distance to five nearest neighborhood center (km)

3.2.2.3 Maps of analytical concepts

Geocoding survey respondents and creating GIS-based objective measures of transit service provides the additional opportunity to develop maps that conveys used data, measurements concepts, and neighborhood types (Figure 3.4). To maintain survey respondent anonymity, the map presenting fine scale examples of measures were developed using fictitious points positioned near existing ones. A supplementary map of King County is provided in Appendix 1, Figure A.1 as a visual example of differences by neighborhood in commuting to work.

Figure 3.4 Map of survey design and public transit line and stops



The map represents four sampled neighborhoods in the King County area, one for each type of neighborhood (high and low walkability and high and low income combinations). The regional location of each neighborhood is presented in the center map. A grid-like street network covers both high-walkability neighborhoods, and a network of loops and cul-de-sac covers the two low-walkability neighborhoods. They are also more typically found on the outer edges of Seattle.

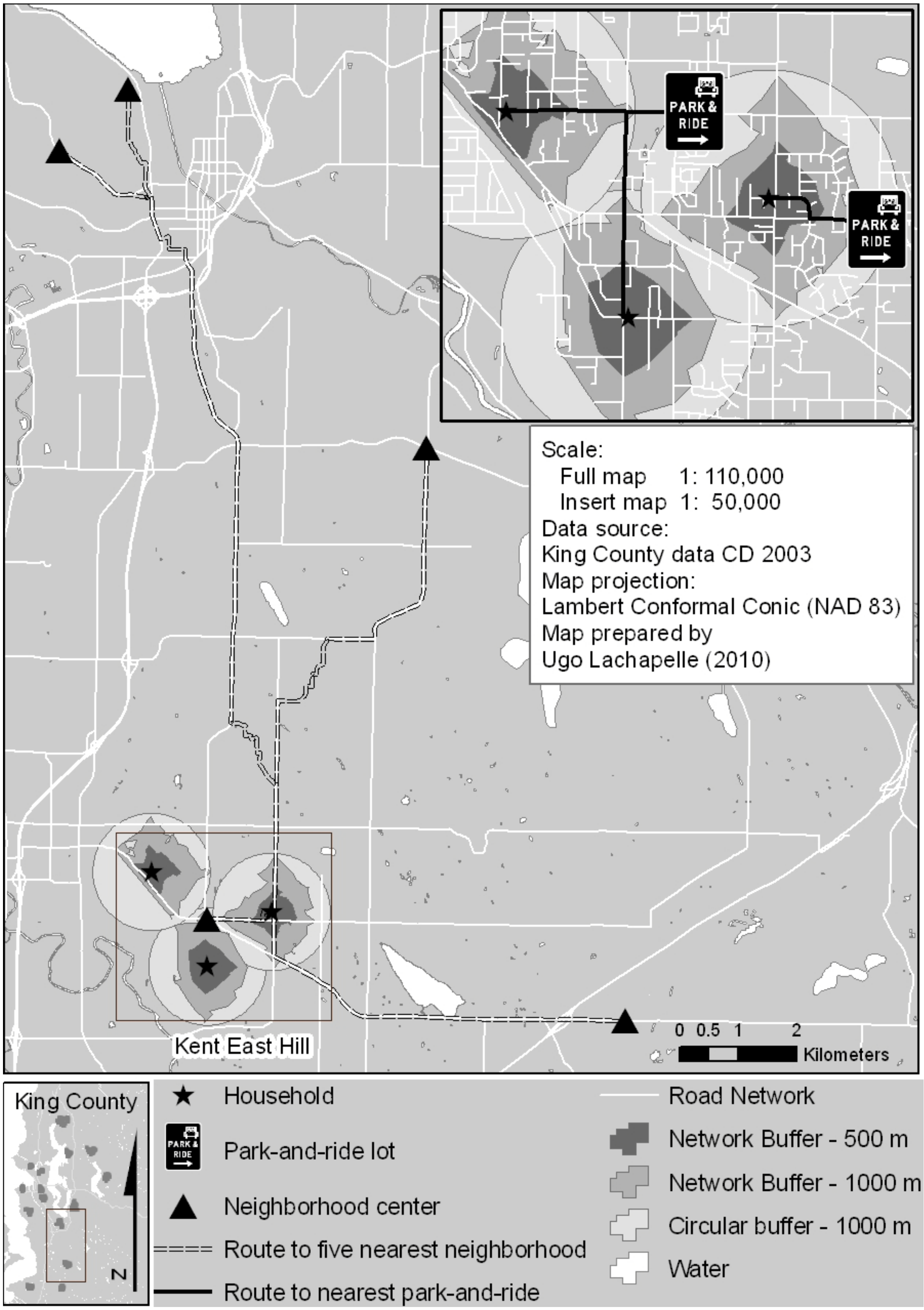
The maps denote by a star 12 fictitious households and show their respective 500 and 1000-meter street network buffers. The maps on the right side also show how a 1000-meter circular buffer relates to the network buffers. The points were positioned to give an idea of the outer boundaries of the sampling areas. For example, Capitol Hill respondents were sampled in a much smaller, but more densely populated area. In the smaller sampling areas (typically high walkability), standard deviations will be smaller as the buffers associated with respondent overlap considerably more than in low walkability neighborhoods.

The transit network is represented by dark gray streets lined with points representing the bus stops. Where express lines are present they a show atop of other lines and are black.

Two example points are used to describe the transit service measures: A on the top right corner, and B on the Bottom left. Point A contains one bus line and two bus stops within the kilometer network buffer, and none within the 500-meter network buffer. In contrast, point B's 500-meter buffer contains 3 lines, 10 bus stops, a hub (Lines running north-South and East-West) and an express line. This contrast is congruent with the idea that transit service is more frequently found and in better quality in high walkability neighborhoods.

A second map is used to convey the two regional measures developed – shortest network distance to the nearest park-and-ride and mean shortest network distance to the 5 nearest neighborhood centers – using the spatial analyst's shortest network distance (Figure 3.5).

Figure 3.5 Map of example of measure of distance to nearest park-and-ride and mean distance to 5 nearest neighborhood centers



3.2.3 Discussion of measures and integration to survey analysis

The measures that were described through this map will be used in chapter 4 to assess satisfaction with transit service and the use of public transit. They also serve to explore the relationship between high and low walkability neighborhoods and transit service. To complement and augment the neighborhood high and low walkability neighborhood design variables, previous work linking household locations to built environment measures was appended to the NQLS data set. Based on a set of built environment measures created for each surveyed individual at the 1 km network buffer level, a walkability index measure was available in the dataset. The Walkability index was the summed z-scores of a*2, b, c and d (see below). Doubling street connectivity's value was shown to improve the predictive power of the index for the 2000 US census journey to work data (Frank et al., 2009).

a. Connectivity (Intersection with three or more legs per square km);

b. Net residential density (ratio of residential units per residential land area);

c. Land use mix for 5 land uses (residential, retail, entertainment, office, institutional);

d. Retail Floor Area Ratio (retail building square footage divided by retail land square footage).

Because the walkability index is a linear construct used to represent what is by nature a non-linear phenomena, there is a possibility that the walkability index does not adequately represent variation in the characteristics of a neighborhood that makes it more walkable. Land use mix, residential density, intersection density and retail floor area ratio are all variables that are not normally distributed. As such using the z-score to represent their variations to the mean, and summing these z-scores is potentially problematic. In the thesis, the continuous walkability index created for each surveyed individual is not used in any analysis, but rather served in the neighborhood sampling process that occurred prior to survey field period. The only measure of walkability retained in the empirical chapters is a dichotomous variable representing low (deciles 2,3,4) and high (deciles 7,8,9) walkability selected neighborhoods. A continuous measure of walkability at the network buffer level is only used below to evidence its high correlation with transit service.

The reader will likely wonder why the transit service measures were not used in the manuscripts assessing physical activity as dependent variables (chapter 5 and 6).

Theoretical reasons for this will be presented in section 3.3.2. A simple empirical test is presented here (Table 3.6) to provide further justification. In preliminary testing of the transit service variables, both were highly correlated with neighborhood walkability – either as an indicator variable of neighborhood sampled (not shown here), or as a continuous variable developed for each survey respondent. This was expected based on the review conducted by Ewing and Cervero (2001). The continuous measure of walkability was not reported elsewhere, but follows the description presented in the framework, section 2.1.1. In pairwise correlations, the transit service variables were sometimes individually correlated with the accelerometer measures used in chapter 5, and with the self-reported active transportation measure of chapter 6 (not shown here). However, in partial correlations controlling for the continuous measure of neighborhood walkability, none of the continuous or count transit service measures were associated with accelerometer measures or other measures of physical activity.

Table 3.6 Transit service, walkability and physical activity (accelerometer): pairwise and partial correlations

	Pairwise correlation				Partial correlation	
	Moderate to vigorous physical activity		Distance to nearest stop (m)		Moderate to vigorous physical activity	
	Corr.	Sig.	Corr.	Sig.	Corr.	Sig.
Distance to nearest stop (m)	-0.105	0.001			0.0044	0.890
Walkability (continuous)	0.207	0.000	-0.490	0.000	0.1795	0.000
			Transit service factor[2]			
Transit service factor	0.1964	0.000			0.0458	0.147
Walkability (continuous)	0.2069	0.000	0.8478	0.000	0.0806	0.010

Corr. = Pearson Correlation; Sig. = Statistical significance (p-value).

In the next section, a discussion on how the survey information and transit measures will be analyzed using statistical methods and concepts is presented.

[2] A graphical presentation of the relationship between the continuous measure of walkability and the continuous transit service factor (plot and fitted line) is presented in Appendix 1, Figure A.3.

3.3 Statistical approaches and modeling framework

Various statistical modeling techniques were used to assess hypothesized relationships. The specific techniques typically reflect the type and distribution of the dependent variable, and the hypotheses being studied. In the following sections, three broad sets of topics are discussed. A presentation of the logic of causality sets the stage for statistical analysis. This is followed by a presentation of basic concepts of multivariate analysis, as well as the statistical models than can be used depending on the dependent variable being studied. To assess the different hypotheses, sequential regression techniques, interaction terms, and stratified analysis were also used. These are discussed below.

As the NQLS survey sampling was based on neighborhood clusters, hierarchical modeling techniques were required to partition the effects of neighborhood-invariant characteristics, and individual-specific characteristics (Masse et al., 2002; Bingenheimer and Raudenbush, 2004). In the context of the NQLS survey design, random effects were included in all models to control for clustering, but neighborhood levels effects were not interpreted *per se*.

While efforts were made to standardize the use of vocabulary, the statistical traditions of econometricians and epidemiologists have developed distinct terminologies that were used based on the targeted journal. Specific model formulation discussed in the analytical chapters are not explicitly stated for simplicity but rather discussed in general terms. However, because discussions arose during the review process about material not included in the empirical chapters, some theoretical concepts from the thesis will be used in the discussion.

3.3.1 The logic of causality: theory, associations, time order and spurious correlation

In their 2005 report, the Transportation Research Board and the Institute of Medicine conclude that our understanding to date of the relationship between travel, physical activity and the built environment was limited. The lack of an agreed upon theoretical framework and the lack of sufficient conceptual tools have hampered researchers' ability to clearly identify the individual contributions of the numerous factors that may link travel and physical activity behavior to built environment (TRB, 2005). Research tends to proceed in stages of increasing complexity first laying out simple empirical associations and strengthening conceptual models, then subjecting these to rigorous statistical testing and further hypothesizing on confounding and mediating factors. The ultimate goal is to ascertain processes of causality. To ask what caused something is to ask what factors influenced an event, or effectively made an event happen. If an independent variable can be modified through policy, as may be the case for the built environment and transit service, it has the potential to be used to influence an outcome variable, such as individuals' physical activity levels and the use of transit. In statistics, determination of causality rests on four pillars:

- A relationship or association must be found between two variables;
- There must be a clear explanatory rationale for the causal link in the form of a theoretical framework and conceptual model;
- Researchers must ascertain temporal succession. The variable or factor which is believed to influence the dependent variable must precede this dependent variable in time;
- Spurious relationships caused by other variables should be eliminated by testing the introduction of these variables in the models (Spicer, 2005; Handy et al., 2006).

Because they only observe a phenomenon at a single point in time, traditional cross-sectional studies only enables the identification of associations; they do not provide conclusive evidence of the temporal succession required to establish a causal link. However, by testing the strength and magnitude of effects from cross-sectional studies, researchers have accumulated evidence, completed theoretical models and identified potentially spurious relationships, justifying the need to conduct more costly, time consuming and complex data gathering and analyses. In the absence of longitudinal datasets, however, some approaches may strengthen cross-sectional studies. Self-selection, or the choice to move to a neighborhood because it enables the travel behavior a person desires (rather than the neighborhood actually influencing the behavior), has been the most important potential spurious relationship studied. The TRB/IOM report (2005) mentioned earlier identified a few studies that addressed the self-selection bias through various approaches:

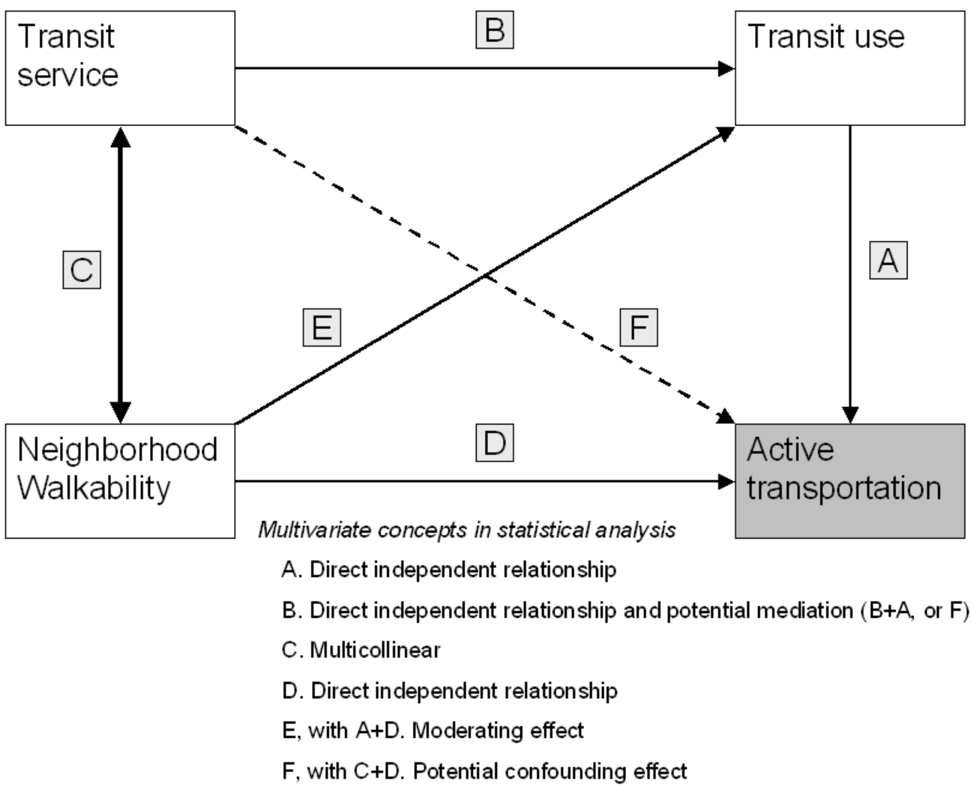
- Instrumental variable technique (Boarnet and Crane, 2001);
- Structural equation modeling (Bagley and Mokhtarian, 2002) to assess the multiple directions of causality;
- Follow-up survey of household moves to compare at changes in walking and changes in the built environment (Krizek, 2003);
- Preference studies that compare matched or "consonant" individuals, to mismatched, or "dissonant" individuals in their relationship between residential location, residential preference and travel behavior (Schwanen and Mokhtarian, 2004 in TRB, 2005 p.135).

An approach similar to this last one is used in Chapter 4 to assess not walking but rather transit use as a dependent variable. The statistical methods used in an analysis will depend on the type and distribution of the outcome, the characteristics of the data and the research questions. Concepts of multivariate analysis related to the independent variables are used to formulate and test hypotheses. These are presented first, followed by the actual statistical models.

3.3.2 Multivariate analysis: direct independent effects, mediators, moderators, multicollinearity and confounding factors

When multiple independent variables are assessed against one dependent variable, the nature of relationships may be found to vary in more complex patterns. A number of conceptual tools and statistical formulation may be used to assess these relationships. The frameworks and questions used in this research will serve as examples of the statistical concepts used on independent variables in a multivariate context. Examples of direct independent effects, mediation, moderation and confounding effect are presented in Figure 3.6 using four basic constructs: two behaviors (active transportation and public transit use), and two environmental settings (neighborhood walkability and public transit service). This conceptual model is by no mean an exhaustive description of all relationships studied in this thesis, but rather serve to describe the complexities involved in theorizing about the relationships analyzed, and present the statistical approaches used to address these relationships. The reader will find here some of the concepts described in the introduction and theory chapter on the relationships that may support or negate the catalyst hypothesis. While each of these concept is not individually presented here, every tool used in the thesis to assess the relationships are described here.

Figure 3.6 Concepts of multivariate analysis applied to the research questions



The most widely assessed relationship is the **direct independent effect**, which differ from as simple association in that the relationship exists when other variables are controlled for. Example of direct independent effect: In this thesis, transit use is hypothesized to have a direct independent relationship with active transportation (A), an association for which there is little theoretical evidence. On the other hand, a well-established example is the direct and independent association between better transit service and higher population levels (or mode shares) of transit use (B). Additionally, years of research have shown the relationship between the build environment and active transportation (D), yet some still question this relationship. Finally, because transit journeys involve a pedestrian segment, neighborhood walkability may make it easier and more pleasant to use transit (E). Not shown in this model, but also of potential importance is the following: higher income is associated with more physical activity; higher income is associated with less transit use. Transit use is associated with higher physical activity levels independently of household income.

Multicollinearity occurs when two independent variables are so closely associated with each other that their effect is difficult, and sometimes impossible to disentangle. Because a denser, more walkable built environment tends to be better served by transit, there is potential multicollinearity between these two variables (C). Sequential regression techniques, and the use of pairwise and partial correlation can allow the identification of multicollinearity (This confounded relationship was shown above in Table 3.6 and will not be further analyzed in chapter 5 and 6).

A **confounder**, or confounding variable is associated with the outcome, physical activity for example, but is also associated with an independent variable of interest. It may influence the strength of the association between an independent variable and the physical activity outcome, typically by transforming a significant relationship into a non-significant relationship (Bauman et al., 2002). Confounding variables can be identified through sequential regression techniques.
Examples of confounder: walkability confounds the relationship between transit service and active transportation (F, with C+D).

A **mediator** is “an intervening variable that is necessary to complete a cause-effect link between an intervention program and physical activity” (Bauman et al., 2002, p.8). Sequential regression techniques (adding variable in the model and inspecting changes in key parameters) and interactions can be used to assess mediation.

Example of mediator: Using transit is necessary in the relationship between transit service and physical activity. Say transit service is defined in two different ways: frequency of service on the one hand, and distance to transit on the other hand. For transit users, living farther from transit service could result in more active transportation because they would need to walk farther every time they would access transit. For non-users, this relationship would be non-existent because they do not use transit (B+A for users, or F for non-users). If the frequency of transit is considered instead, a higher share of the population in this area may decide to use transit (which may make them walk more as will be seen in chapter 5), but there are no theoretical reasons to believe that transit users would walk more directly as a result of having a better service. Again, for non-users, this relationship would likely be non-existent because they do not use transit.

A **moderator**, or moderating variable, is an independent variable that affects the strength, direction, or both of the relationships between another independent variable and the outcome (Bauman et al., 2002). For an independent variable to be considered a moderator, it must be interacted with another independent variable. Interacting continuous variables is the equivalent of multiplying them. Interacting categorical variables is the equivalent of creating subcategories of variable 1 based on variable 2. Stratifying the model by the moderator variable is another way to present relationships of different strength between the independent variables of interest and the outcome, depending on the moderating variable. Because the identified relationships are often difficult to interpret, Sociologist Arthur L. Stinchcombe (1968) suggests the use of “type-concepts”, constructed out of a combination of the values of several variables. Creating such typologies and naming them based on what they represent, provides a convenient way to more simply present the data.

Example of moderator: The synergy between using public transit and neighborhood walkability may provide more opportunities for active transportation through walking to nearby services, as well as walking to the transit stop to go to farther destinations (E, with A+D). As such, transit use may moderate the relationship between built environment and physical activity. However, another possibility is that transit users in high walkability neighborhoods would not walk much more than non-users that take advantage of neighborhoods services, but on the other hand, transit users living in low walkability environment, however few, would walk much more than their non-user counterparts that never walk around the neighborhood for lack of destinations.

3.3.3 Statistical models used

The breadth of situations encountered by researchers and the diversity of fields contributing to the development of statistical methods has generated modeling frameworks that can account for many types of research questions and types of dependent variable, which largely influences which model will be used. For each model used in the empirical chapters, the type and distribution of the dependent variable required to use the model is presented here in greater details and in its mathematical formulation. The simplest model, the Ordinary Least Square (OLS) regression is presented first, followed by the Hierarchical Linear Model (HLM) framework.

Because all models use a hierarchical model formulation, they are estimated using Maximum Likelihood Estimators (MLE). As such, no information matches the traditional model fit values of R^2. MLE can however be used to compare model fit after adding a variable, or to compare models using a different formulation. MLE is an iterative procedure that produces a log-likelihood value for a constant only model and for the full model. The specific formulation of the log-likelihood (LL) function depends on the model. A discussion of these estimators goes beyond the scope of this section. In the thesis, the log-likelihood (the result of MLE) is used as a measure of goodness-of-fit and allows comparing model fit depending on model specification. The likelihood ratio test is done through the following equation: -2 [ll (base model) – ll (expanded model)]. The returned value has a chi-squared distribution that can be assessed for its statistical significance. A significant difference between the base and full model means that addition of the variable(s) significantly improves model fit. All variables contained in the base model must also be in the full model for the log-likelihood test to be adequate. A discussion is presented below on what models are appropriate and in what situations.

3.3.3.1 Ordinary Least Square regression

The Ordinary Least Square (OLS) regression model is the simplest and most commonly used form of regression. It fits a continuous dependent variable that is assumed to follow a normal distribution. Y ~ N (0, σ^2). The dependent variable can be intervals or ratios. The linear regression models take the following mathematical form (1).

$$Y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p + \varepsilon_i \qquad 1$$

Where y_i is the predicted value; β are coefficients associated with independent variables *x*, and ε is the error term, which represents an observation's deviation from the conditional mean. Regressions analyses allow multivariate assessment of variation in the dependent variable. Relationships between dependent and independent variables are assumed to be linear. In all models presented in this thesis, independent variables can be continuous, count, categorical or binary. For continuous and count independent variables, the assumption of normal distribution required for dependent variables can be relaxed (Washington et al., 2003). Categorical variables must be converted into a series of dummies (binary variables) one for each of the categories, minus one, which will be the reference category against which other variables are assessed.

While this model is appealing for its computational ease, it is a rather inflexible model that is only applicable to normally distributed dependent variables that do not occur frequently in the social sciences. Numerous models have been developed to address the limitations of OLS regression, and to broaden the possibilities of statistical analysis. The dependent variables presented throughout the thesis require a number of different models designed to fit binary, ordinal and censored continuous dependent variables. A summary presentation of each model used in empirical analyses follows.

3.3.3.2 Hierarchical linear models

To account for clustering of respondents in selected neighborhoods, the introduction of neighborhood random effects is required. A recent trend in statistical analyses of the effect of place on health is the use of hierarchical linear models (HLM), also referred to as multilevel models and mixed effect models (Masse et al., 2002). HLM can be fitted to most of the traditional statistical methods, while using a hierarchical data structure. Simply put, individuals of the same household all have the same value for household income since they are all part of the same household. Similarly, residents of a neighborhood share similar circumstances with respect to their opportunities for travel. Hence, correlation in the data is not random, but rather the product of a higher-level association. Failure to account for this may bias estimates. The same may be true for measures of the built environment in which individuals of the same household reside. HLM was developed initially in education studies to understand the role of individual, classroom and school setting factors in predicting school grades and academic success. Since then, it has become widely used in the health field, and is gaining in popularity in the transportation field. Regression modeling typically includes an error term representing variance unaccounted for by the model, either through known omitted variables, bias in response, bias in metric used or through randomness. In HLM, this error term is split between the two or more levels of measurement, allowing researchers to distinguish the intraclass correlation (proportion of variability in independent variables that is captured between groups) from the interclass correlation (proportion that is between individuals) (Rasbash et al., 2000). In the built environment and physical activity literature, HLM will become more commonly used since respondents are nested within households that are nested in a neighborhood (Masse et al., 2002). Examples of recent research using such techniques include Kelly-Schwartz et al. (2004) (individuals nested in their Primary Metropolitan Statistical Areas - PMSA) and Ewing et al. (2003) (individuals nested in their county). All models presented in this thesis used a Hierarchical Linear Modeling framework. HLM has the following mathematical formulation for a random effect model with individual level covariates only, as is used in the analysis. The notation refers to individuals *i* nested in neighborhoods *j*.

$$Y_{ij} = \beta_{0j} + \beta_{1j} x_{ij} + \varepsilon_{ij} \qquad 2$$

$$\beta_{0j} = \gamma_{00} + \mu_{0j} \qquad 3$$

$$\beta_{1j} = \gamma_{10} x_{ij} + \mu_{1j} \qquad 4$$

$$Y_{ij} = \gamma_{00} + \gamma_{10} x_{ij} + (\mu_{0j} + \mu_{1j} + \varepsilon_{ij}) \qquad 5$$

Where y is the dependent variable β is the constant (or mean) for group *j* and the coefficients, γ is the mean for all groups, μ is the neighborhood level error term, ε is the individual level error term within group *j*, and *x* is an observed independent variable. Combining equation 2 with 3 and 4 leads to equation 5

3.3.3.3 Logistic regression model

The logistic regression is a special case of the generalized linear modeling framework that fits a binary outcome variable. In the thesis, it was used to assess the binary dependent transit use variable. The logistic model takes the following mathematical form (6):

$$P(i) = \frac{e^{g(x)}}{1 + e^{g(x)}} \qquad 6$$

Where p is the probability of binary outcome *i*, one of the two possible responses, x is the set of dependent variables, g(x) is the logit function (Hosmer and Lemeshow, 1989). The logit function, $g(x) = \ln(p(i) / (1-p(i)) = \beta_0+\beta_1 x$, is linear in its parameters, may be continuous, and may range from -∞ to +∞, depending on the range of x. The principle that guide multivariate ordinary least square regression analysis are also used in logistic regression. It can be show that equation 6 bounds the conditional mean p(*i*) between 0 and 1. Other models can be used for binary dependent but this one is the most popular because it produces more interpretable parameter estimates. The alternative model, the probit, is much less frequently used, at least in planning, and mathematically and computationally more complex.

3.3.3.4 Ordinal regression

The ordinal regression model accommodates categorical data that are ordered. For example, there is no logical order in categories of modes of transport (auto, bus, train). On the other hand, a likert-scale of satisfaction (not satisfied, somewhat satisfied, satisfied and very satisfied) presents a progressive order of increasing satisfaction. Chapter 4 uses two ordinal scales as dependent variables: one of satisfaction, and one of perceived importance. Likert-scales are the most frequent form of ordinal dependent variables. Ordinal regressions are also named ordered logit and cumulative logit regression. The model is derived from the logit model formulation and uses the logit function as a link between dependent and independent variables. The structural model is (7):

$$y^{*} = \beta x + \varepsilon \qquad 7$$

Y, and **y*** (read y star) are used to represent respectively the observed dependent variable (the actual information contained in the database) and the latent variable (the variable used in model estimation). The rule that can be used to relate the latent observations to the ordinal response variable is the following (8):

$$y_i = \begin{cases} 0 & if \quad y^{*} \le 0 \\ 1 & if \quad 0 < y^{*} \le \mu_1 \\ 2 & if \quad \mu_1 < y^{*} \le \mu_2 \\ \vdots & \\ n & if \quad \mu_{n-1} < y^{*}. \end{cases} \qquad 8$$

Where μ_1, μ_2, … μ_n are estimable parameters (referred to as thresholds) that are estimated jointly with the coefficients. The model can also be expressed in terms of probabilities but the empirical analyses in chapter 4 do not use this feature.

The assumptions supporting the use of the ordinal regression are: that the dependent variable is not normally distributed, and that the effect of an independent variable on a dependent variable is the same for each level of the dependent variable. This is referred to as the assumption of parallel lines. This assumption can be tested using the log-likelihood ratio technique. Statistical software packages often provide a test of the null hypothesis that regression lines are parallel for each level of the ordinal dependent variable, against a model where regression lines are allowed to be estimated without parallelism constraint (general). –2 (ll (null hypothesis) – ll (general)). A non-significant result means that the assumption is not violated. If the assumption is violated, categories may be combined or a multinomial regression technique may be used.

3.3.3.5 Tobit model

In chapter 6, self-reported physical activity variables developed using the International Physical activity Questionnaire (IPAQ) produced a continuous variable that is censored: the question imposes a boundary on the response of individuals. In this case, reported physical activity had to be practiced for at least ten minutes at a time in order to be reported. This case of censored dependent variable is distinct from truncated dependent variables, where both the dependent and independent variables are missing from the data set. In the case of censored dependent variable, only the dependent variable is missing, while the independent variables are still available for estimation. The Tobit model avoids the bias inherent in modeling censored variable using OLS regression, which would yield a downward-biased estimate of the coefficient and an upward-biased estimate of the constant. The Tobit model takes the following form (9):

$$y^*_i = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p + \varepsilon_i \qquad 9$$

The observable variable y_i is defined to be equal to the latent variable whenever the latent variable is above zero and is set to zero otherwise, as below (10):

$$y_i = \begin{cases} y^*_i & if \quad y^*_i > 0 \\ 0 & if \quad y^*_i \leq 0 \end{cases} \qquad 10$$

Where y* is a latent non-observed variable. The reported coefficients show direction and significance of associations between independent variables and the latent variable y*. Coefficients cannot be used directly to interpret y_i. Associations of interest with the observed variable y_i are rather estimated through $\hat{y}$, which is equal to the coefficient weighted by the probability that variables were above the censoring threshold, ($\hat{y}$, | y_i > threshold).

3.4 Conclusion

In this chapter were presented the survey and transit data used in the empirical analyses that follow, as well as the statistical concepts and models used throughout the empirical chapters. The following chapters present the empirical analyses that use the theories, data, statistical concepts and models presented throughout chapter 2 and 3. The time order between an independent variable and a dependent variable cannot be established using a cross-sectional data set, but the results of the analyses can nonetheless be used to identify associations, strengthen the theoretical framework, and rule out potential spurious correlations caused by mediating, moderating and confounding variables. As such, it may set the ground for further analyses using longitudinal datasets.

In the next chapter

In chapter 4, transit use was explored as a precondition to the studied association with active transportation using the Seattle sample. Personal characteristics such as car ownership and income, and quality of transit service are known factors associated with the probability of using transit. A retrospective assessment of the important factors in housing location choice, and objective measures of transit service near the residents' homes, were used to develop transit-housing match categories and estimate associations between attitudes and transit use. Characteristics of pedestrian environments associated with walking are assessed for associations with transit use. The ability to locate according to preference for transit was not always met. Individuals had to make trade-offs in housing location which prevented them from locating near good transit service. Yet not having located near good transit service was not significantly associated with a lower probability of using public transit. Instead, transit use likely occurred in less than ideal conditions. Provision of different types of housing opportunities (e.g. for smaller households and larger families) of a variety of price ranges within transit access is likely required.

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Chapter 4 Public transit service and housing location choice: predisposition, satisfaction and transit use[3]

4.1 Introduction

Public transit is sparsely and unevenly distributed within and amongst metropolitan regions in the US (TRB, 2001; TRB, 2002). Individuals wanting to use public transit may try to gain convenient and adequate access to transit service by making transit a preferred characteristic in their housing location choices. In fact, in so many cases, they need to. Whether individuals are able to conveniently locate near transit has largely gone unobserved. Hence, longer-term housing location choices and predisposition to use transit as expressed through housing location preferences may influence short-term decisions to use public transit (Scheiner and Kasper, 2003; Scheiner, 2006; Litman, 2009). Yet access to transit may be only one of a series of characteristics required by households when they move.

In a study conducted in California on motivation to move to a Transit-Oriented Development (TOD), only a third of respondents chose access to transit as one of the three primary reasons they decided to move to a TOD. Motivation to move to a TOD because of better access to public transit was however associated with an increased probability of using public transit (Lund, 2006). A recent report to congress stated the problem in the following way: “Transportation, housing and energy can no longer be viewed as completely separate spheres with little or no coordination through the different levels of government” (HUD, 2008). The report includes a recommendation to better coordinate transportation and housing policies and programs.

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[3] A version of this chapter will be submitted for publication.
Lachapelle, U., Frank, L.D., Sallis J.F., Saelens, B.E., Conway, T.L. Public transit service and housing location choice: predisposition, satisfaction and transit use.

Research on the effects of self-selection in the relationship between the built environment and travel choices has had the benefit of clarifying whether people make housing location choices that suit and potentially reinforce their desired travel patterns, or if living in a location that enables or restricts the use of certain modes actually influences travel choices (Handy et al., 2005; 2006; Schwanen and Mokhtarian, 2005a, 2005b; Cao et al., 2006; Frank et al., 2007; Kahn and Morris, 2009). In this body of research, little attention has been given to the actual ability of people of different socio-economic groups to locate in places that satisfy their travel preferences. Socio-economic differences in access to travel options – referred to as travel disadvantage, travel disparities or transportation equity – has become an important topic both in the US (Thompson, 1998; Blumenberg, 2003; Bullard et al., 2004; Sanchez and Brenman, 2007; Sanchez, 2008; Sanchez and Brenman, 2008) and abroad (Lucas, 2006). Competing preferences, housing needs (according to household characteristics) and financial limitations may reduce a household's ability to locate in a place that supports their travel preferences and needs. Furthermore, market surveys show that transportation is not the most highly prioritized characteristic in choosing a house and its location (TCRP, 2008). Quality of schools, house and lot size, and safety from crime are typically the highest-ranking features in neighborhood choice (Litman, 2009). In Lund's study (2006), cost, quality and type of housing were also considered central in choosing TOD. Once all trade-offs are made, the neighborhood where an individual locates can potentially discourage the choice to travel by public transit, even when an individual is predisposed to transit use.

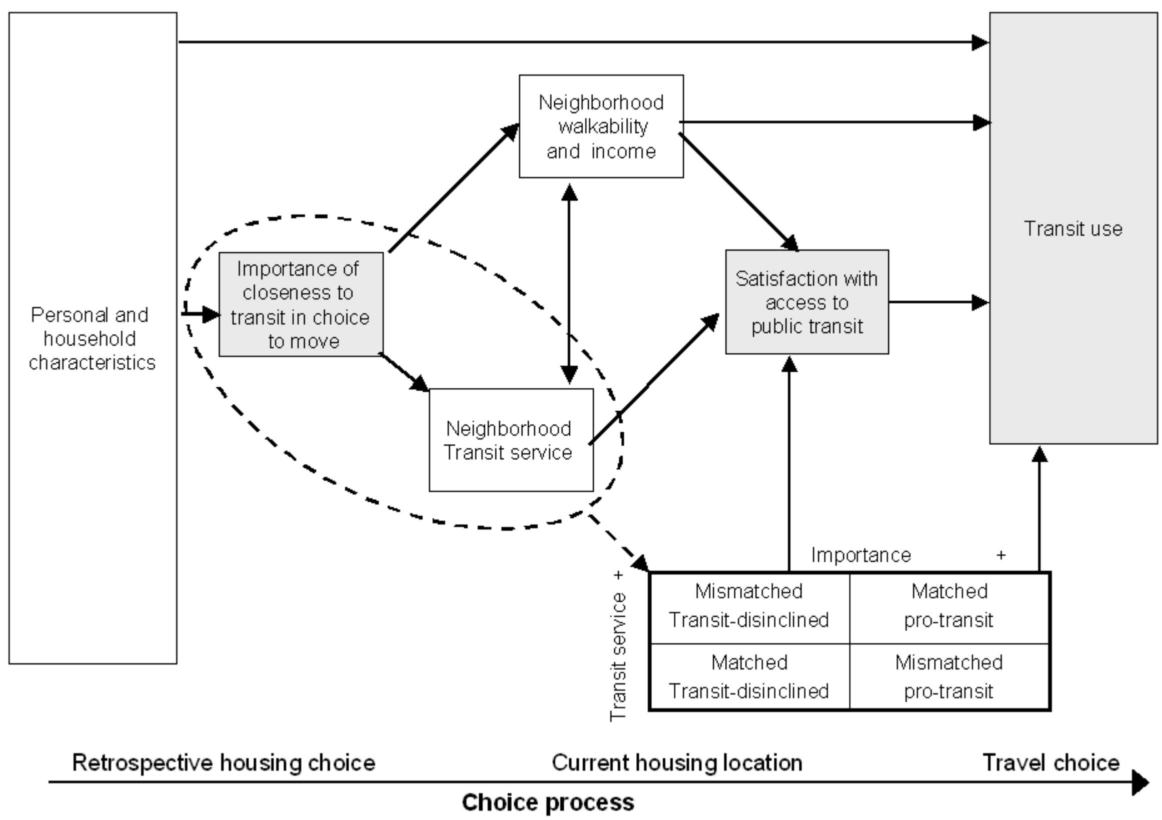
Market research has shown that Americans want more compact developments, shorter commutes, nearby shops and services, and good walking and public transportation infrastructures (Litman, 2009). Demographic and economic trends (smaller family size, double-income earners without children and people living alone) have led to an increased demand for such development over time. The result is a supply shortage and increases in the market value of this type of housing (Litman, 2009). No previous analysis of the ability of individuals with different socio-economic characteristics to locate according to their preference for public transit was found in the literature. An exploratory analysis of this central gap is structured using the following research questions: Were those wanting to move to a neighborhood with public transit able to do so? Did success at locating according to travel preference influence transit use? The following research premises serve to structure the current study:

- Individual and household socio-demographics are associated with the importance of public transit in housing location choice;
- Satisfaction with access to public transit varies across built environments, transit service levels, and socio-demographic characteristics;
- Some respondents, likely of lower income, may have placed importance on public transit when they were looking for housing, but ended up living in a place with lower quality of transit service, and others may have been more successful; and
- Transit use is associated with retrospective housing location decisions and with the quality of transit service. Not all survey respondents were able to satisfy their preference for a transit accessible neighborhood, and this may influence their use of transit.

4.2 Analytical framework

In this analysis, transit use was explored within the context of socio-demographic characteristics, longer-term housing location choices, transit service quality and neighborhood walkability. Differences in ability to actually live in neighborhoods that provide good access to transit were contrasted to socio-demographics, neighborhood characteristics, and transit service. Integration of the housing and transportation choice process over a hypothetical timeline is presented in Figure 4.1. Personal and household characteristics were used to estimate three outcomes: self-reported importance of closeness to transit in choice to move, satisfaction with access to public transit, and transit use in the month preceding the survey (shaded in Figure). The long-term process of neighborhood selection based on desire for good transit leads to a current housing location that in turn may be associated with travel behavior. Individuals in this study located in a neighborhood with a certain walkability level, socio-economic profile and transit service level which can be characterized. The neighborhood wherein people have located can then be assessed for its apparent transit supportiveness through objective measures of transit service, and through perceived satisfaction with access to public transit. By combining importance of transit in housing location choice and actual transit service, individuals can be categorized as pro-transit or transit-disinclined, and be matched or mismatched to their expressed preferences. This transit-housing match categorization is represented in the figure by a quadrant with four categories on the lower-right corner. The dashed ellipse identifies the variables used to create the transit-housing match. Socio-demographic characteristics, neighborhood location choices, current neighborhood of residence, quality of transit service and perceived satisfaction may all be associated with transit use.

Figure 4.1 Analytical framework



Shaded areas represent studied outcomes; ellipse represents measures used to create the matched and mismatched transit-housing categories.

4.2.1 Housing location choices

Although increasing, the provision of high quality public transit in urban environments is sparse in the US (TRB, 2001). Many areas, especially in suburban fringes and small communities, are poorly served or not served at all by public transit. Only about half of the communities in the United States have public transportation systems (TRB, 2002). If a person wants or need to use public transportation, they must include this in the characteristics of the housing they will choose. Housing location choice may play an important role in the availability and subsequent use of public transit.

Levine and Frank (2007) document a latent or unmet demand for walkable environments where households can self-select to be more active and walk to destinations in their neighborhoods. Litman (2009) reviewed a number of studies and reports showing that demand for more walkable development exceeds supply. That is, some people would actually want to live in areas with walkable characteristics, but are unable to for various reasons (cost and availability for example). There is also likely an unmet demand for environments supportive of public transit use. Accessibility is a valued good in housing purchase (Ryan, 1999; Hess and Almeida, 2007; Ryan, 2005), making locating near transit potentially more expensive and difficult for lower income individuals (Reconnecting America, 2007).

4.2.1.1 Transit-housing match

A retrospective assessment of the importance of public transit in location choice, combined with a measure of the current quality of public transit near an individual's home, provides a way to assess whether respondents were able to locate in a place with adequate public transit. Accordingly, four categories of transit-housing match were created (Table 4.1).

Table 4.1 Transit-housing match

Did not want transit / Poor transit service	Matched transit-disinclined (1);
Did not want transit / Good transit service	Mismatched transit-disinclined (2);
Wanted transit / Poor transit service	Mismatched pro-transit (3);
Wanted transit / Good transit service	Matched pro-transit (4).

More details on this classification are presented in the method section. Individuals that responded that closeness to public transit was important in neighborhood choice but had lower than average access to transit (Mismatched pro-transit, shaded) bear the burden of an unfavorable location mismatch with respect to public transit. This unfavorable situation likely reduces the probability that they use public transit as part of their travel options.

4.2.2 Travel behavior

Travel choices are frequently analyzed using the econometric decision-making framework of discrete choice (Domencich and McFadden, 1975; Ben-Akiva and Lerman, 1985; Meyer and Miller, 2001). The framework was developed under the assumption that choices are made to maximize personal utility. The utility function traditionally included impedances such as costs incurred per trip and distances or time traveled while controlling for individual and household level socio-demographic characteristics. Cervero (2002) suggested to enhance the discrete choice framework by including built environment characteristics (objectively measured or self-reported) thought to influence mode choices by making traveling by some mode easier or by impeding the use of other modes. Transit service characteristics can also be included in this framework. Attitudes and preferences are becoming more commonly integrated to the utility function (McFadden, 2007).

Making cities more sustainable requires increased attention to alternative modes of transportation such as public transit use and non-motorized travel (TRB, 2001; TRB, 2005; Sallis et al., 2004). The choice to use public transit is thought to be influenced by characteristics of the transit system itself, but also by the pedestrian experience between home and the transit access point and between the transit network egress point and the final destination (Krygsman et al., 2004; Martens, 2004; Rietveld, 2000a; Cervero, 2001).

4.2.2.1 Public transit service, walkable environments and transit use

The overall quality of a transit trip is no better than its worst link (Krygsman et al., 2004). That is, even with good transit service that quickly and frequently serves central areas, a poor connection between a home and transit access point, and between the transit egress point and the final destination, may hamper the competitiveness of the transit journey as compared with completing the journey using other modes. The importance of the complete travel journey from door to door, including the non-motorized access to transit stations (Brons et al., 2009; Brons et al., 2005; Krygsman et al., 2004) are important considerations in research on public transit. Distance to the stop or station and the pedestrian characteristics found along the pathway may increase or decrease the appeal of the transit journey (Zhao et al., 2003; Cervero, 1998; Cervero, 2001; Kim et al., 2007; Stradling et al., 2007; TRB, 2001). Distance to transit, the diversity of service options and destinations, the frequency and speed of service, the presence of nearby park-and ride, and distance to other activity centers where destinations can be found may all support the use of public transit. Public transit trips are multimodal in nature because they typically begin and end on foot or bicycle, even if a person uses park-and-ride for one segment of the trip. Transit friendlys neighborhood characteristics can be elements of land use (e.g. presence of commercial or recreational destinations nearby), physical infrastructure and design (e.g. crosswalks, sidewalks) or be part of the social environment (e.g. perceptions of safety and security). Typically, a built environment that is walkable is also transit friendly, although transit is also found in less walkable places (Ewing and Cervero, 2001). Characteristics of the built environment associated with walkability, such as higher residential density, more diverse land use mix and greater network connectivity provided by a grid-like road network, support the provision of transit service by transit agencies, and have also been associated with transit use (Frank and Pivo, 1994; Ewing and Cervero, 2001; Frank et al., 2005). Neighborhood pedestrian characteristics may influence the use of public transit by making transit access easier and more pleasant, as well as by providing nearby destinations where mid-trip stops can be made. A built environment unsupportive of non-motorized access to transit stations may impede transit use. This is especially important when non-walkable environments form a barrier effect over a considerable distance. Transit users must also be able to reach specific destinations by foot from a transit egress point since they do not have other motorized modes available.

4.2.2.2 Satisfaction with access to transit service

Transit agencies are increasingly attempting to shift towards better understanding quality of service from a passenger's perspective instead of from a provider's perspective (Loukopoulos et al., 2004; Rietveld, 2005; Stradling et al., 2007). Assessing perceived satisfaction with access to public transit can help identify what improvement to service quality can yield increased satisfaction from current riders and attract new riders. Satisfaction with access to public transit service is a function of socio-demographic characteristics, the quality of transit service and neighborhood walkability – all features that may enhance the pleasantness of the access journey to public transit.

4.2.2.3 Commonly used survey instruments and proposed use of the NQLS

The most important tools used to study transit users have been on-board surveys, census records, and travel diaries. Travel diary data is typically collected over one or two days and has the advantage of recording specific origins and destinations, and allowing the analysis of chains of trips (Krizek, 2003; 2005; Frank et al., 2007; Bowman and Ben-Akiva, 2002). They may however inaccurately represent the variations in modes used over the course of a month and the infrequent use of transit. On-board surveys are only focused on transit users and are often used to identify travel patterns along specific corridors (Meyer and Miller, 2001; Cherrington, 2007), although transit agencies sometimes also develop rider/non-rider surveys to assess market potential. Census micro data provides detailed socio-demographics based on large representative samples, but focuses only on the most common mode used for the journey to work. Most research has been focused on the commute as an important and structuring part of travel and housing location. However, there is a growing understanding that people engage in a considerable amount of travel for leisure and other utilitarian purposes (Meyer and Miller, 2001; Chatman, 2009). A health and quality of life survey designed to analyze relationships between neighborhood types and behavioral patterns was used in this analysis.

4.3 Methods

4.3.1 Sampling of neighborhoods and respondents

The Neighborhood Quality of Life Study (NQLS – see www.nqls.org), a cross-sectional survey instrument of respondents between 20 and 65 years of age was used in this analysis. This observational study was designed to understand the relationship between the built environment, neighborhood socio-economic characteristics and health and quality of life outcomes. A number of transportation and travel-related components were included in the survey. It was conducted in the Baltimore, MD and Seattle, WA regions and was fielded in two waves within 6 months, between 2002 and 2005. Only the Seattle sample was used in this analysis. The Baltimore region included four counties and was served by multiple transit authorities (including the Washington DC subway) and by bus, light and heavy rail service and regional trains, making the creation of comparable and consistent measures of transit service between the two regions difficult. The larger sample in Seattle and the quality of the available GIS data made Seattle the preferred choice.

Random sampling of respondents was done within 16 King County neighborhoods purposefully selected for their mean walkability and median income levels in a four-quadrant design (high walkability/ high income, high walkability/ low income, low walkability/ high income, and low walkability/ low income). Median household income for 2000 census block groups was deciled. Contiguous block groups in the 2nd, 3rd and 4th deciles were considered low-income neighborhoods and those in the 7th, 8th and 9th deciles were considered of high income. Similarly, block group level walkability was also split into deciles (2, 3 and 4 – Low walkability; 7, 8, and 9 – high walkability). Block group walkability was measured as the sum of standardized z-scores for net residential density, intersection density, land use mix and retail floor area ratio (Frank et al., 2009).

Four neighborhoods representing each walkability and income quadrant were selected. Sallis and colleagues (2004) summarized eleven studies that used a high and low walkability design to assess the correlates of physical activity. Travel behavior studies have also compared the travel behaviors of residents of neighborhoods with different designs or walkability levels – sometimes defined as traditiona/neo-traditional vs. suburban (i.e. Schwanen and Mokhtarian, 2005; Handy et al., 2005). The neighborhood sampling design stratified by high and low income and high and low walkability allows the comparison of individuals in four types of neighborhoods across transit service characteristics.

Mailed-in surveys provided information on travel behavior, socio-demographic characteristics and attitudes towards public transit. Self-reported survey items on retrospective importance of neighborhood features in moving to a location (recalling the time of the move) and current satisfaction with neighborhood features can provide insights into the process of neighborhood self-selection and varying ability of individuals to locate in places with satisfactory transit. This provides an interesting complement to existing research that rely on more conventional travel diaries, on-board surveys and census information.

The first survey's return rate was of 26% (n=2199, 1287 in Seattle) and a second survey, sent six months later to respondents of the first survey, had a return rate of 87%, after eliminating those that moved out of the region. Items from both surveys were used, providing a sample of 1022 respondents. As 48 of these respondents did not report on household income or other variables, the final sample size used in this analysis was of (n=974). More details on individual sampling and mailing procedures can be found in Frank et al. (2009) and Sallis et al. (2009).

4.3.2 Transit service

Objective measures of transit service were developed using Geographical Information System (GIS) software. Locations of transit lines, transit stops, and park-and-ride facilities for 2003 were made available by King County Metro through the King County GIS center. Data transformation operations used the network analyst extension of ArcGIS 9.3, as well as spatial joins. The transit measures developed and the GIS information used are presented in Table 4.3 and described overall and by neighborhood type (result section).

Participant's addresses were geocoded to their physical location and 500 and 1000 meters street network buffers were created. Straight-line buffers create a circle area based on a defined radius and a center point (an individual's home). In network buffers, the distance is calculated along the street network, typically creating smaller areas of varying shapes reflecting the configuration of the road network. These buffer areas were used to calculate counts of transit stops, transit lines, indicators of presence of express transit lines, and to create indicators of transit cross-roads (which was defined as the presence of both North-South and East-West lines intersecting each other in the buffer). The number of transit stops in a buffer was normalized by area. Because of potential correlation in these variables, factor analysis was used to extract underlying information. Analyses and factor development were carried out with both buffer sizes.

ArcGIS's network analyst was also used to develop shortest path distance to nearest features. For each survey respondents, nearby bus stops, park-and-ride lots and neighborhood centers were identified. Distance to nearest transit stop (kilometers), distance to nearest park and ride lot (kilometers), distance to nearest neighborhood center, and the mean network distance to the 5 nearest neighborhood centers (kilometers) were developed. A map of four neighborhoods (one for each walkability/income combination), with individual level buffers and transit service information is presented in Figure 4.2. A second map providing examples of network distance to three nearest park-and-ride and to five nearest neighborhood centers is presented in Figure 4.3.

Figure 4.2 Map of survey design and public transit line and stops

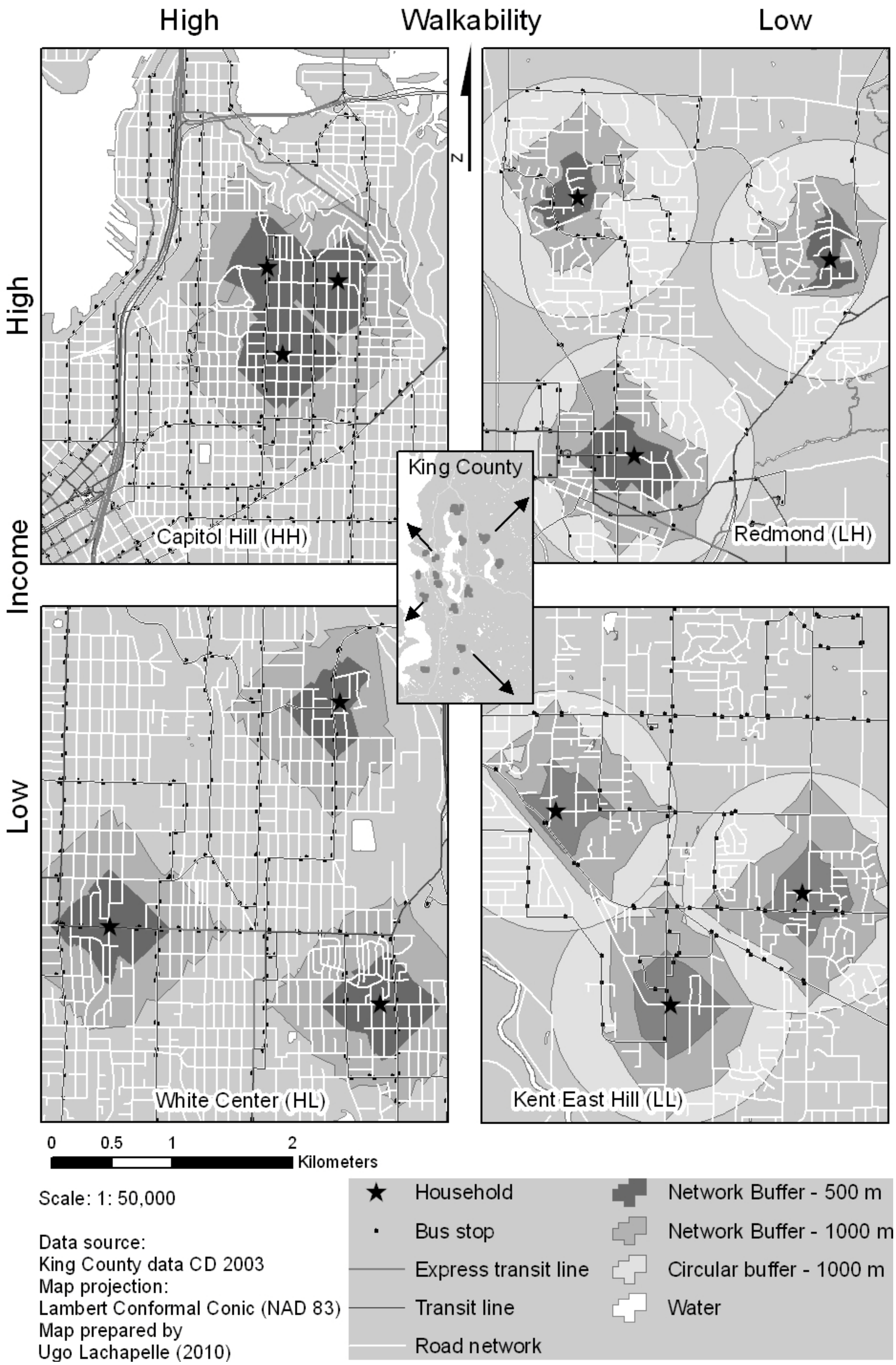
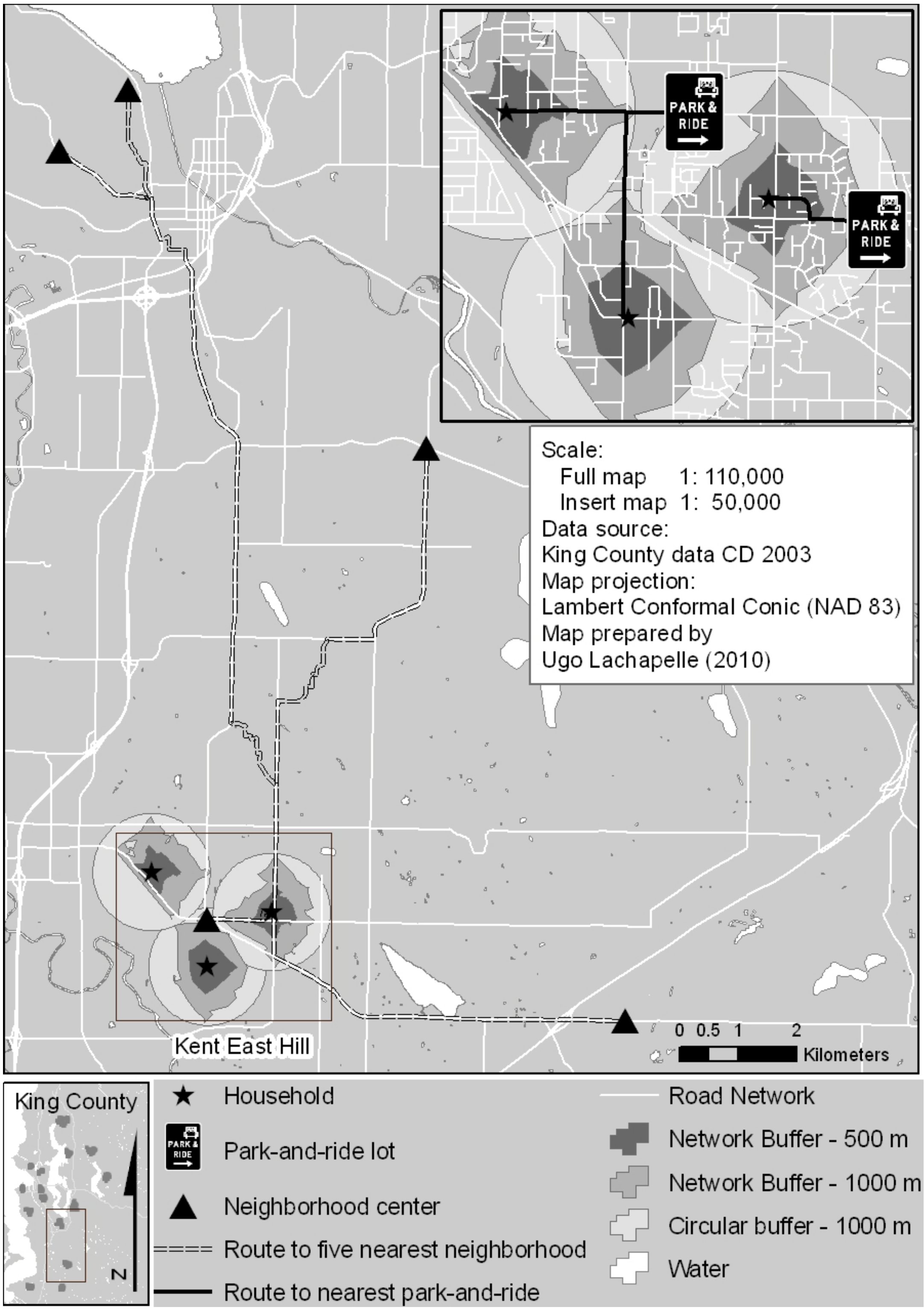


Figure 4.3 Map of example of measure of distance to nearest park-and-ride and mean distance to 5 nearest neighborhood centers



Descriptive analyses were performed with original transit service variables, but to avoid the problem of multicollinearity in regression, factor analysis was used to reduce the data. The factors and their composition are presented in Table 4.2.

4.3.3 Travel behavior outcome: transit use

The dichotomous transit use outcome was constructed from the questions: "How many days in the past month have you walked from home to public transit?" and "How many days in the past month have you walked from work to public transit?" A dichotomous variable of monthly transit use was created to represent those that recorded at least one trip to transit.

4.3.4 Attitudinal variables

Respondents were asked to complete the Neighborhood Environmental Walkability Scale (NEWS), a series of self-reported items assessing perceived characteristics of the environment and attitudinal factors with respect to the neighborhood of residence. The NEWS survey was tested and validated by previous studies (Saelens et al., 2003; Cerin et al., 2007). Perceived neighborhood environment attributes contained in the NEWS had moderate to high test-retest reliabilities (Leslie et al., 2007). This analysis focused on attitudinal items hypothesized to be associated with transit use.

The survey's first wave included self-reported items on the perceived importance of eleven neighborhood features in the decision to move to neighborhood ("How important was **closeness to public transportation** in your choice to move to this neighborhood?"). The items were measured on a five-point likert-scale with no neutral point (1= Not at all important; 3= Somewhat important; 5= Very important). This survey section was inspired by the SMARTRAQ travel survey (Frank et al., 2007).

The survey's second wave included items on satisfaction with seventeen neighborhood features. "How satisfied are you with **access to public transportation** in your neighborhood?" was used as a measure of satisfaction with the overall quality of transit service. Items were measured on a five-point scale with a neutral response (1= Strongly dissatisfied; 3= Neither satisfied nor dissatisfied; 5= Strongly satisfied). Satisfaction with transit contrasts with importance of public transit in location choice since perceived satisfaction theoretically follows a location decision, as an evaluation of how a chosen neighborhood and its features meets an individual's expectation.

4.3.5 Transit-housing match

By combining retrospective importance of transit with a measure of objective transit service into categorical indicators, how the desire for adequate transit (as determined by importance of transit in housing location choice) is being met with adequate access to transit (as determined by actual public transit service) is analyzed. This analysis simulates a longitudinal approach by contrasting a retrospective question on housing preferences at the time of housing location choice, to measures of transit service that reflect current state. For the importance of public transit variable, the cut point was established between negative values on one side, and neutral and positive values on the other side. For the transit service variable, the mean was used as cut point between those with better than average transit service and those with lower than average service because the factor variable approximated a normal distribution. Using such typological categorization to combine variables can ease interpretation of the model parameters and produce more clearly explainable results (Stinchcombe, 1968).

The upper right quadrant presented in Figure 4.1, with high values on importance and on transit service would have expectedly a stronger association with transit use than all three other categories. Those that did not want transit to begin with and had low transit service would be expected to record the smallest share of transit users.

4.3.6 Individual and household socio-demographic characteristics

Socio-demographic characteristics were used to describe the transit-housing match categories and were tested in all models. These include gender, household income (<$10,000; $10,000-$19,999; $20,000-$29,999; $30,000-$39,999; $40,000-$49,999;

\$50,000-\$59,999; \$60,000-\$69,999; \$70,000-\$79,999; \$80,000-\$89,999; \$90,000-\$99,999; ≥ \$100,000, recoded to four categories for description), age, white non-Hispanic vs. others, married or living with partner vs. not, being employed vs. not, having children vs. not, household size renter vs. owner, housing type (Single family house, multi-family house, apartment, condominium/townhouse, others) and length of stay at current address.

Drivers license status (dichotomous : *lic*), the number of adults in a household (number of household members minus number of children ≤ 16 year old : *adult*) and the number of vehicles owned (count : *veh*) were used to create three categories of car availability: shared car (if $lic = 1$ & $adult/veh < 1$), and one car per adult (if $lic = 1$ & $adult/veh \geq 1$) and no car or no license (else).

4.3.7 Statistical analysis

Factor analysis (with Varimax rotation) was used to reduce the public transit measures to underlying constructs. The transit-housing match categories were compared across socio-demographics using univariate chi-squared and ANOVA tests. Three dependent variables were then modeled using multivariate ordinal and logistic regression. To account for the hierarchical structure of respondents clustered in 16 neighborhoods, models were fitted using STATA 9.0's xt command with random effects for the 16 neighborhoods. Because there were to few neighborhoods to conduct neighborhood level statistical analysis, random effects only served to compute robust standard error and adjust the error term (Bingenheimer and Raudenbush, 2004).

4.3.7.1 Ordinal logistic regressions

Self-reported importance of transit in housing choice and satisfaction with public transit were analyzed using the ordinal regression framework with a logit link. Underlying this model is the assumption that the effect of an independent variable on the dependent variable does not vary for each level of the dependent variable. The assumption of parallel lines test was successful for both ordinal dependent variables.

4.3.7.2 Binary logistic regression of transit use

A binary logistic model of transit use in the past month was used to analyze associations between transit-housing match and the use of public transit, while controlling for other socio-demographic and regional location variables. Such binary choice model, albeit not a case of discrete choice because it rather refers to an overall portrait of an individual's travel over a month, are nonetheless theoretically grounded in the utility maximization framework (Washington et al., 2003). Dichotomous neighborhood walkability and income, socio-demographic characteristics, transit-housing match, car availability and transit service were used as covariates in the models.

4.4 Results

4.4.1 Transit service

Measures of transit service were highly correlated with each other. Factor analysis was used to reduce the data to a smaller number of underlying constructs. As shown in Table 4.2, two factors had eigenvalues superior to one. Most variables loaded on the first factor (which accounted for nearly 73% of variance in data). Together, the first and second variables accounted for about 92% of variance in the data. While the first factor was considered a good proxy for overall quality of transit service, the second factor seemed to load more strongly on very close proximity transit service.

Table 4.2 Factor analysis

Variable	Factor1 Overall transit service	Factor2 Very close proximity service
Number of lines (1000m)	0.8367	-0.4849
Number of lines (500m)	0.775	0.4551
Express lines1000	0.7373	-0.5663
Express lines 500	0.3226	0.4939
Stops/ 1000 area	0.8911	
Stops/ 500 area	0.7631	
Transit crossroad (1000m)	0.5436	
Transit crossroad (500m)	0.6959	
Eigenvalue	4.10463	1.07745
Proportion of variance explained	0.7266	0.1907

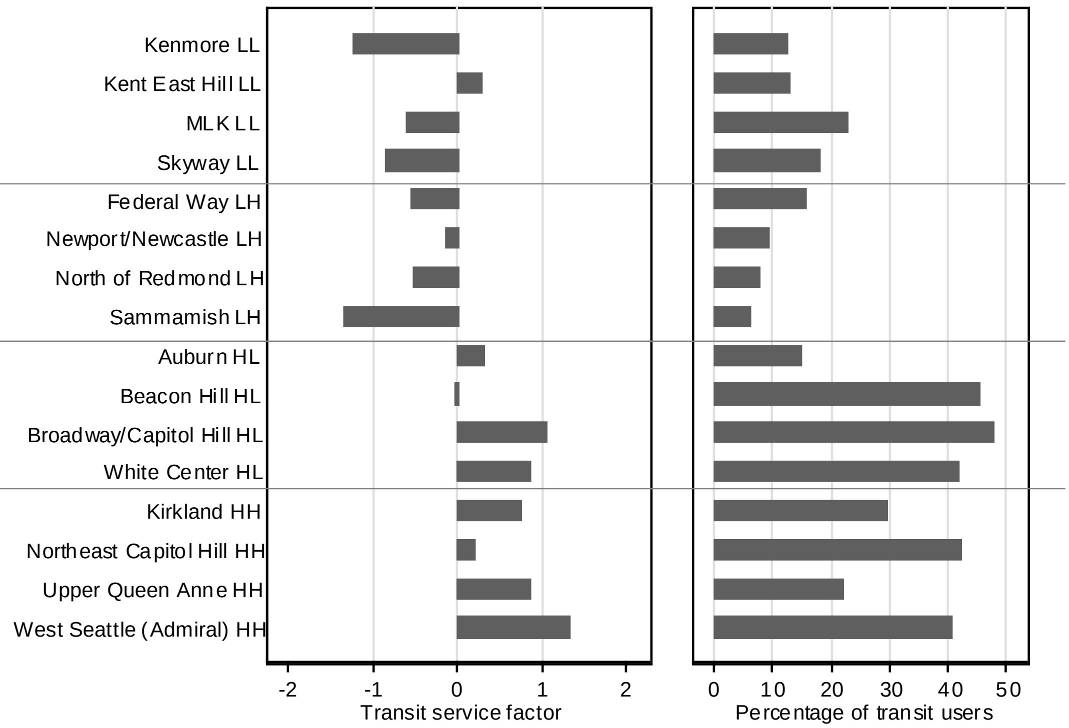
Descriptive analysis of transit service across four types of neighborhood was first performed to show the inherent relationship between neighborhood walkability and transit service. The transit measures and factor distribution across neighborhood types is assessed in Table 4.3 for the entire sample of surveyed individuals. Neighborhood walkability and transit service were highly associated. High walkability neighborhoods always had better transit service and low walkability, low-income neighborhoods had better service than their low walkability, high income counterparts. In high walkability, transit service was stronger in low income neighborhoods but the very close proximity service was highest in high income neighborhoods.

Table 4.3 Transit service across neighborhood walkability and income

	Low walkability		High walkability		Total
	Low income	High income	Low income	High income	
n	311	325	316	335	1287
Distance to nearest:					
Park-and-ride (km)	1.9	2.4	2.1	4	2.7
Neighborhood center (mean of 5, km)	6.3	14.9	6.7	5.6	8.4
Transit stop (m)	579	625	180	171	391
Transit service					
Lines in 1000 meter buffer	4.7	2.6	16.1	8.1	7.6
Lines in 500 meter buffer	2.1	1.5	5.1	4.7	3.3
Express lines in 1000m buffer	1.2	0.3	4.2	1.3	1.7
Express lines in 500m buffer	0.5	0.1	0.4	0.6	0.4
Transit stops/sq.km in 1000m buffer	9.4	8.3	22.6	23.8	16
Transit stops/sq.km in 500m buffer	12	11.2	25.1	27.6	18.9
Transit crossroad (1000m) (%)	52.1	44.0	94.9	83.9	68.8
Transit crossroad (500m) (%)	6.8	3.7	54.7	43.3	27.3
Express line indicator, 1000m buffer (%)	55.0	24.3	89.9	71.3	60.1
Express line indicator, 500m buffer (%)	34.7	11.4	31.0	46.0	30.8
Composite measures					
Overall transit service quality	-0.6	-0.8	0.8	0.4	-0.1
Very close proximity service	-0.1	-0.1	-0.3	0.6	0.0

Transit use varied between neighborhoods of similar walkability and income. The overall quality of transit service (the first transit service factor) and percentage of transit users in each neighborhood is graphed in Figure 4.4. The names of the neighborhoods are followed by a combination of two letters: the first for low or high walkability, and the second for low or high income (e.g. LH: Low walkability and high income; HL: High walkability and low income, etc.). Overall, high walkability neighborhoods had considerably higher proportion of transit users but some discrepancies are apparent (for low walkability neighborhoods, transit use is considerably higher in the low income neighborhoods, where transit service is higher). The distinction between low and high-income neighborhoods of high walkability was not as clear. Differences in percentage of transit users may also be a function of neighborhood location within the region and regional accessibility on roads and on the transit system.

Figure 4.4 Transit service and use by sampled neighborhoods



Note: LH: Low walkability and high income; HL: High walkability and low income; etc.

4.4.2 Transit-housing match

Were respondents successful at matching the characteristics of transit-oriented housing they desired at the time of move? Were some respondents more prone to being mismatched? The distribution of socio-demographic characteristics across transit-housing match categories is presented in Table 4.4. Categorical socio-demographic characteristics were analyzed using Chi square tests, and continuous socio-demographics and scales of attitudinal variables were assessed using one-way ANOVAs.

The first category (Matched transit disinclined) refers to those that did not give much importance to closeness to transit in choosing their neighborhoods and that lived in an area with poor transit service. This group had lowest transit ridership, highest car ownership, tended to be the wealthiest and lived more frequently in low walkability/ high-income neighborhoods.

The second category represents people having attributed low importance to transit and that located in areas with good service (mismatched transit disinclined). The third category represents those mismatched individuals that sought closeness to transit in their housing choices, but that located in neighborhoods with poor quality of transit. They represent a group of travel-disadvantaged individuals of particular importance to policy-making (mismatched pro-transit). This later group had lower car ownership and income level, and lived overwhelmingly in low walkability neighborhoods and particularly in low-walkability/ high-income neighborhoods. Mismatched pro-transit used public transit at a higher rate than the two transit disinclined groups. Approximately 24% (232) of the sample were mismatched pro-transit, a considerable value that is indicative that some respondents were unable to locate in neighborhoods that enabled the use of their preferred travel mode. Compared to mismatched transit disinclined, mismatched pro-transit individuals were slightly poorer, had a similar share of renters and apartment dwellers, but more home owners and lived farther from transit stops but closer to regional neighborhood centers and par-and-ride lots.

Finally, the fourth category represents those that successfully located in neighborhoods with good access to transit service (matched pro-transit). This group has by far the highest percentage of transit users (44.6%), and of individuals with no cars and no license (13.6%). They had the highest share of the lowest income group yet also had more higher income individuals than the mismatched pro-transit, and had the highest proportion of renters and apartment dwellers of all groups. Compared with mismatched pro-transit, fewer of them lived in single-family homes. What seems to distinguish the two pro-transit groups is lower car ownership smaller families with less children, more unemployed, ethnic composition and type of residence. Nearly 50% of the matched pro-transit lived in high walkability high income, and lived the closest to transit stops and regional neighborhood centers.

Table 4.4 Housing and socio-demographic characteristics across transit-housing match

	Matched transit disinclined	Mismatched transit disinclined	Mismatched pro-transit	Matched pro-transit	Total	Chi sq. or ANOVA sig.
n	**283**	**186**	**232**	**273**	**974**	
Walkability-income survey design (%)						0.000
Low Walkability/Low Income	34.6	10.2	46.1	5.9	24.6	
Low Walkability/High Income	50.9	15.1	23.3	7.0	25.2	
High Walkability/Low Income	8.8	28.5	17.7	37.4	22.7	
High Walkability/High Income	5.65	46.2	12.9	49.8	27.5	
Transit user(%)	5.3	10.3	31.2	44.6	23.4	0.000
Car ownership and availability (%)						0.000
One car or more per adults	93.6	88.2	76.7	65.6	80.7	
Shared car	5.3	10.8	16.8	20.9	13.5	
No car or no license	1.1	1.1	6.5	13.6	5.9	
Household income (%)						0.000
Below $30,000	6.4	12.4	16.0	20.5	13.8	
$30,000 - $59,999	21.9	31.2	32.3	31.5	28.9	
$60,000 -$99,999	38.5	28.5	33.6	25.3	31.7	
More than $100,000	33.2	28.0	18.1	22.71	25.7	
Women **(%)**	35.7	45.2	53.0	48.4	45.2	0.001
White, non-Hispanic **(%)**	88.7	86.6	73.7	82.4	83.0	0.000
Married or living with partner **(%)**	76.7	62.9	66.8	56.0	65.9	0.000
One or more child **(%)**	51.9	32.3	34.1	31.9	38.3	0.000
Employed **(%)**	85.2	80.1	84.1	78.0	81.93	0.115
Type of residence (%)						0.000
Single family house	85.2	71.5	78.0	60.4	73.9	
Multi-family house	0.7	2.7	1.7	2.6	1.9	
Apartment	9.9	13.4	13.8	24.2	15.5	
Condominium/townhouse	3.5	10.8	6.0	11.7	7.8	
Other	0.7	1.6	0.4	1.1	0.9	
Renter **(%)**	13.8	21.5	22.9	34.2	23.2	0.000
Mean values						
Age (years)	45.3	44.9	45.6	45.3	45.3	0.913
Months living at current address	122	115	121	116	119	0.857
Number of household members	3	2	3	2	3	0.000
Distance to nearest:						
Transit stop (km)	0.71	0.19	0.42	0.16	0.39	0.000
Park-and-ride (km)	2.30	2.72	2.36	3.19	2.65	0.000
Neighborhood centers (km)	11.53	8.04	7.66	6.04	8.40	0.000

Note: Income was recoded from 11 original categories <$10,000; $10,000-$19,999; $20,000-$29,999; $30,000-$39,999; $40,000-$49,999; $50,000-$59,999; $60,000-$69,999; $70,000-$79,999; $80,000-$89,999; $90,000-$99,999; ≥ $100,000

4.4.3 Location choice and satisfaction models

The previous description are confirmed by asking:what socio-demographic characteristics were associated with importance of public transit in choice to move to a neighborhood? An ordinal regression model of importance of closeness to transit in housing location choices is estimated using socio-demographic characteristics (Table 4.5) Poorer people, minorities, smaller households, woman and those with no drivers license were more likely to have made public transit an important feature of their housing choices.

Table 4.5 Importance of closeness to transit in housing location choice

Ordinal logistic regression	Coef.	Sig.
Age	0.01	0.425
Women	0.29	0.004
White non-Hispanic	-0.64	0.005
Household income	-0.08	0.003
Have drivers license	-1.86	0.000
Number of household members	-0.13	0.020
Cut points		
1	-3.66	0.000
2	-2.7	0.000
3	-1.85	0.004
4	-0.97	0.145
Number of observations	974	
Log Likelihood Wald chi2 (6 df)	165.97	
Significance	0.000	

Standard Error adjusted for 16 clusters
Note: Income is coded in 11 categories (<$10,000; $10,000-$19,999; $20,000-$29,999; $30,000-$39,999; $40,000-$49,999; $50,000-$59,999; $60,000-$69,999; $70,000-$79,999; $80,000-$89,999; $90,000-$99,999; ≥ $100,000)

What socio-demographic characteristics, neighborhood characteristics and transit service characteristics were associated with satisfaction with access to public transit? In Table 4.6, positive associations for being a women, being married, and a negative association for household income is shown in the base model. Mismatched pro-transit respondents were less likely than their matched counter-parts to be satisfied with access to transit. In the expanded model, living in a walkable neighborhood was positively associated, and living farther from the nearest transit stop was negatively associated with satisfaction with access to public transit.

Table 4.6 Satisfaction with access to public transit

Ordinal logistic regression	Base model		Expanded model	
	Coef.	Sig.	Coef.	Sig.
Age	0.01	0.541	0.01	0.167
Women	0.3	0.017	0.28	0.028
Married or living with partner	0.25	0.118	0.37	0.016
Household income	-0.07	0.023	-0.07	0.001
Transit-Housing Match				
Matched transit disinclined	-1.93	0.000	-0.80	0.002
Mismatched transit disinclined	-0.98	0.000	-0.82	0.000
Mismatched pro-transit	-0.84	0.002	-0.08	0.731
Matched pro-transit (ref.)				
Neighborhood types				
Walkable neighborhood			1.00	0.000
High income neighborhood			-0.07	0.692
Distance to nearest:				
Transit stop (km)			-0.57	0.008
Park and ride (km)			0.04	0.612
Neighborhood centers (mean of 5, km)			-0.03	0.282
Cut points				
1	-4.05	0.000	-3.33	0.000
2	-2.66	0.000	-1.88	0.000
3	-1.61	0.004	-0.75	0.161
4	-0.49	0.398	0.46	0.414
Number of observations	974		974	
Log Likelihood Wald chi2 (6 df)	202.36		429.34	
Significance	0.000		0.000	
Likelihood ratio (-2ll)	92.57		0.000	

Standard error adjusted for 16 neighborhood clusters
Note: Income is coded in 11 categories <$10,000; $10,000-$19,999; $20,000-$29,999; $30,000-$39,999; $40,000-$49,999; $50,000-$59,999; $60,000-$69,999; $70,000-$79,999; $80,000-$89,999; $90,000-$99,999; ≥ $100,000

4.4.4 Transit use model

Was transit-housing match associated with transit use? A binary logistic regression of public transit use in the past month is presented in Table 4.7. A parsimonious base model included significant socio-demographic characteristics and the transit housing match categories. Expanded models added associations with transit service, regional neighborhood centers and neighborhood walkability and income.

The largest association was attributed to the car availability categories. Both having a shared car or no car at all influenced positively transit use. The matched pro-transit group was used as the reference category for the housing-transit match variable. This reference category was chosen because the association of most interest was the difference between this group and the mismatched pro-transit. As was shown in variable description (Table 4.4), all other categories had significantly lower percentage of transit users. The first category, matched transit-disinclined, had the strongest negative association with transit use, followed by the mismatched transit disinclined. In the base model, mismatched pro-transit were less likely than matched pro-transit to use public transit, but this was not significant. This relationship was inversed in the full model, but also not significant. When adding neighborhood walkability and income, distance to transit service and measures of regional access to the base model, the reduction in transit use associated with mismatched pro-transit was no longer apparent. It is unclear whether the strong effect of car availability and high walkability actually changed the nature of the relationship. As distance to park-and-ride and neighborhood centers increased, the probability of transit use declined. The distance to the nearest transit stop did not yield any significant differences.

Table 4.7 Logistic regression of transit use with transit-housing match categories

Logistic regression	Base model		With transit service	
	Coef.	Sig.	Coef.	Sig.
Age	-0.012	0.171	-0.012	0.172
Women	-0.175	0.331	-0.201	0.265
Married or living with partner	-0.599	0.006	-0.540	0.012
White non-Hispanic	-0.080	0.730	-0.086	0.704
Household income	0.031	0.393	0.031	0.396
One or more car per adult (ref.)				
Shared car	0.973	0.000	0.930	0.000
No car or no license	1.901	0.000	1.923	0.000
Satisfaction with access to transit	0.079	0.405	0.013	0.891
Transit-housing match				
Matched transit disinclined	-2.007	0.000	-1.451	0.000
Mismatched transit disinclined	-1.582	0.000	-1.604	0.000
Mismatched pro-transit	-0.202	0.390	0.225	0.354
Matched pro-transit (ref.)				
Neighborhood characteristics				
Walkable neighborhood			0.775	0.002
High income neighborhood			0.418	0.078
Distance to nearest:				
Transit stop (km)			-0.604	0.161
Park-and-ride (km)			-0.123	0.042
Neighborhood center (mean of 5, km)			-0.050	0.038
Constant	-0.194	0.786	0.149	0.840
Number of observations	974		974	
Log Likelihood	-417.07438		-404.07817	
Likelihood ratio -2(ll)	127.81		161.16	
Model Significance	0.000		0.000	

Standard error adjusted for 16 neighborhood clusters

Note: Income is coded in 11 categories <$10,000; $10,000-$19,999; $20,000-$29,999; $30,000-$39,999; $40,000-$49,999; $50,000-$59,999; $60,000-$69,999; $70,000-$79,999; $80,000-$89,999; $90,000-$99,999; ≥ $100,000

4.5 Discussion

Between 1995 and 2008, public transportation ridership grew 38 by percent, which is almost three times the growth rate of the U.S. population (14 percent). In 2008, total transit ridership reached approximately 10.7 billion unlinked trips for all transit modes combined (APTA, 2009). Changing attitudes towards public transit, the rising cost of energy and automobile travel and increased provision of transit service likely all played a role in this mode share increase (APTA, 2009).

Yet, public transit still only captures a small share of trips, and many Americans still do not have access to good quality transit service near their home (TRB, 2002). A respondent's long-term housing decisions and attitudes towards transit and how it relates to the transit service context in the neighborhood of residence may further provide appeal to public transit use, or detract a person from using it. Ensuring that those interested in using transit are in a favorable position to choose this mode must be considered to increase public transit's mode share. The preference to use transit within the context of long-term decision on housing location, and the resulting use of transit was assessed.

4.5.1 Transit-housing match

Correlates of transit-housing match were analyzed. When choosing their neighborhoods, those that wanted to locate near transit also sought other pedestrian-friendly features represented here by neighborhood walkability. Some respondents failed to locate near transit even though it was an important feature of their housing choice Mismatched pro-transit respondents had a lower percentage of transit users with respect to matched pro-transit respondents, but this was not statistically significant. In other words, even in a less than optimal situation, respondents that desired transit still often made the choice to use it. Car ownership and shorter distance to park-and-ride may partially explain this result.

On the other hand, the mismatched transit-disinclined had higher probability of transit use compared to the matched transit-disinclined respondents but this was only significant in the base model (This was tested by changing the reference category to the latter category, not shown in Table). Even with no intention to locate near transit, once in a walkable neighborhood with good access to transit, a higher percentage of these respondents decided to use it as compared with their matched disinclined counter-parts. When choosing their neighborhoods, those that did not care for transit but sought other pedestrian-friendly features may have discovered the ease of use of transit and started using it.

In order to reduce transportation costs in terms of travel time and distance, transit users may be willing to pay higher costs to locate near quality transit service. Hess and Almeida (2007), for example, documented that living near a transit station commands a premium on housing prices, all other things being equal. A report from the Center for Housing Policy Alternatives (2006) suggested that as distance to central business district increases, housing prices go down but the cost of car travel increases. Because housing costs eventually stop decreasing but the cost of car travel keeps increasing, the combined housing and transportation costs continues to increase as housing gets further away from the center. Location efficient mortgages use this rationale to enable people to take on a larger mortgage on their home purchases since they will save on transportation costs by not relying as much on automobiles (HUD, 2008). While many Americans still typically choose to live further and drive greater distances, it appears that some may be willing to invest more in their housing to benefit from reduced transportation costs associated with using transit. This trend is expected to become even stronger as energy costs increase. Lower available income and environmental beliefs may in part explain this behavior. It is in this spirit that Reconnecting America (2007) has placed emphasis on promoting the preservation and development of affordable housing opportunities near transit.

In this analysis, satisfaction with transit service was associated with a number of socio-demographic characteristics (the most important was being a woman). Lowest mean satisfaction values were recorded in the low walkability and high-income neighborhoods, which is where the lowest quality of transit service was found. Differences in satisfaction based on neighborhood income could be either associated with lower access to transit service in high-income neighborhood than in low-income ones (where carless riders are likely more prominent) or with higher standards of quality of service for wealthier residents of higher income neighborhood. As income provides more opportunities for traveling, a higher quality of service needs to be deployed to attract users. Transit agencies generally target high walkability neighborhoods for transit service development and expansion because concentration of trip ends in these locations increases transit ridership (Ryan and Frank, 2009). This association between neighborhood walkability and transit service was confirmed.

4.5.2 Transit use

How did neighborhood location choice and quality of transit service collectively influence transit use? Observation of the percentage of transit users in each sampled neighborhood suggests that high walkability neighborhoods had, as expected, a higher proportion of transit users. However, there were considerable variations between neighborhoods of the same walkability/income groups. The logistic model of transit use confirmed these relationships by displaying the significant effect of walkability, and the non-significant effect of income.

How retrospective importance of transit in housing location choice relates to current access to transit service can influence, or detract, potential users from using public transit. The transit-housing match categorization presented here suggests the presence of a potential transit market that was not able to locate near quality transit, and that as a result used transit at a lower, yet not significant rate. This housing restriction may have reduced the potential use of transit. For those that placed importance on transit in housing choice (pro-transit), had mismatched individuals been matched with desired transit service, their transit mode share would have expectedly been similar to the group with high quality transit service. Because the relationship was not significant, another interpretation is that mismatched pro-transit respondents have knowingly traded-off lower quality transit for other housing or neighborhood features. Nonetheless, these results provide evidence that not all individuals get to locate near good public transit even if they wanted to at the time of housing location choice.

On the other hand, among those giving low importance to proximity to transit in location choice (the transit disinclined groups), the mismatched group (that ended up living near good transit) had a higher share of transit than their characteristics would otherwise lead us to expect. Transit-oriented developments provide neighborhood characteristics that attract individuals that are not interested in transit use (Lund, 2006). While this may reduce availability of housing for those wanting to use transit, some TOD residents (or other places with good transit service) may begin to use transit as a result of moving to a location with better service.

4.6 Limitation

A few limitations associated with the data, framework and analysis are noted. The cross-sectional design precludes conclusions on the causal link between relationships explored. The long-term process of housing location was not actually measured through longitudinal data, but rather by a retrospective item on desired neighborhood features at the time of moving. There may be a recall bias on the self-reported importance of closeness to public transportation in the choice to move.

4.6.1 Study design and sample

Because participants were not randomly sampled across the region, the proportions generated should not be interpreted as being directly representative of proportions across the region. The analysis rather served to explore and clarify the role of attitudes and long-term housing location choices on travel behavior. Few transit users in low walkability areas (as expected) is also noted. The survey included individuals between 20 and 65. Younger and older transit users are typically more often dependent on transit service and as such, should be assessed in future analyses.

4.6.2 Survey items

The transit use dependent variable was less precise than individual trips recorded in a travel survey but, in turn, captured infrequent transit use for any purpose. Lack of detailed travel data was a central limitation of this research. The economic mode choice framework emphasizes the use of mode- and trip-specific costs and travel times, which were not available in this survey. There was also no information on the purpose of individual transit trips over the month, nor was there information on the use of park-and-ride lots to access transit.

Future studies should consider availability of different types of housing (e.g. apartments, family-oriented housing, multifamily housing) and tenure forms and the extent to which they can be found near transit. Sample sizes prevented a detailed assessment of these characteristics.

There may also be a difference between transit users and non-users in how they reported level of satisfaction. Transit users may have a higher propensity to be satisfied with service quality than non-users who likely know much less about the actual quality of the service. Do non-users base their satisfaction on claims from their family members, from social image, or from previous experience?

4.7 Conclusion

This study's main contribution was to identify relationships between neighborhood walkability and transit service, to describe the characteristics of those bearing a location mismatch through the concept of transit-housing mismatch, and to assess how location mismatch with respect to public transit may influence the use of public transit.

Transit use was independently associated with physical and socio-economic characteristics of neighborhoods, individual level socio-demographic characteristics, as well as attitudes of respondents towards transit in their housing location choices. Predisposition to transit use as suggested by the importance of closeness to transit in location choice was found to positively influence transit use, but less so when a respondent did not locate near good transit.

As modal accessibility is a valued good for housing choices, good transit access may increase the value of housing, leaving some to accept the trade-off, and others unable to locate in the places that support their desire for public transit. Those with lower incomes available for home purchase, or larger families with children may be less able to satisfy their preference for a transit-rich neighborhood.

While research has shown that people may self-select into neighborhoods that provide greater access to the modes of transportation they prefer, not all respondents were able to actually choose a location that had good transit service and fulfill their competing desires. Mismatched individuals that were not able to locate in a place that fulfilled their desire for housing close to transit had reduced opportunities to use transit. Yet it is unclear whether they used it less once the regional location and types of environments they lived in were taken into account.

4.8 Significance

Awareness of trade-offs and drawbacks involved in housing choices can help planners identify how to combine neighborhood features conducive to transit use. Ensuring that potential riders wanting to use transit live in a place where this is possible is an important consideration for planners. Focusing on the provision of diverse and affordable housing (rental and owned), as well as on the design of neighborhoods that enable and make walking to transit pleasant can potentially increase transit use. Conversely, the amenity rich environment near high quality transit may attract residents that, without previous inclination, discover the value and advantages of using transit.

In the next chapter

In chapter 4, the relationship between transit use, transit service and walkability was described to set the stage for an analysis of how transit use may modify the relationship between walkability and physical activity. As not all transit users were able to locate near good transit service, some transit users living in low walkability neighborhoods with limited transit service may have walked long distances to have access to transit service. In chapter 5, employed individuals working outside the home were used to assess the associations between commuting to work by public transit, and overall physical activity in neighborhoods of high and low walkability. Physical activity was measured objectively by accelerometers and included any form of activity. The analysis was stratified by neighborhood walkability. Transit commuters, especially frequent ones, were found to have the highest levels of physical activity. Transit users living in low walkability had higher mean physical activity levels than those living in higher density neighborhoods, what was shown to be a product of longer walks to neighborhood destinations, and likely to transit stops or stations. These associations were assessed when controlling for socio-demographics and enjoyment of physical activity. As all forms of activities are joined in one accelerometer measure and an association with transit use are still identified, the results suggest that the higher levels of walking associated with transit use were not counter balanced by less practice of other forms of physical activity, a point further explored in chapter 6.

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Chapter 5 Commuting by public transit and physical activity: where you live, where you work and how you get there [4]

5.1 Introduction

The relationship between physical activity and the built environment is well documented (Handy et al., 2002; Saelens et al., 2003; Sallis et al., 2004; Frank et al., 2005; TRB-IOM, 2005), but the use of public transit – a potential mediator, or effect modifier in this relationship – remains understudied (Dannenberg et al., 2003; Lee and Moudon, 2004). Positive associations between physical activity and transit use were found in various settings, using self-reported measures of physical activity, accelerometers, pedometers, as well as network distance using home and transit location (Moudon et al., 2006; Wener and Evans, 2007; Brown and Werner, 2007; Villanueva et al., 2008; Lachapelle and Frank, 2009). Many public transit users were found to achieve physical activity recommendations solely by walking to transit (Besser and Dannenberg, 2005). Transit trips always include some walking (e.g., to/from stops), especially at the destination end of a trip, and may potentially be supportive of physically active utilitarian lifestyles. The provision of public transit enables lower levels of auto ownership and has a major role to play in meeting energy consumption, greenhouse gas emission, and air pollution reduction objectives (TRB, 2001; Ewing et al., 2007; Zheng, 2008). Quantifying more precisely the relationship between physical activity and public transit use and exploring the mechanisms through

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which this relationship occurs can inform decision about land development and transportation investment actions that increase the quality and convenience of a lifestyle involving public transit.

Built environments that are more walkable tend to also be supportive of public transit use (Frank and Pivo, 1994; Boarnet and Crane, 2001; Ewing and Cervero, 2001). Higher residential density, greater land use mix, and street connectivity work interactively to enable walking by providing nearby destinations. A walkable built environment supports transit ridership by combining potential users, destinations and a higher quality of transit service. Such walkable environment can also improve the ability to walk to transit from home and work, and may ease pedestrian access to destination. Hence, comparing the relationship between transit use and walking in different built environments can improve understanding of the independent effect of each.

Because commuting by transit inevitably involves some walking, individuals that enjoy moderate physical activity may be more prone to commuting by transit. If so, the relationship between transit commuting, walkable environments and physical activity should be explained independently of enjoyment of physical activity. Enjoyment of physical activity and other demographics need to be considered in examining built environment, transit commute, and physical activity relationships.

Several important questions remain unanswered. Is the association between transit commuting and objectively measured physical activity observed in residents of both high and low walkability neighborhoods? Does this relationship hold for both frequent and infrequent commuters? Are people who enjoy moderate physical activity more prone to commuting by transit? Do transit commuters also walk more frequently to services and destinations near home and near the workplace? Since transit commuters do not have a car available at the workplace, we expected they might engage in more walking to services during the workday before coming back home.

The current study assesses if commuting by public transit is related with more physical activity than commuting by other modes, and whether this relationship remains when considering walkability in the neighborhood surrounding home. Associations between commuting by transit and walking to services and amenities near home and near the workplace are tested as a potential explanation for higher levels of walking of transit commuters. Finally, whether enjoyment of moderate physical activity helps explain the relationship between transit use and physical activity is investigated.

5.2 Methods

5.2.1 Survey sampling and participants

The Neighborhood Quality of Life Study (NQLS) is an observational epidemiologic study conducted between 2001 and 2005. Published papers present the study design, methods, and other results in more detail (Sallis et al., 2009; Frank et al., 2009). Thirty-two neighborhoods were selected based on median income and mean walkability in the metropolitan areas of Baltimore, MD and Seattle, WA. Median neighborhood income was determined using 2000 census block group level information. Both regional distributions were split into deciles, and block groups in deciles 2, 3, 4, and 7, 8, 9 were considered low and high-income neighborhoods respectively. A walkability index was calculated at the block group level across each region using the sum of the z-scores of net residential density, intersection density, retail floor area ratio and an entropy-based measure of land use mix (Frank et al., 2009). An index of walkability was used to classify block groups into low (deciles 1, 2, 3, 4) and high (deciles 7, 8, 9, 10) walkability (Frank et al., 2009). Contiguous block groups that were categorized as high or low for income and walkability were used to identify potential neighborhoods across both regions. Investigators used ground validation to ensure that neighborhood surroundings were not inconsistent with the categorization (i.e. a high walkability neighborhood surrounded by low walkability ones). Transit service was generally higher in high walkability neighborhoods although some low walkability neighborhoods had good service. A subway, a light rail and stations of Washington, DC metro serve the Baltimore region, while Seattle is served by busses and trolleys. Both regions have park-and-ride lots by many transit lines.

Two waves of survey were mailed to respondents randomly selected within neighborhoods using marketing company data. An invitation letter and a consent form preceded surveys. NQLS was based on an ecological model and designed to evaluate multiple levels of potential influences on physical activity (Sallis et al., 2006). Included participants were between 20 and 65, did not reside in a group establishment, were able to complete the survey in English, and did not have a medical condition preventing them from walking.

Recruitment and completion rate for the first survey was 26% (contacted/returned survey), and the second survey, sent 6 months later to respondents of the first survey, had a return rate of 87%. Socio-demographics and the psychological variable were retrieved from the first wave and items on the commute modes were taken from the second survey. There were 2199 respondents who completed the first survey (1287 in Seattle and 912 in Baltimore), 1735 who completed the second survey and wore accelerometer, and the final sample of employed respondents (with one outlier removed) was of 1237, 717 in Seattle, and 520 in Baltimore.

5.2.2 Outcome: accelerometer and MVPA

To ensure that survey completion did not influence physical activity patterns, the survey was preceded by a one-week (7 days) accelerometer deployment (Sallis et al., 2009). Actigraph model 7164 or 71256 (Actigraph inc; Fort Walton Beach, FL) accelerometer recorded intensity of movement each minute. Variables of valid minutes and valid days (at least 5 days were needed or a total of 66 valid hours) based on published cut points were calculated from records (Freedson et al., 1998). More details on accelerometer variable construction can be found in (Sallis et al., 2009) and on-line (http://www.ipenproject.org/pdf_file/VI_ACCELEROMETER_PROCEDURES.pdf, Accessed on December 15, 2009). Moderate to vigorous physical activity minutes (MVPA) per valid days was chosen as the primary outcome since there is at least anecdotal evidence that transit users often rush to get to stops, or between connections and physical activity guidelines are based on physical activity of “at least moderate intensity” (USDHHS, 2008). Weekdays and weekend days were combined because of evidence that some individuals worked on weekends (more than a 100 individuals reported more than 20 work days). One outlier with over 4 hours of moderate to vigorous physical activity per day (243 minutes) was removed. The next highest value was 159 minutes, or a little over 2 ½ hours. Data collection occurred throughout the year in both regions.

5.2.3 Main independent: commute by transit

Reported percentage of commute trips taken by public transit (bus, subway and trolley) was the main independent variable. Participants working outside the home were asked to report the number of days that they commuted to work using 9 travel modes (walking, bus, subway-trolley, biking, driving, carpool driver, carpool passenger, vanpool, and taxi), across an assumed 20 workdays per month. In a few cases, participants reported 30 workdays, and others likely assumed two trips per day (i.e., sum of trip per all modes were clustered at 20, 30, 40 and 60). As these sum of all trips seem to be logical and internally consistent, but not comparable, we computed the percentage of all commute trips taken by public transit ($\%T_{tr}$). This continuous variable was then categorized into those who did not commute to work by public transit, no transit ($\%T_{tr}=0\%$), those who used public transit for less than half of their commutes, infrequent transit commuters ($0 < \%T_{tr} < 50\%$), and those who used public transit on half or more of their commutes, frequent transit commuters ($\%T_{tr} \geq 50\%$).

5.2.4 Psychosocial measure

The psychosocial item “I enjoy doing moderate physical activities” was developed by NQLS investigators and measured on a 5-point likert scale (1=strongly disagree to 5=strongly agree). Self-reported enjoyment of moderate physical activity was hypothesized to have an independent effect on MVPA, be similar across transit commute frequency categories, and not confound the relationship between transit commute and MVPA.

5.2.5 Covariates

Socio-demographics were reported by participants in the survey and controlled for in analyses. Transit ridership is typically composed of a higher proportion of lower income, minorities, women and younger people with no car (Bullard et al, 2004). Household income (four categories), age, gender, whether a person was married or living with partner, ethnicity (White non-Hispanic vs. others) and cars per household members were therefore selected as controls.

Neighborhood walkability and income design variables as well as an indicator of region (Seattle or Baltimore) were used as independent variables in the model. High walkability neighborhoods generally have better transit service, although a transit corridor may traverse a low walkability neighborhood (Ewing and Cervero, 2001; Frank et al., 2005).

Transit service was assessed using the survey item "It is easy to walk to a transit stop (bus, train) from my home" measured on a 4-point likert scale (1=strongly disagree to 4=strongly agree). It was hypothesized to be associated with transit use but not with MVPA.

5.2.6 Self-reported walk trips to destinations at home and work

The survey asked: "How many days in the past month have you walked to the following places (9 items, see results) from your home or work? If none, put 0." Participants responded separately for walk trips from home versus walk trips from work (with the exception of possible walk trip home to/from work, not included in analyses). Walking to transit stops or station from home and work was not included in analyses as the results would be tautological. Walking to school or daycare had low variation in response and was not used. Each walk trip item was categorized as no walking, less than ten, and ten days or more.

5.3 Statistical analyses

5.3.1 Neighborhood clustering

Because individuals were clustered in neighborhoods, a Hierarchical Linear Regression Modeling approach was employed with the 32 neighborhoods entered as a random effect to control for neighborhood clustering and adjust error variances (Bingenheimer and Raudenbush, 2004; Masse et al., 2002). The differences between the two cities were assessed with a dichotomous variable in the model. Stratified analyses by cities were not reported but estimated MVPA was provided.

5.3.2 Moderating effect

The potential moderating effect of an intermediate variable, transit commute frequency, along a hypothesized causal pathway from walkability to MVPA, was assessed by interacting transit commute and walkability as well by as stratifying the model by walkability and comparing the strength of transit commute coefficients of residents of high and low walkability neighborhoods (Bauman et al., 2002). Because physical activity and public transit use are both likely associated with socio-demographic and psychological factors, these were included in the model as potential confounding variables. Other potential confounding and moderating effects (i.e. age, gender, neighborhood income and region) were tested because they were part of the design but not included in final analysis. For example, perceived safety was associated with MVPA, but not with transit commute.

5.3.3 Walk trips to destinations at home and work

Walk trips to different services and amenities near home and workplace were compared across commute categories using Chi Square tests. The analysis was stratified by high and low walkability of home neighborhood to assess if the associations occurred in both types of neighborhood.

5.4 Results

5.4.1 Description of transit commuters

In Table 5.1 is presented sample characteristics for the three categories of commuters: those who never used public transit to commute (81%), infrequent transit commuters (8%) and frequent transit commuters (12%). Transit commuters differed in composition, in distribution across built environment and in practice and enjoyment of physical activity. They also were distributed differently across cities and had slightly different physical activity levels. As seen by the distribution of socio-demographics within each category, transit commuter groups had a higher proportion of women (55 and 49%, vs. 43% for entire sample), a lower proportion of married individuals and white non-Hispanic and had less access to vehicles compared with non-transit commuters. A higher percentage of both transit commuter categories was found in high walkability neighborhoods. There was little difference between transit commuters and their counterparts in distribution across neighborhood income. Frequent transit commuters reported significantly higher ease of access to transit than non-transit commuters, but not infrequent ones (two tailed independent sample t-test: $t = -4.477$, $p<0.001$)[5].

[5] A graphical presentation of ease of walking to transit from home and from work for the three commuter categories, and across neighborhood walkability is presented in Appendix 1, Figure A.6 to complement this analysis.

Table 5.1 Socio-demographics of commute by transit categories

		No transit	Infrequent transit commute	Frequent transit commute	Total
Total	%(n)	80.7 (1000)	7.8 (95)	11.5 (142)	100 (1237)
Seattle	%(n)	82.4 (591)	8.2 (57)	9.6 (69)	100 (717)
Baltimore	%(n)	78.7(409)	7.3(38)	14.0(73)	100 (520)
MVPA	mean(sd)	31.42 (22.35)	39.43 (24.84)	39.37 (20.7)	33.11 (23.33)
MVPA -Seattle	mean(sd)	32.11 (22.15)	40.22 (22.77)	38.49 (20.29)	33.37 (22.17)
MVPA -Baltimore	mean(sd)	30.42 (22.62)	38.24 (27.94)	40.21 (21.21)	32.36 (23.12)
Age (years)	mean(sd)	45.1 (10.13)	44 (10.22)	45.7 (10.49)	45.1 (10.18)
Women	%(n)	41.7 (417)	55.2 (53)	49.3 (70)	43.6 (540)
Married or living with partner	%(n)	66.5 (665)	58.3 (56)	51.4 (73)	64.1 (794)
White non-Hispanic	%(n)	77.1 (771)	71.9 (69)	67.6 (96)	75.6 (936)
Household income					
Less than $30,000	%(n)	9.5 (95)	12.5 (12)	12 (17)	10 (124)
From $30,000 to $59,000	%(n)	29.1 (291)	25 (24)	33.1 (47)	29.2 (362)
From $60,000 to $99,000	%(n)	33.3 (333)	27.1 (26)	33.1 (47)	32.8 (406)
More than $100,000	%(n)	28.1 (281)	35.4 (34)	21.8 (31)	28 (346)
Vehicles per person	mean(sd)	0.91 (0.46)	0.80 (0.41)	0.67 (0.43)	0.87 (0.46)
I enjoy moderate PA	mean(sd)	4.28 (0.81)	4.52 (0.63)	4.22 (0.92)	4.29 (0.81)
(1= Strongly disagree; 5=Strongly agree)					
Easy to walk to transit from home	mean(sd)	3.42 (0.96)	3.68 (0.79)	3.8 (0.59)	3.49(0.92)
(1= Strongly disagree; 4=Strongly agree)					
Survey design					
Low walkability/ Low income	%(n)	26.2 (262)	16.84 (16)	16.9 (24)	24.41 (302)
Low walkability/ High income	%(n)	29.1 (291)	16.84 (16)	14.79 (21)	26.52 (328)
High walkability /Low income	%(n)	21.5 (215)	30.53 (29)	30.99 (44)	23.28 (288)
High walkability/ High income	%(n)	23.2 (232)	35.79 (34)	53 (37.32)	25.79 (319)

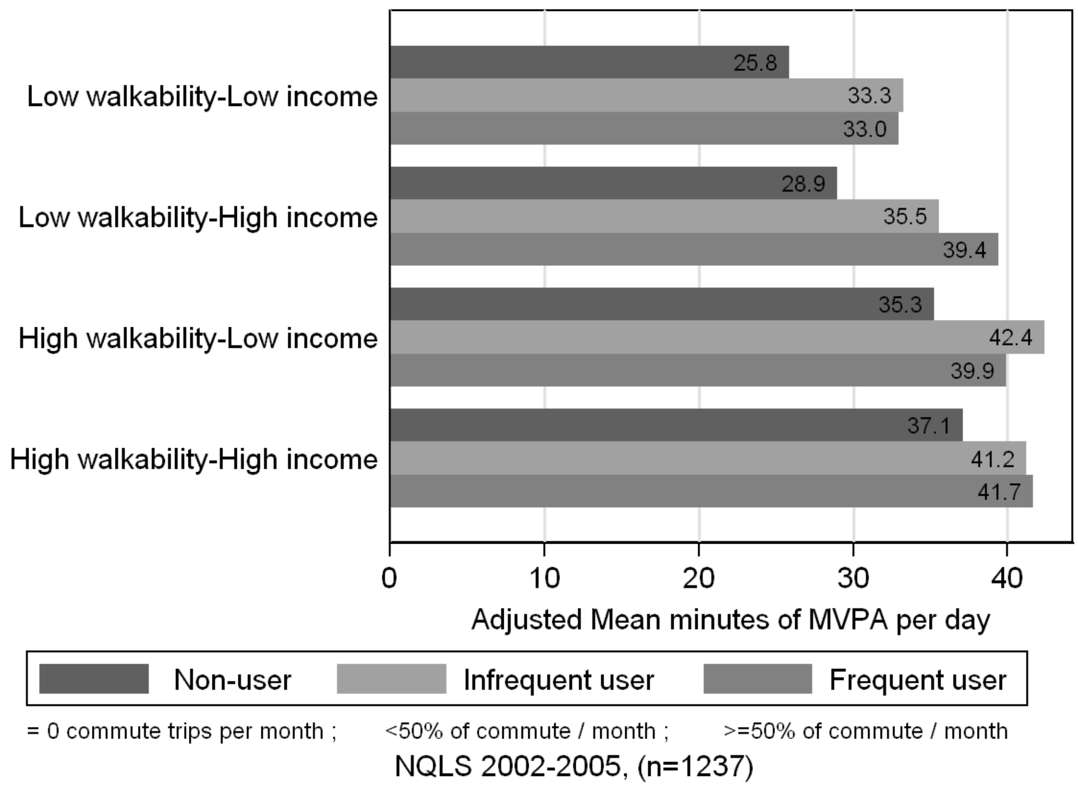
Note: No transit = 0%; Infrequent transit commutes = 1 to 49%; Frequent commutes = 50% or more
MVPA: Moderate to vigorous physical activity

5.4.2 Transit commute and enjoyment of physical activity

While the mean differences were small, infrequent transit commuters enjoyed moderate physical activity more than the frequent commuters (two tailed independent sample t-test: $t = 2.814$, $p<0.005$), and more than those not commuting by transit (two tailed independent sample t-test: $t = -2.797$, $p<0.005$). Enjoyment may partially explain the level of physical activity of infrequent transit commuters. Infrequent transit commuters were wealthier than the frequent ones, had the highest proportion of women (55%, vs. 43% for the entire sample), and the highest mean MVPA.

Overall, MVPA was highest for infrequent transit commuters, about ten minutes more than non-users, and slightly more than frequent commuters. Slight variations between regions were observed. Unadjusted mean MVPA for commuter groups across neighborhood walkability and income categories are presented in Figure 5.1. First, regardless of the type of neighborhood within which a person resides, both groups of transit commuters had a higher mean MVPA than non-transit commuters within their neighborhood and in most cases across all neighborhood groups. For example, non-transit commuters in high walkability neighborhoods had comparable MVPA to frequent transit commuters in low walkability neighborhoods. Second, mean MVPA was overall higher in high walkability neighborhoods. Third, transit commuters in low-income neighborhoods reported similar MVPA levels as transit commuters living in high-income neighborhoods.

Figure 5.1 Mean MVPA across categories of commute and types of neighborhoods



5.4.3 MVPA regression: full sample and stratified

Adjusted coefficients for linear regressions of mean minutes of moderate to vigorous physical activity per day (MVPA) for the entire sample and for high and low walkability separately are presented in Table 5.2.

In the full sample regression, transit commuters (frequent and infrequent) had significantly higher MVPA than those who did not commute on transit after controlling for socio-demographic characteristics, survey design variables and enjoyment of physical activity. Neighborhood walkability was also independently and positively associated with MVPA. However, the interaction term between walkability and transit commute showed that the combined effect of frequently commuting by transit and living in a high walkability neighborhood was associated with lower levels of MVPA.

The two next columns present the same MVPA regression stratified by neighborhood walkability to compare the magnitude of coefficients of the frequency of commute by transit. Frequent and infrequent commuting by transit was significant in low walkability neighborhoods and had a smaller, borderline significant effect size in high walkability neighborhoods, and only for frequent commuters.

There were multiple significant demographic correlates of MVPA. Those earning $100,000 and more had significantly more MVPA than the reference category (less than $30,000), but not in the high walkability sample. Non-Hispanic whites had more MVPA than their counterparts, while other socio-demographic variables (age, women, being married) were negatively associated with MVPA. The psychological variable of enjoyment of physical activity was independently and positively associated with MVPA for the entire sample and for the stratified analyses.

As Sallis and colleagues (2009) showed using NQLS data, neighborhood income and study regions were not significantly associated with self-reported and objective measures of active transportation and physical activity.

Table 5.2 Interaction of neighborhood walkability and frequency of commute by transit in relation to MVPA, adjusting for socio-demographic variables

	All sample		High walkability		Low walkability	
	Coef.	sig.	Coef.	sig.	Coef.	sig.
Age (years)	-0.30	0.000	-0.34	0.000	-0.28	0.002
Women	-10.22	0.000	-11.17	0.000	-9.65	0.000
Married or living with partner	-5.12	0.000	-5.19	0.001	-4.50	0.086
White non-Hispanic	6.02	0.000	6.90	0.008	5.35	0.005
Less than $30,000 (ref.)						
From $30,000 to $59,000	3.36	0.113	2.16	0.490	3.70	0.198
From $60,000 to $99,000	2.97	0.137	3.76	0.253	1.34	0.616
More than $100,000	4.87	0.021	3.33	0.354	4.68	0.029
Vehicles per person	-3.03	0.061	-1.98	0.202	-4.01	0.172
I enjoy moderate PA	3.47	0.000	3.02	0.014	3.83	0.000
No transit (ref.)						
Infrequent transit commute	13.68	0.022	4.83	0.079	13.22	0.029
Frequent transit commute	11.12	0.000	4.05	0.054	10.18	0.000
High neighborhood walkability	7.81	0.000				
High walkability*infrequent	-8.58	0.189				
High walkability*frequent	-6.84	0.039				
Easy to walk to transit from home	-0.22	0.785	-1.31	0.509	-0.09	0.925
High neighborhood income	-0.04	0.977	1.06	0.669	-0.68	0.701
Baltimore	0.44	0.796	-0.97	0.725	2.00	0.366
constant	38.61	0.000	51.78	0.000	34.91	0.001
n	1237		607		631	
Neighborhood clusters	32		16		16	

Note: Coef. = adjusted coefficients; sig. = significance level ; ref. = reference category

The reference category for the full model was a single, non-white male, earning less than $30,000, not using public transit, living in a Seattle low-walkability and low-income neighborhood.
MVPA: Moderate to vigorous physical activity
PA: physical activity

Example cases are estimated using full sample and per region outcome values. Table 5.3 shows estimated mean adjusted MVPA minutes/day for variations in neighborhood walkability and commuting by transit when other variables are considered at their means. In the full sample, transit commuters had up to 8 more minutes of MVPA more than non-commuters in high walkability neighborhoods, and in low walkability. The effects of high vs. low walkability on non-commuters were of nearly 7 additional minutes, and slightly lower for the two transit commuter groups.

Table 5.3 Adjusted minutes of MVPA per day for transit frequency and walkability

	n	High walkability	Low walkability
Total			
No transit commute	1000	44.29	37.37
Infrequent transit commute	95	50.4	43.5
Frequent transit commute	142	52.01	45.1
Seattle			
No transit commute	591	44.18	35.61
Infrequent transit commute	57	51.01	42.43
Frequent transit commute	69	48.94	40.36
Baltimore			
No transit commute	409	45.25	40.55
Infrequent transit commute	38	51.04	46.35
Frequent transit commute	73	56.3	51.61

Note: All other variables (age, gender, marital status, ethnicity, household income, vehicle per person, Enjoyment of moderate PA, easy to walk to transit from home, neighborhood income) are kept at their mean values. MVPA: Moderate to vigorous physical activity; No transit = 0%; Infrequent transit commutes = 1 to 49%; Frequent commutes = 50% or more.

5.4.4 Self-reported walk trips to neighborhood and workplace destination

Why do transit commuters accrue higher levels of MVPA than their non-user counterparts, and why is this effect stronger in low walkability neighborhoods? Table 5.4 compares non-commuters to the collapsed frequent and infrequent transit commuters in the number of days they walked to destinations from home and from work in the past month. Again, the analysis was stratified by high and low walkability to show that the differences between transit commuters and their counterparts were independent of the home neighborhood walkability. Transit commuters, if they lived in low walkability environments, walked significantly more frequently both near their home and near their workplace than their non-commuter counterparts. If they lived in high walkability neighborhoods, transit commuters walked significantly more than non-commuters to all destinations near work except food stores (carrying groceries in the bus may be avoided). Near home, they walked significantly more than non-commuters to retail stores, restaurants and cafés, but not to other destinations.

Table 5.4 Walking to destinations near home and work across commute categories and neighborhood walkability[6] [7]

	Near home						Near workplace					
	High walkability (n=605)			Low walkability (n=629)			High walkability (n=605)			Low walkability (n=629)		
	No transit	Transit commute	Chi sq. sig.	No transit	Transit commute	Chi sq. sig.	No transit	Transit commute	Chi sq. sig.	No transit	Transit commute	Chi sq. sig.
n	446	159		551	78		446	159		551	78	
Number of days walked in past month (% in categories)												
Walking to food stores												
Never	36.8	28.3		81.7	60.3		82.7	76.1		87.3	70.5	
Less than ten days	46	51		17	35.9	***	13.3	16.4		10.1	20.5	***
Ten days or more	17.3	20.8		1.3	3.9		4.3	7.6		2.5	9	
Total (%)	100	100		100	100		100	100		100	100	
Walking to retail stores												
Never	58.4	43.4		89	74.4		80	46.5		87.7	59	
Less than ten days	35	46	**	10.9	23.1	***	17.8	45.9	***	10.5	34.6	***
Ten days or more	6.5	10.7		0.2	2.6		2.3	7.6		1.8	6.4	
Walking to bank or credit union												
Never	65.9	66		93.7	70.5		80.5	51.6		87.7	55.1	
Less than ten days	31.8	32.1		6.2	29.5	***	18.4	41.5	***	11.8	41	***
Ten days or more	2.2	1.9		0.2	0		1.1	6.9		0.5	3.9	
Walking to post office												
Never	78	71.7		95.1	84.6		85.4	66		94.2	61.5	
Less than ten days	21.5	27.7		4.7	15.4	***	14.4	34	***	5.3	38.5	***
Ten days or more	0.5	0.6		0.2	0		0.2	0		0.5	0	

[6] To address the problem of multiple comparison on the same dataset, the bonferroni adjustment can be used. In this case, to obtain a significance level of <0.05, the significance level should be of <0.007 (0.05/7 different destination hypotheses).
[7] Another way of visualizing these relationships is presented in Appendix 1, Figure A.4 and A.5

	Near home						Near workplace					
	High walkability (n=605)			Low walkability (n=629)			High walkability (n=605)			Low walkability (n=629)		
	No transit	Transit commute	Chi sq. sig.	No transit	Transit commute	Chi sq. sig.	No transit	Transit commute	Chi sq. sig.	No transit	Transit commute	Chi sq. sig.
Walking to restaurant or café												
Never	48.2	32.7		93.1	79.5		68.8	35.2		78.8	43.6	
Less than ten days	40.8	57.23	***	6.5	20.5	***	21.4	42.1	***	16.9	38.5	***
Ten days or more	11	10.1		0.4	0		9.9	22.6		4.4	18	
Walking to gym, health club, or recreational facility												
Never	89.5	90.6		97.6	92.3		95.7	89.9		98.6	92.3	
Less than ten days	7.6	4.4		1.6	6.4	*	3.4	6.9	*	0.7	5.1	***
Ten days or more	2.9	5		0.7	1.3		0.9	3.1		0.7	2.6	
Walking to park												
Never	47.8	53.5		76.4	66.7		92.4	84.9		96	83.3	
Less than ten days	39.7	35.2		18.9	26.9		6.5	12	*	3.3	15.4	***
Ten days or more	12.6	11.3		5.1	6.4		1.1	3.1		0.7	1.3	
Total	100	100		100	100		100	100		100	100	

Note: Transit commute = frequent and infrequent transit commuters collapsed

Chi sq. sig. = Significance of Chi Square test (* p<0.05; ** p<0.01; *** p<0.001)

5.5 Discussion

Infrequent and frequent transit commuters differed in socio-demographic composition, distribution across neighborhood walkability, and in practice and enjoyment of physical activity. The main finding was that frequent and infrequent public transit commuters respectively accumulated approximately 8 and 6 more minutes of moderate to vigorous physical activity per day than those who did not commute by transit (see Table 5.3). Variations by region were not significant. This association of transit commute to MVPA was higher if participants lived in low-walkability neighborhoods as shown by negative interaction coefficient and stratification. Ten minutes per day would translate into almost one hour per week of additional physical activity for transit users, which is about 40% of the recommended 150 minutes of MVPA per week (USDHHS, 2008; USDHHS, 1996). The use of accelerometers to objectively measure physical activity strengthens confidence in the results.

The findings are generally consistent with other studies comparing transit users to non-users (Moudon et al., 2006; Wener and Evans, 2007; Brown and Werner, 2007; Villanueva et al., 2008; Lachapelle and Frank, 2009). Present analyses accounted for psychological influences of enjoyment of moderate physical activity to isolate the effect of environment and transit use on MVPA. Enjoyment of physical activity was independently and positively associated with physical activity, but did not confound the relation. Transit commuter's preference for an active lifestyle was not evidenced in this analysis.

To clarify the mechanisms potentially involved in the association between commuting by public transit and MVPA, public transit commuters and non-commuters were compared for walking to services and destinations near home and near the workplace. Transit commuters (frequent and infrequent combined) walked more often than non-commuters to some destinations within their home neighborhood and most destinations near their workplace. More transit commuters walked to destinations and in most cases walked more frequently, especially in low walkability neighborhoods and at the workplace. In low walkability neighborhoods, significant differences between transit commuters and non-commuters were found for walking trips to almost all destinations near home and near the workplace. These findings helped explain results of MVPA models. The difference in walking to destinations near home between transit commuters and non-commuters living in high walkability neighborhood was not significant for most destinations except for retail stores and restaurant or café. In high walkability neighborhoods, those not commuting by transit walked as frequently to destinations as transit commuters. In addition to the walking required to access transit from home and to get to work from transit, transit commuters engaged in a lifestyle involving considerably more walking for errands and other activities near their home and, especially near the workplace. Once at the workplace, and without a car, they engaged in more walk trips than commuters not using transit.

Transit users may accrue part of their daily physical activity by walking to transit, but the present analysis suggests that their active utilitarian lifestyle at home and at the workplace also involves walking to multiple destinations. Availability of services and amenities at the workplace may partially explain why transit commuters living in low walkability environments have higher MVPA. As transit stops and destinations near home may be farther in low walkability neighborhoods, trips to these services may involve walking longer distance.

5.5.1 Limitations and strengths

This analysis benefited from objective measures of physical activity and a two-stage survey sampling design conducive to analyzing the relationship between physical activity and commuting by public transit within the context of built environments of varying walkability. Self-reported utilitarian walking behavior and enjoyment of physical activity items served to provide explanation for the transit commute—physical activity association.

Because transit use typically has low mode shares, small samples sizes of transit commuters reduced the ability to reach statistical significance with multiple confounding variables in the models. Future studies should be sufficiently powered to overcome this limitation.

The analysis focused on the use of transit in the commute to work and does not account for other daily motorized travels. The survey format did not allow associating accelerometer measure with self-reported days walked and specific destinations. Combining an activity-based travel diary with the simultaneous deployment of accelerometers could support such analysis. Furthermore, accelerometers were deployed over a week, while the transit commute items assessed monthly commute patterns. With the two study regions and the neighborhood walkability and income study design, the analysis was not sufficiently powered to assess other neighborhood features such as crime. The public transit literature provides detailed information on the service characteristics associated with transit use (TRB-TCQSM, 2003). Increasing the quality of transit service can increase transit usage, and provide derived health benefits.

While active transportation required by transit commuter was more likely moderate, the combined moderate and vigorous measure (MVPA) was used to avoid loss of information and to assess general physical activity patterns. There is at least anecdotal evidence that people often have to rush to transit (Beirão, 2007) and the use of a combination of cycling (higher intensity activity) and transit (Martens, 2004) may potentially be recorded as more vigorous activity. Objective accelerometer measures do not separate leisure physical activity from active transportation (the theoretical source of association between MVPA and transit use). The relationship between transit use and different types of physical activity should be considered in future research.

5.6 Conclusion

The current study showed a positive association between the frequency of commute by transit and physical activity, as measured by MVPA, when controlling for socio-demographic characteristics, car availability and neighborhood income and walkability. The results strengthened previous studies in five ways. First, by testing if the relationship was similar respectively in high and low walkability neighborhoods (moderating effect). Second, by separating frequent commuters from infrequent ones. Third, by controlling for enjoyment of physical activity and car availability (confounding effects). Fourth, by using an objective measure of physical activity. And finally, by associating transit commuting with walking to services and destinations near home and near the workplace. Transit commuters, it was found, not only walk more to transit, they adopt a more active lifestyle to access utilitarian destinations.

The adjusted relationship between commuting and MVPA was similar for frequent transit commuters as for infrequent ones, and both were stronger than not commuting by transit. Transit commuters walked more than non-commuters. However, stronger effects of commute by transit were found when a person lived in a low walkability neighborhood, suggesting the greater distances likely required to get to transit stops and other destinations.

Infrequent and frequent transit commuters were found to differ in composition, in distribution across built environment and in practice and enjoyment of physical activity. Self-reported enjoyment of moderate physical activity was positively and significantly associated with walking, but did not confound the relationship between physical activity and commuting by transit.

Individuals residing in neighborhoods where they would not be expected to use transit likely make this choice because the combination of their workplace and home neighborhoods provides pedestrian access to a considerable number of destinations. Providing destinations and services near the workplaces should be considered as a potential means of increasing levels of physical activity. Promoting public transit use is associated with health, social and environmental benefits.

5.7 Significance

Commuting by transit was strongly associated with objectively measured moderate to vigorous physical activity, especially if transit commuters lived in low walkability neighborhoods. Policies known to support public transit use, such as increased availability, frequency or speed of service and lower fares, could have derived physical activity benefits.

Zoning policies and other programs to provide destinations around homes and worksites may enable an active lifestyle based on transit use.

In the next chapter

In the previous chapter, the use of an accelerometer-based measure was presented as having both strengths – because of its objective nature – and as a limitation, because of its inability to differentiate between purposes of physical activity. In chapter 6, self-reported measures of physical activity were used to isolate active transportation from other forms of physical activity. Furthermore, a more detailed scrutiny of the potential influence of car ownership on active transportation is required to address the concept of transit dependence present in transportation research. Individuals were categorized into four transit markets based on car availability and reported transit use over the past month: Choice and dependent transit riders, car exclusive travelers and potential transit market. This enabled an analysis of the differences between choice and dependent transit riders. A time use perspective suggests that individuals, based on their characteristics, may use time differently, be associated with different levels of physical activities, and perceived lack of time for physical activity may have a larger influence for some transit markets, namely the transit-dependent riders.

In chapter 6, I demonstrate that transit-dependent riders had the highest levels of active transportation. There was a positive association between active transportation and leisure physical activity, although longitudinal panel data is required to ascertain displacement. Results nonetheless suggest that transit-dependent riders' active transportation levels are not likely to reduce the amount of leisure physical activity they practice. Transit-dependent riders were however associated with the highest negative influence of lack of time on the practice of leisure physical activity.

A conclusion unifying each analysis will be presented in Chapter 7.

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Chapter 6 Active transportation of choice and dependent transit riders: associations and potential displacement of other physical activity [8]

6.1 Introduction

Many public transit users achieve physical activity recommendations solely by walking to and from transit (Besser and Dannenberg, 2005). Lachapelle and Frank (2009) found that additional transit trips increased the probability of meeting the Surgeon General's guideline for physical activity of at least moderate intensity – approximately 30 minutes a day, five days a week (DHHS, 1996; 2008) by walking on streets. They also found that additional car trips reduced the probability of meeting this guideline. Self-reported commuting by transit was also found to reduce the probability of being obese (Ming Wen and Rissel, 2008). General use of public transit and specifically commuting by transit has also been associated with higher overall levels of physical activity recorded by accelerometers (Brown and Werner, 2007) and pedometers (Wener and Evans, 2007). Associations were also reported between using public transit and walking as measured by a pedometer device in a university student population (Villanueva et al., 2008). Hence, studies have focused on the walk to transit, overall walking, and objectively measured physical activity. Many of the objective measures failed to capture if this higher physical activity level was actually associated specifically with transportation and travel. Moreover, none explored active transportation patterns across different types of transit users based on car ownership.

In order to clarify the relationship between public transit use, active transportation (walking, cycling, and other non-motorized modes) and overall physical activity, a transportation and time use perspective is applied to the study of the potential health

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benefits of transit use. Public transit research often separates populations into transit user markets of choice and dependent transit riders (Bullard et al., 2004; Sanchez and Brenman, 2007). Non-users of transit can be categorized into a near market of potential users, and exclusive car drivers, unlikely to shift travel behavior to transit use. Do these transit markets differ in practice of active transportation? Are overall levels of physical activity different across transit markets? Using self-reported time practicing different types of physical activity (transportation, leisure, home-based and work-based), active time for multiple types of physical activity was explored in order to identify evidence of potential activity displacement. Perceived lack of time for physical activity was used to identify activities most likely to be practiced less, as a result of time constraints. Does spending more active transportation time lead to an overall increase in physical activity or does it contribute to reducing the amount of time spent participating in other domains of physical activity? Is this relationship different across transit markets? Transit-dependent, riders, because they are constrained to transit use and walking, would potentially be more likely to reduce their levels of other physical activity. Such analysis, however cross sectional, can inform transit planners on the behavioral characteristics of transit markets with respect to active transportation. It may also provide valuable information on how choice and dependent transit riders may practice more active transportation for distinct reasons, and how active transportation relates to their practice of other forms of activity and their perceived lack of time. While physical activity behavior has direct health implication, the studied behaviors may inform transportation planners on the limiting consequences of transit dependence on lifestyles.

This study explores the following hypotheses (See Figure 6.1):

H1 Choice and dependent transit users are positively and significantly associated with more active transportation time than potential transit rider and exclusive car drivers, but are not significantly associated with other types of physical activity;

H2 Active transportation time is not associated with time spent on leisure physical activity, and this relationship does not vary across transit market;

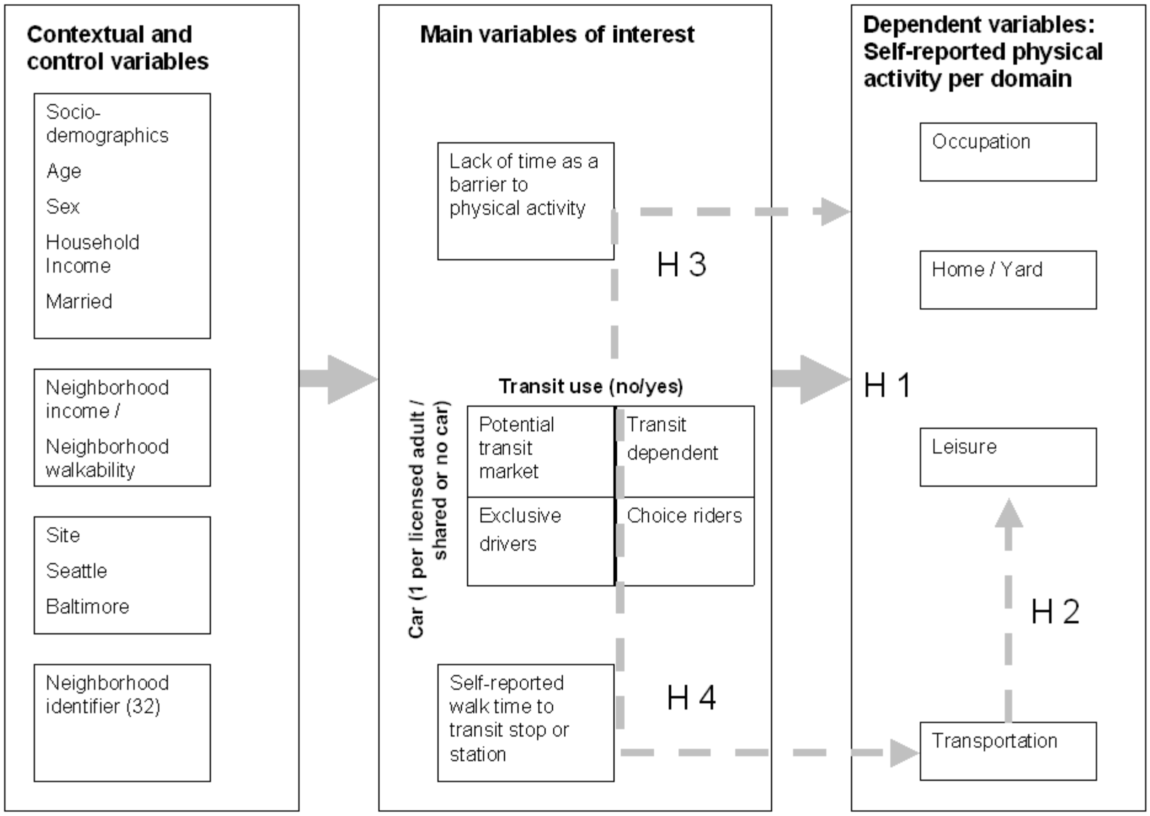
H3 For the sub sample of choice and dependent transit riders, perceived lack of time for moderate physical activity is associated with the practice of active transportation and leisure physical activity;

H4 For these two groups of transit riders, longer access time to transit stops is associated with higher levels of active transportation.

6.2 Framework

The ecological model has provided a flexible framework for exploring the correlates of physical activity. In the ecological model of active living, types of physical activity behavior are influenced internally by personal attributes, attitudes and perceptions, as well as externally, by the surrounding built environment and by public policies (Sallis et al., 2006). In this analysis, we augmented this model with a public transit research framework and concepts from time use perspectives (Michelson, 2005). A conceptual framework of associations between transit markets and self-reported time spent being active in each domains of the International Physical Activity Questionnaire (IPAQ) (transportation, leisure, home, and work), a set of self-reported physical activity measures, is presented in Figure 6.1. The first column (contextual and control variables) will be described in the methods section. How transit markets, a time use perspective and perceived lack of time are conceptualized an integrated in the analysis of domains of physical activity is described below.

Figure 6.1 Conceptual framework of the relationship between transit markets and domains of physical activity



6.2.1 Transit markets

Car availability is considered an important predictor of the use of public transit and a structuring influence on travel behavior (Frank et al., 2007; Zhang, 2006; Deka, 2002; Coogan et al., 2007). Transportation and urban planning literature often separate transit users into those that are dependent upon public transit (not having a car is the central aspect of transit dependence), and those that choose public transit (Bullard et al., 2004; Beimborn et al. 2007; Krizek and El-Geneidy, 2007). Transit-dependent riders do not have a car or at least not one available at the time of the trip. The term choice rider typically implies the use of transit in the context of availability of an alternative motorized mode, the car. These two user markets have distinct socio-demographic profiles, as well as distinct lifestyles, preferences and constraints (for example time constraints). Car availability provides a simple but clear distinction between the two groups.

Transit agencies considering how to expand transit patronage for non-users of transit, often distinguish the near market of potential users with limited access to cars (potential transit users), and a car-dependent (here referred to as car exclusive) market that may be harder to influence. Again, car ownership and availability is a key distinction between the two groups, as well as access to transit service (Zhang, 2006). There isn't a standardized approach developed to categorize markets because the concepts encompass many potential dimensions. Classifications based on perceived availability of service, attitudes towards transit use, car ownership and income have been used to identify and describe users and potential markets and assess travel behavior and accessibility to transportation (Vandersmissen et al., 2004; Krizek and El-Geneidy, 2007; Beimborn et al., 2007).
In this study transit-dependent riders are hypothesized to do more active transportation than their choice rider counter-parts. They are also hypothesized to be more likely to displace leisure physical activity by active transportation than choice transit riders, since their decision to use transit and reach destinations through active transportation is more a constraint than a choice. The influence of lack of time is also expected to have a stronger impact on their activities, as transit trips typically take longer.

6.2.2 Time use, activity displacement and lack of time

The analysis of time use diaries is frequently used to help understand how individuals and groups differ in the way they use time (Michelson, 2005). Groups can be previously defined and compared for the practice of specific activities, or the practice of activities themselves can be used to identify specific population. The SLOTH model considers the practice of different forms of physical activity in four domains, in order to elaborate policies specific to each domain (Sleep – a non-active daily activity, Leisure, Occupation, Transportation and Home-based) (Pratt et al., 2004). Each of these activities is part of an individual's fixed time budget (24 hours) and changes in one activity may influence the practice of another. Discretionary activities are considered more flexible and can be adjusted to other set time constraints. Non-discretionary activities are much less flexible or have to be done. Having children and finding a specific type of employment can be considered choices, but once these choices are made, a person is bound to these time budget constraints.

Within a fixed time budget of twenty-four hours, and with limited available discretionary time, the practice of one activity may displace another (Sturm, 2004; Pratt et al., 2004). Using the International Physical Activity Questionnaire (IPAQ) instrument, a time use approach can be used to compare the practice of types of physical activity based on pertinent individual characteristics. Such instrument can also help assess if an individual's physical activity patterns for one activity can lead to the displacement of other activities (e.g. active transportation vs. going to the gym) (Sturm, 2004, Zhang, 2005; Michelson, 2005). Associations between transit markets and different types of physical activity assessed by the IPAQ are explored in this study. The concept of potential activity displacement is used to assess the relationship between active transportation and the time spent in leisure physical activity, but cross-sectional data limits our ability to infer causal relationships. Assessing potential displacement of activity can provide information on the lifestyle constraints associated with transit dependence.

The practice of physical activity also depends on whether people have time available for physical activity. Modern daily life is often constrained by multiple time commitments. Lack of time is frequently reported to explain low levels of physical activity (Sturm, 2004). Yet lack of time likely only influences the practice of physical activity for activities that are more flexible (discretionary). Perceived lack of time is used in this analysis to assess its associations with the practice of types of activities. The influence of lack of time on a specific type of physical activity is used as a marker of how discretionary activities actually are. It also enables the exploration of differences between choice and dependent riders in how lack of time may potentially influence the practice of activities. In this study, associations between lack of time and outcomes are not interpreted as displacement effect but rather as the reduced practice of activities as a result of other broader life constraints.

6.3 Method

6.3.1 Study design and sampling

The Neighborhood Quality of Life Study (NQLS), an observational epidemiologic study designed to compare multiple health outcomes among residents of distinct neighborhoods, was used in this analysis. Data collection was carried out in the metropolitan region of Seattle, WA and Baltimore, MD between 2002 and 2005 (two waves) A number of key published papers present the neighborhood sampling methods in more details (Sallis et al., 2009; Frank et al., 2009). Thirty-two neighborhoods (16 per region) were selected based on median income and mean "walkability" of contiguous block groups. Median neighborhood income was determined using block group level 2000 census information. Both regional distributions were split in deciles, and block groups in the second, third and fourth deciles, and seventh eighth and ninth deciles were retained for respectively low and high-income neighborhoods. Similarly, an index of neighborhood walkability was used to identify block groups of low and high walkability within deciles 2, 3, 4 and 7, 8 and 9 (Frank et al., 2009). Multiple studies have used the same walkability index to describe the built environment characteristics that are associated with walking (Frank et al., 2005; Frank et al., 2006; Frank et al., 2008; Sallis et al., 2009). The index is equal to the sum of z-scores for four measures theoretically and empirically associated with walking behavior in numerous studies. They are: intersection density, retail floor area ratio, land use mix and net residential density (Ewing and Cervero, 2001; Handy et al., 2002; Frank et al., 2005). Contiguous block groups that matched the selected low and high deciles of walkability and income were used to sample 32 neighborhoods across both regions. Eight neighborhoods (four by region) were identified for the combination of high or low income and high or low walkability (see Table 6.2).

6.3.2 Participants and survey

Two waves of survey with self-reported items on physical activity behavior, attitudes towards physical activity, barriers to regular physical activity, and perceived neighborhood environment were sent to respondents randomly selected within the identified neighborhoods. Contact information was obtained from a marketing company. The first survey's return rate was of 26% (n=2199) and the second survey, sent six months later to respondents of the first survey, had a return rate of 87%, after eliminating those that moved out of the region. The analysis was conducted using the smaller sample of respondents of the second wave because survey items on public transit use were only available for this time period and could be matched to dependent variables collected at the same time. Transit use and car ownership and availability variables used to create the transit market categories were available for (n=1729). Of those, 1622 respondents reported all covariates, and depending on the dependent variables modeled, sample sizes varied between 1622 and 1315 respondents (only employed individuals reported work-based physical activity). Socio-demographics, car ownership and availability, as well as attitudinal variables were retrieved from the first survey.

6.3.3 Dependent variables

The dependent variables were computed from questions on the four domains of the long version of the International Physical Activity Questionnaire (IPAQ Research Committee, 2005). The average times spent being physically active in household tasks (indoor and yard work), for transportation (walking and cycling) at the workplace and for leisure (moderate and vigorous) were all computed by multiplying the reported number of days per week and number of minutes per day (days*minutes/day = min./week). IPAQ survey items have shown to be reliable and valid (Craig et al., 2003). Minutes of active transportation per week are defined as the sum of time spent walking and biking for transportation. Leisure time physical activity is the sum of walking for leisure, other moderate physical activity and vigorous physical activity. The following is an example question from the survey:

> Think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, washing windows, scrubbing floors and sweeping inside your home? (Days per week)
>
> How much time did you usually spend on ONE of those days doing moderate physical activities inside your home? (Minutes per day).

6.3.4 Independent variables

6.3.4.1 Transit market

The main predictor of physical activity in this study is a categorical variable of transit markets as defined by transit use and categories of car availability. Public transit users are defined as those having responded at least 1 day for any of these questions: “How many days in the past month have you walked to [public transit] from home?” and “How many days in the past month have you walked to [public transit] from work?”

A categorical variable of car availability was developed using the following items: “How many adults live in your household?”; “Do you have a valid drivers license?” and “How many cars does your household own?” The variables were used to identify 1) licensed adult living in households with one vehicle or more available per adult, 2) households where there are less than one vehicle available per adults, 3) households with no cars and 4) individuals with no drivers license in a car owning household.

The two categorical variables of transit use and car availability were then crossed to create four transit market categories: two transit user groups, choice transit riders and transit-dependent riders, and two non-user groups, car exclusive and potential transit users. The categorization is presented in Table 6.1. Choice transit riders and car exclusive were defined by having one car or more per adults in the household, a marker of always having the option to use a car. The four transit markets were used to frame the analysis. Attention was focused on the two transit user groups, but all categories were retained to avoid loosing information on automobile availability for those not using transit.

6.3.4.2 Perceived lack of time

To complement the time use perspective, perceived lack of time as a barrier to moderate physical activity was used for two purposes: first to identify physical activity types that are more discretionary and therefore less likely to be practiced because of lack of time, and second, to identify candidates for potential displacement.

As perceived lack of time increases, choice riders were expected to do less active transportation and dependent riders were expected to not be influenced. Lack of time was measured on a five-point likert-scale (0=never, 1=rarely, 2=sometimes, 3=often, 4=very often) Higher values indicate lack of time as preventing a person from participating in physical activity more often and for longer periods.

6.3.4.3 Self-reported walk time to public transit stop

Six categories of self-reported walk time to transit stop were recoded as: Less than 5 min, 5 to 10 min, or more than ten minutes away from home. These self-reported time categories were assessed for their associations with active transportation across choice and dependent transit riders to evaluate the potential influence of the walk time to transit on levels of active transportation. This analysis was restricted to transit users because associations between distance to transit stops and active transportation for individuals not using transit is illogical, and more likely to be the product of correlations between walkable built environments and better transit service.

6.3.5 Control variables

Public transit users have different socio-demographic characteristics than non-users. Lower average income and a greater representation of women and people of color are some of the key characteristics identified in previous research (Bullard et al., 2004). Variations also exist amongst transit users, between choice and dependent riders. The transit markets were first compared across these socio-demographic indicators: Being a woman, having children, being married, being white non-Hispanic, having completed a college degree (all dichotomous), age (continuous) and four categories of household income were identified as covariates of importance through exploration. These socio-demographic characteristics were also used as control variables in the four physical activity models in order to identify the independent associations between physical activity levels and transit markets. As transit users may be distributed unevenly across and between cities, the two dichotomous design variables of high and low income and high and low walkability, as well as the Seattle and Baltimore indicator were used in descriptive comparisons and included in the models.

6.3.6 Statistical framework

6.3.6.1 Hierarchical linear model

Three modeling specification are required to account for sampling framework, outcome distribution, and research questions. The multilevel (individuals clustered in neighborhoods) sampling strategy leads to a violation of the independence of observation assumed in OLS regression, and requires a hierarchical modeling structure that includes neighborhood level random effects to account for clustering of participants within the 32 study neighborhoods (Masse et al., 2002; Bingenheimer and Raudenbush, 2004). The higher-level distinction between the two study sites was included as a dummy variable in the model. Stratification by site and site by market interactions were tested but not reported for lack of significance.

6.3.6.2 Tobit model

As suggested by Edwards (2008), the clustering of zero values (some respondents not reporting days or minutes of physical activity) for IPAQ items can be accommodated with the Tobit regression model. A censored dependent variable model allows inclusion of participants not reporting any physical activity for a physical activity outcome (which actually amount, based on the question, to less than 10 minutes) if the independent variables are available. It is inefficient to discard information on the value of a dependent variable when it is available.

The expected value ($\hat{y}$) of the observed y, conditional on it being uncensored is used to provide adjusted estimates. Use of OLS when a dependent variable is censored would potentially result in bias of the constant, or of the coefficients (Washington et al., 2003). A censored distribution would also violate the assumption of normal distribution.

6.3.6.3 Moderating effect: categorical by continuous interactions

The concept of a moderating effect refers to a theoretical causal model ($A \rightarrow B_1 / B_2 \rightarrow C$) where the association between continuous variables A and C varies across levels of categorical variable B. Moderating effects can be tested through the use of interaction terms, as well as model stratification (splitting the sample) (Bauman et al., 2002). The first series of models assessed associations between transit markets and each of the domains of physical activity, controlling for socio-demographics and perceived lack of time. In a separate model, the activity displacement hypothesis was explored using active transportation as a dependent variable to estimate leisure physical activity. Interactions were used to evaluate the impact of active transportation (A) on leisure physical activity (C) across transit markets (B_{1-4}). Unreported models for the sample of transit user markets (choice and dependent riders) provided estimates used to plot the associations between lack of time and leisure and physical activity across transit markets. Interactions were used to evaluate the impact of perceived lack of time (A) on active transportation and leisure physical activity (C) across transit markets (B_{1-4}).

6.4 Results

6.4.1 Transit markets

The study included 418 transit users, of which 182 used transit, but never from work; and 51 have walked to public transit from work but not from home. The latter could have walked to work, been driven there, or used a park-and-ride facility, thereby not walking to a stop or station from home.

The distribution in each of the four transit markets based on reported transit use and vehicle ownership patterns is reported in Table 6.1. Exclusive drivers and potential transit users are found on the first column (not using transit). Choice and dependent transit users are on the second column.

Table 6.1 Transit market groups classified using transit use and car availability

Categories of car ownership and availability level		Non-user	Transit user	Total
No car household	n (%)	18 (1.4)	56 (13.4)	74 (4.3)
Car owning household with no license	n (%)	14 (1.1)	18 (4.3)	32 (1.9)
Licensed - shared car	n (%)	161 (12.3)	96 (23.0)	257 (14.9)
		Potential users	*Dependent riders*	
Licensed - one or more vehicle per adult	n (%)	1118 (85.3)	248 (59.3)	1366 (79.0)
		Car exclusive	*Choice riders*	
Total	n (%)	1311 (100)	418 (100)	1729 (100)

Pearson chi2 (3 Degrees of freedom) = 176.3845 Pr = 0.000

The distribution of socio-demographics, attitudes and physical activity behavior for the transit markets and the entire sample is presented in Table 6.2. The four markets differed in socio-demographic characteristics. Exclusive drivers and choice transit riders were wealthier and shared other similar characteristics beyond full car availability. Transit-dependent and potential markets share similar features beyond limited car access. Car availability levels are considerably lower in the transit-dependent markets than in the potential transit user market (Table 6.1). Potential users were more frequently members of households with at least one shared automobile. When comparing the two transit user groups to their counter-parts, proportionally fewer transit users were married and had children, and a much higher percentage were renters. Choice riders had the highest percentage of college graduates, the lowest percentage of children and of married couples than all three other categories.

The distribution of the transit markets across neighborhood walkability and income was also indicative of the neighborhood characteristics chosen by each transit markets. Non-users of public transportation were spread more evenly across neighborhood quadrant types, although car-exclusive respondents were more frequently found in low walkability/high-income neighborhoods and potential riders are more frequently found in high walkability/low-income neighborhoods. Choice and dependent transit users were more highly concentrated in the walkable (high and low-income) neighborhood groups. The distinction between choice and dependent transit users in neighborhood of residence was clear, with 63% of transit-dependent living in low-income neighborhoods (45% are in high walkable/low income), and 54% of choice riders living in high-income neighborhoods (45% in high walkable/high income). For both transit use categories, more than 20% of the transit users were found in the low walkability neighborhoods, mostly in low-income neighborhoods.

Home- and work-based physical activity were the largest sources of physical activity for everyone. Both transit user categories reported more leisure and active transportation than the non-user groups. Transit-dependents had the highest mean active transportation value.

Lack of time was, on average, a greater barrier to physical activity for the wealthier individuals with full car availability (car exclusive drivers and choice riders).

Table 6.2 Sample descriptive by transit markets

		Transit markets				
		Car exclusive (n=1118)	**Potential riders (n=193)**	**Transit-dependent riders (n=170)**	**Choice riders (n=248)**	**Total (n=1729)**
Seattle (n)		677	100	98	138	1013
Baltimore (n)		441	93	72	110	716
Neighborhood						
Low walkability/Low income	%	25.9	29.5	17.7	17.7	24.3
Low walkability/High income	%	34.5	16.1	6.5	11.7	26.4
High walkability/Low income	%	16.2	29.5	43.5	29.0	22.2
High walkability/High income	%	23.4	24.9	32.4	41.5	27.1
Women	%	45.7	54.9	50.6	51.2	48.0
Have children	%	41.6	39.4	32.4	29.0	38.6
White non-Hispanic	%	79.2	63.9	68.5	73.6	75.6
Completed college degree	%	68.4	59.6	54.1	77.0	67.2
	Mean(SD)					
Age (Years)		46.0 (10.4)	46.6 (11.6)	45.4 (11.1)	45.6 (10.1)	46.0 (10.6)
Household income ($)		74 537 (30 581)	60 223 (32 606)	54 240 (35 441)	72 791 (31 515)	70 757 (32 171)
Log of mean income		11.1 (0.6)	10.8 (0.8)	10.6 (0.9)	11.1 (0.6)	11.0 (0.6)
Lack of time is barrier to PA (0=Never; 4=Very often)		2.5 (1.1)	2.4 (1.1)	2.2 (1.2)	2.5 (1.1)	2.5 (1.1)
Active transportation (mins.)		101.5 (225.1)	146.1 (337.2)	273.9 (386.0)	166.3 (191.2)	132.5 (260.3)
Leisure PA (mins.)		199.3 (298.5)	138.0 (202.6)	231.4 (376.6)	214.9 (241.0)	197.9 (291.4)
Home PA (mins.)		553.8 (728.1)	515.8 (698.0)	531.5 (743.9)	422.6 (564.9)	528.6 (506.2)
Work PA (mins.)		572.1 (1050.8)	675.7 (1390.9)	687.4 (1138.3)	348.3 (821.6)	559.3 (1072.0)

Note: PA: physical activity; SD: Standard Deviation

6.4.2 Transit markets and IPAQ domains

Associations between transit markets and different forms of physical activity (domain of the IPAQ) were assessed in a multivariate context and estimated using the Tobit model (Table 6.3). As presented by the number of censored variables for each IPAQ domains outcomes, more respondents reported no active transportation (574) compared with home-related physical activity (139) or leisure physical activity (422). Work-related physical activity had a lower sample size to begin with since not all survey respondents were employed outside of home, and a higher percentage of respondents reported no work-related physical activity (nearly 40%).

Transit users, both choice and dependent, were positively and significantly associated with active transportation although dependent riders had higher coefficients. Transit market had no association with other physical activity outcomes with two exceptions: dependent riders were positively associated with leisure physical activity, and choice riders were negatively associated with work-related physical activity, two surprising findings worthy of further discussion. Household income was not significantly associated in the active transportation model but was highly significant for other domains except home-based physical activity. Household income was significantly associated with active transportation when transit markets were not considered in the model.

Table 6.3 Tobit model of minutes of physical activity in IPAQ domains

	Active transportation		Leisure PA		Home PA		Work related PA	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Car exclusive [Ref.]								
Potential transit user	34.0	0.250	-80.1	0.012	-88.4	0.142	56.9	0.688
Dependent rider	194.0	0.000	74.4	0.025	-21.9	0.734	-73.8	0.632
Choice rider	127.3	0.000	25.3	0.355	-91.7	0.085	-308.5	0.014
High walkability neighborhood	106.6	0.000	31.3	0.128	-94.4	0.013	93.8	0.297
High income neighborhood	-14.1	0.621	52.6	0.015	-38.3	0.337	-283.7	0.002
Region: Baltimore	32.1	0.230	21.0	0.287	38.2	0.310	104.0	0.243
Age	0.0	0.985	-1.7	0.066	5.9	0.001	9.4	0.031
Women	10.7	0.551	18.0	0.342	238.5	0.000	-401.4	0.000
Have children	3.7	0.849	-22.3	0.272	175.7	0.000	85.2	0.354
White non-Hispanic	26.0	0.255	63.7	0.006	78.0	0.076	82.3	0.432
Log of household income	-28.9	0.067	56.2	0.001	-3.5	0.915	-593.6	0.000
College graduate	-11.8	0.573	37.9	0.082	-135.7	0.001	-559.4	0.000
Lack of time is barrier to PA	-23.3	0.004	-57.5	0.000	5.2	0.755	-35.8	0.359
Constant	302.1	0.096	-403.6	0.040	-61.7	0.868	7370.3	0.000
n	1622		1621		1621		1315	
Left-censored observations	574		422		139		516	
Log likelihood		-7946.063		-9079.597		-11960.32		-7270.541
Wald chi2 (13 df)		109.72		114.81		106.39		200.81
Model Sig.		0.0000		0.0000		0.0000		0.0000

Coef. = Coeficient; Sig. = significance level; chi2 = Chi square test of significance; Lack of time (0 = never; …4 = very often)

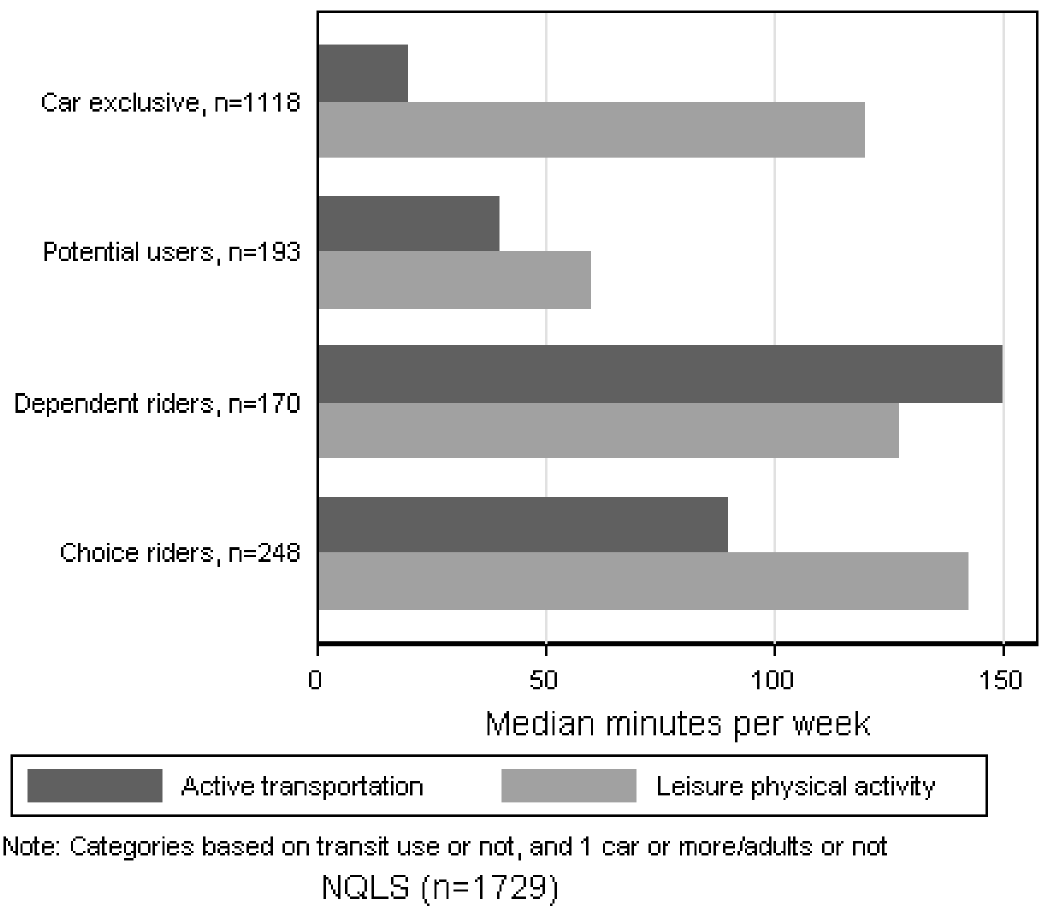
In the active transportation model, choice and dependent transit riders had larger coefficients than the dichotomous neighborhood walkability variable. Living in a walkable neighborhood was negatively associated with home activity. Smaller homes, condos and rental units available in denser walkable neighborhoods require less indoor and outdoor maintenance (an important source of home-based physical activity) and house smaller households without children. Having children was positively associated with active time at home, and was not associated with other types of physical activity.

Increased importance of perceived lack of time as a barrier to physical activity was negatively and significantly associated with active transportation and leisure physical activity, and not significantly associated with work and home-based physical activity. As these later two activities were not associated with perceived availability of time, their non-discretionary nature was revealed. Active transportation and leisure physical activity were interpreted as being more discretionary activities, as shown by their negative association with perceived availability of time. Even for transit-dependent riders forced to walk more, lack of time may reduce overall travel to needed and desired destinations. The larger negative coefficient of lack of time on leisure physical activity was consistent with expectations that it is the most discretionary of all four types of physical activity. The potential displacement between active transportation and leisure physical activity, and the potential moderation of choice and dependent transit riders in this relationship was analyzed next.

6.4.3 Activity displacement

Can the amount of time spent on leisure physical activity be influenced by the amount of time spent on active transportation? The first step in assessing a potential displacement effect between active transportation and leisure physical activity was to graphically compare values across transit markets. Adjusted median minutes of active transportation and leisure physical activity for each transit markets are presented in Figure 6.2. The median was favored as a measure of central tendency because of the skewed nature of the IPAQ data (IPAQ Research Committee, 2005). Transit-dependent riders reported the most active transportation. Choice riders also reported more active transportation than those not using transit. Less active transportation time for choice riders may reflect their ability to locate nearer to transit stops or stations, a point that is discussed later. Choice and dependent transit users did not have lower median minutes of leisure physical activity than the potential transit market or the car exclusive group. In fact, choice riders had the highest median minutes of leisure physical activity of all transit markets.

Figure 6.2 Median leisure and transportation physical activity across transit markets



A test of whether active transportation time was associated with time spent in leisure physical activity, and whether this relationship was different depending on the transit market was summarized in Table 6.4. The model provided estimates of leisure physical activity as a function of an interaction between active transportation and transit markets, while assessing the main effect of transit markets. Active transportation time was independently positively and significantly associated with leisure time physical activity when controlling for other covariates. For each market (except the car exclusive, used as a reference category), the coefficient needs to be interpreted in the context of the independent effect of active transportation.

Table 6.4 Model of Leisure physical activity and influence of active transportation for transit markets

	Leisure PA	
	Coef.	**Sig.**
Active transportation	0.5	0.000
Car exclusive [Ref.]		
Potential transit user	-28.8	0.376
Dependent rider	76.6	0.042
Choice rider	-15.1	0.642
Potential transit user*Active tran	-0.4	0.000
Dependent rider*Active tran	-0.3	0.001
Choice rider*Active tran	0.1	0.490
High walkability neighborhood	12.6	0.497
High income neighborhood	53.0	0.006
Baltimore	12.6	0.491
Age	-1.9	0.033
Women	25.1	0.158
Have children	-27.1	0.154
White non-Hispanic	58.5	0.007
Log of household income	68.1	0.000
College graduate	42.8	0.037
Lack of time is barrier to PA	-52.6	0.000
Constant	-586.2	0.002
n	1617	
Left-censored observations	421	
Log likelihood	-8970.9641	
Wald chi2 (20 df)	261.27	
Model significance	0.0000	

Coef. = Coefficient; Sig.= significance; chi2 = Chi Square
Interaction term noted by *

Estimating leisure physical activity values for specific cases clarifies interpretation of the model. Such estimation is presented for the study population's mean, median and three other hypothetical active transportation times, across transit markets, when controlling for other covariates (Table 6.5). All other variables were kept at their means. As active transportation increased, there was an associated increase in leisure physical activity for individuals in each category. The increase was considerably larger for the two categories with full car availability (car exclusive and choice riders). These results, albeit cross-sectional, are not supportive of the hypothesis that active transportation displaces time spent in leisure activity. While these results did not provide evidence of activity displacement for any of these markets, they suggest that car availability (and perhaps more likely associated higher income) may be more important than transit use in modifying the relationship between the two forms of physical activity.

Table 6.5 Estimating Leisure Physical Activity as a function of active transportation and transit markets

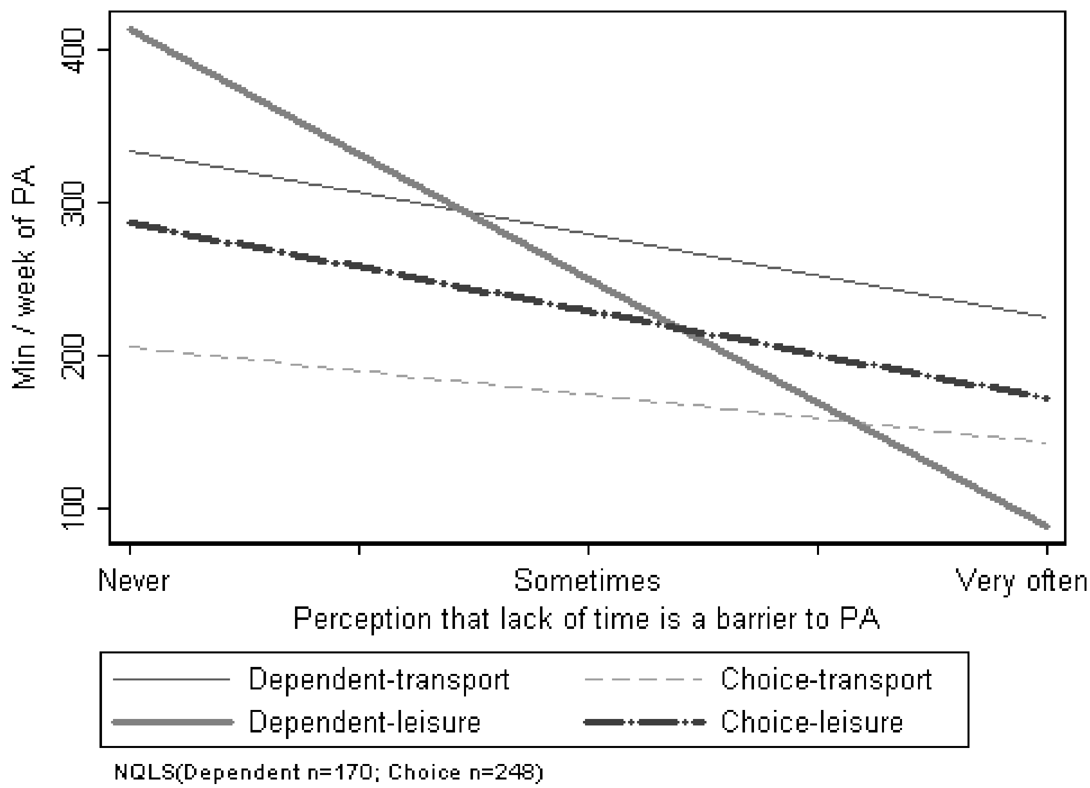
Active transportation (minutes)	Car exclusive (n=1118)	Potential transit users (n=193)	Dependent transit riders (n=170)	Choice riders (n=248)
65	168.7	112.7	224.9	159.3
132	200.6	116.5	235.7	197.2
200	233	120.4	246.6	235.6
265	263.9	124.1	257.1	272.3
400	328.2	131.9	278.9	348.6

Case is woman, no children, college education, white, living in high walkability and high-income neighborhood, and other values at mean.
132 minutes is the mean value for active transportation.

6.4.4 Attitudes: lack of time for transit user markets

The rest of the results only used the two transit user markets of choice and dependent riders. Plotting the relationship between lack of time for physical activity and both active transportation and leisure physical activity for choice and dependent transit riders allowed an exploration of the potential influence of attitudes on the time spent practicing these two physical activities. In Figure 6.3, perceived lack of time for physical activity was negatively associated with the level of active transportation and leisure physical activity for choice and dependent riders. For transit-dependent riders, lack of time had a stronger association with the practice of leisure physical activity. If a transit-dependent individual has no other means but to walk or cycle to transit (a combination of slower modes of transportation), lack of time may have had a greater influence on the practice of discretionary activities like leisure physical activity even in the absence of observed potential displacement. The accumulation of other daily activities reduced their ability to spend leisure time physical activity.

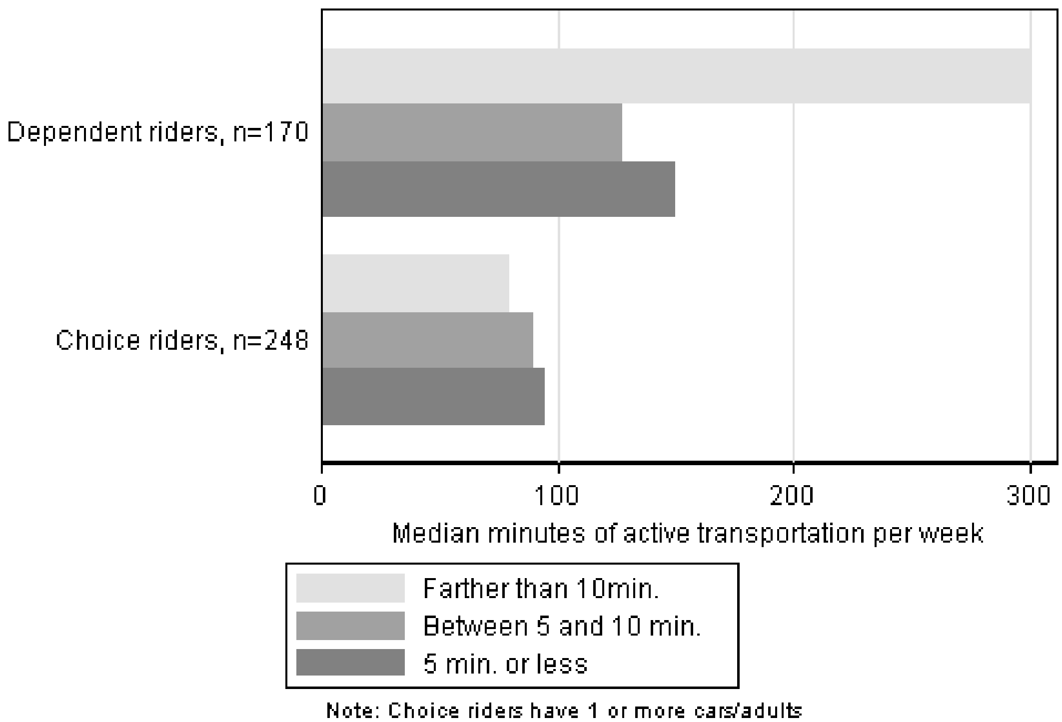
Figure 6.3 Active transportation and leisure physical activity for choice and dependent transit riders as a function of perceived lack of time



6.4.5 Distance to transit for transit user markets

Finally, one of the reasons why transit user markets may report more active transportation is likely associated with the distance required to walk to public transit stops or stations. In Figure 6.4, active transportation of choice and dependent riders was assessed across three categories of walk time to transit. In a Chi square test, there was no statistically significant differences (significance 0.309) in the percentage of choice and dependent riders across categories of walk time to transit. For dependent riders, living 10 minutes or farther from transit was associated with much higher reported active transportation. The median active transportation time suggests that dependent riders actually walk to transit even if it is farter, while choice riders may rather drive to a park-and-ride.

Figure 6.4 Walk time to transit and median active transportation for choice and dependent riders



6.5 Discussion

The two transit rider markets were found across the spectrum of neighborhood walkability and income assessed in this study. While transit users were concentrated in more walkable neighborhoods, nearly 30% of choice transit riders and about 25% of dependent riders were found in the low walkability neighborhoods. Based on Figure 6.4, it seems likely that choice riders used park-and-ride to avoid longer walks to transit stops. Choice and dependent riders also differed considerably with respect to household income, the former earning on average higher income. More car exclusive lived in low walkability neighborhoods than any other market.

Transit users performed more active transportation than non-users, and dependent riders even more than choice ones. Both transit rider markets spent more time in leisure physical activity than their non-user counter-parts. Two results are somewhat surprising: the positive relationship between transit-dependents and leisure physical activity, and the negative relationship between choice riders and work-related physical activity. In the former case a potential explanation worth exploring further is that transit-dependent riders, by being accustomed to walk more, as part of their daily life, may develop an appreciation for leisure physical activity. A higher mean value of leisure physical activity for dependent riders may be the result of a lesser average influence of lack of time on the practice of leisure physical activity. In the latter case, the choice riders variable may have captured unobserved traits common to a class of young educated urban professionals working in downtown offices (and performing little work-related active time), where transit service is at its best. The considerable influence of other similar demographic characteristics make this hypothesis plausible. These relationships are likely the product of unobserved characteristics of the transit markets and should be the subject of further investigation.

The attitudinal variable of lack of time for moderate physical activity was used to identify the forms of physical activity more potentially subject to activity displacement. It was also used to estimate associations between lack of time and reduced time spent in active transportation and leisure physical activity across transit user markets. Activities not influenced by lack of time can be considered non-discretionary (work and home related) and the ones that are influenced by lack of time are more discretionary. Leisure physical activity, with the highest negative impact of lack of time, was confirmed to be the most discretionary form of physical activity, and therefore the most vulnerable to displacement by other uses of time. Active transportation was also negatively influenced by perceived lack of time and therefore displayed the hypothesized characteristic of a discretionary activity, yet to a lesser extent than leisure physical activity. Theoretical considerations, as well as this result, supported the choice to model variations in leisure physical activity as a function of how much time each transit markets spent in active transportation.

As was shown through the linear relationship between active transportation and leisure physical activity's association with lack of time (Figure 6.3), lack of time had a particularly strong influence on the practice of leisure physical activity for transit-dependent riders. Transit-dependent riders had higher median minutes of active transportation and less leisure physical activity than choice riders as shown in Figure 6.2. Activities are not always purely discretionary or non-discretionary. Personal characteristics, circumstances and limitations may also render the practice of an activity more or less discretionary. For transit-dependent riders for example, active transportation may often be the only alternative to motorized travel by transit. Active transportation is therefore likely more discretionary for choice than for dependent riders. Because an automobile or a ride is less readily available, transit-dependent riders may be forced into active transportation, walking more out of necessity than out of interest. Choice riders, because of their higher income, may better be able to access property or rental housing in places where transit service and other destinations are near.

Results suggest that potential displacement of leisure physical activity by active transportation is not likely for both choice and dependent riders, but rather the contrary. In fact, for all individuals in the study, active transportation was positively associated with time spent in leisure physical activity, whether a respondent used transit or not, and had a car fully available or not. Activity displacement, in this analysis, would have been most clearly evidenced by a negative relationship, such that an increase in active transportation would have been associated with a decrease in leisure physical activity, and only for transit users or a sub-group thereof. This was not the case. Rather, the results suggest that the higher levels of physical activity of transit riders, whether choice or dependent, is added to overall physical activity without reducing time spent practicing physical activity in other domains.

6.5.1 Limitations

The main limitation of this study is its cross-sectional design, which did not allow ascertaining causality in the associations and interactions studied.

The socio-demographic characteristics of categories of respondents used in this analysis are consistent with existing descriptions of transit-dependent and choice riders (Murray and Wu, 2001; Bullard et al., 2004; Deka, 2002) and of exclusive car drivers (Zhang, 2006 refers to "car captive") and provided a simple but effective way to analyze different transit markets. Creating more detailed categories of dependence based on car availability would have resulted in groups too small to infer any results. A more detailed account of lifestyles preferences and attitudes towards travel has also been used to identify the different markets. For example, it is possible that individuals could choose not to own a car and use transit as the only motorized mode even if they have sufficient income to afford an automobile. The categorization used in this paper would not have allowed for their identification as choice riders.

The neighborhood walkability and income-based sampling served to control for the influence of the built environment near home on physical activities. Associations between types of physical activities and transit market were independent of neighborhood walkability.

Self-reported metrics of physical activity that allowed a distinction in types, intensity and purposes of physical activity were used in this study. However, these physical activity measures were subject to recall bias and self-report bias. Time use, as measured by IPAQ items, only accounted for physical activity and therefore did not allow a complete analysis of the use of time. As such, the analysis contrasted with typical time use studies using activity diaries. However, while time use diaries often focus on one or two days, IPAQ items refers to weekly physical activity levels. Because the NQLS travel behavior measures focus on monthly transit use, the time discrepancy between the dependent and independent variable is recognized as a limitation, yet likely does not cast important doubt on the validity of the results.

There were too few cyclists in the sample to carry out separate analyses for time spent cycling. It was decided that grouping cycling with walking would be better than not accounting for it since, like walking, cycling is a travel mode that can complement walking and transit use in multimodal travel. Since activities of different intensity require different energetic output, the IPAQ Research Committee (2005) suggests guidelines to convert time to Metabolic Equivalent of Task (MET), or metabolic equivalent. MET is a physiological concept expressing the ratio of metabolic rate associated with an activity, and the metabolic rate at rest. This allows a more accurate comparison of energy expenditures across domains of physical activity and across intensity within domains. All models were estimated using variables converted to MET. Direction of effect and significance of main variable of interest were consistent with the results displayed here. Time values were used in the analyses because of their more direct and intuitive associations with lifestyles and the concept of lack of time.

6.6 Conclusion

Transit markets are heterogeneous in their socio-demographic composition, residential neighborhood type, physical activity behavior, and attitudinal characteristics.

Both choice and dependent public transit users were positively and significantly associated with more minutes of active transportation than the reference categories of non-users with full car availability. Dependent transit users had the highest levels of active transportation. While active transportation complements the practice of other forms of physical activity, it was not the most important source of physical activity for most survey respondents. From a public health perspective, increasing active transportation nonetheless provides health benefits. Yet, from a transportation perspective, transit-dependent's higher level of active transportation may be interpreted as a lack of access. Hence, transit-dependent riders may walk more out of necessity, and choice riders may walk more because of ease of access and preference for walking. Transportation and land use planners can influence access and active transportation levels of choice and dependent riders through the provision and distribution of transit service.

Greater perceived lack of time as a barrier to physical activity was negatively associated with active transportation and leisure physical activity, revealing the more discretionary nature of these activities. They were analyzed more specifically to assess how active transportation may displace physical activity, and if this relationship was different across transit markets. Choice transit riders, as defined in this study, spent less active transportation time and more leisure physical activity time than their transit-dependent riders counter-parts. Lack of time had a stronger negative association with the practice of leisure physical activity for transit-dependent riders.

For all respondents, and across transit markets, more active transportation was associated with more leisure physical activity. An activity displacement effect seems unlikely and direct benefits of transit use (choice or dependent riders) on physical activity seem plausible. This may explain why transit users in other studies were found to have higher objectively recorded physical activity (Brown and Werner, 2007; Wener and Evans, 2007; chapter 4 of this thesis).

The analyses carried out in this paper confirmed the positive association between transit use and physical activity, and identified higher levels of active transportation of dependent riders. This relationship was qualified by identifying the importance of separating transit-dependent from choice riders as two distinct user markets. As such, the research informs transportation research by presenting implications of transit dependence on excess walking, as well as on reduced time for the practice of other activities. Furthermore, the higher level of active transportation performed by transit users was not accompanied by a decrease, or displacement, in leisure or other types of physical activity. Hence, public transit use may provide physical activity benefits that do not seem to be outweighed by a reduction in other forms of physical activity, a finding that strengthens the public health argument for transit use promotion. Following a cohort of individuals over time to evaluate how changes in active transportation influences leisure physical activity would strengthen results and enable ascertaining causality.

Evidence that supports the need to integrate health issues into public transit planning and to consider physical activity benefits as individual and social externalities of public transit service investments (Litman, 2003) was presented in this paper. Public health authorities can provide support for public transportation in two main ways: first, by directly conveying educational and social marketing messages to the public on the physical activity benefits of using public transportation and, second, by providing interagency support for investments in public transportation infrastructure and policies. By doing so, public health agencies could indirectly support reductions of human impacts on natural systems through reduced automobile use, while working within their mandate of promoting and enhancing population health (Zheng, 2008). For transit agencies, this health-based social marketing could lead to increased ridership. On a longer horizon, cost-benefit analysis of transit projects could come to include the health benefits of a physically active lifestyle (Edwards, 2008) and other health and ecological costs currently unaccounted for.

6.7 Significance

Public transit use may provide direct health benefits through active transportation, independent of the practice of other forms of physical activity or of the lack of time for physical activity. For transit users without cars or with limited car access - the transit-dependent rider market - these health benefits may, however, be a product of their limited ability to access destinations using motorized modes.

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Chapter 7 Conclusion

The primary aim of this thesis was to provide a detailed account of the relationship between public transit use and active transportation. Studying this relationship has been identified as a topic of interest by a group of experts outlining future research in the field of the relationship between the built environment and physical activity (Dannenberg et al., 2003), yet limited evidence and theory on this relationship is found in the literature. The analyses conducted here led to a validation of results of the few available studies to date, theoretical clarifications, and a more detailed exploration of the potential explanatory mechanisms involved in the transit-active transportation relationship. Improving the health of the population through increased participation in physical activity is not the only policy issue that is supported by this research. Providing a means of mobility and access to those without automobiles in the context of the development of more sustainable forms of transportation is also a central social justice and urban planning policy issue driving this research endeavor. A secondary aim was therefore to explore the neighborhood correlates of transit use and to explore the ability of transit riders and potential transit riders to locate near transit service. If the physical activity benefits are accrued because transit stops are far, they are gained at the cost of poor access.

Three manuscripts were included as the empirical chapters of the thesis. Three criteria guided the development of empirical chapters. Analyses were designed to valorize the particularities and uniqueness of the data used and acknowledge its limitations, to be publishable individually as stand-alone pieces, and to be coherently linked as part of this thesis.

In chapter 4, the process of neighborhood and housing location preferences and how it relates to transit use was analyzed. The initial assumption was that individuals do not always have the ability to locate in places with transit service that is satisfactory enough, even if they sought to at the time of the move. Housing location can support or inhibit transit use, through the process of self-selecting into a neighborhood that is well served by public transit (Scheiner, 2006; Litman, 2009; TCRP, 2008). This analysis was developed to present the links between attitudes towards public transit, neighborhood walkability, transit service indicators and transit use.

In chapters 5 and 6, the hypothesis that transit users walk more than non-users was explored and confirmed. Furthermore, using the concept of public transit as a catalyst for an active lifestyle, potential explanatory mechanisms involved in this relationship were explored in greater detail. At the beginning of the thesis, I framed the concept of a catalyst in order to establish the set of criteria by which to evaluate the effects of transit use on walking. A catalyst was defined in the context of this research as “the use of a service (transit service) that enables a behavioral response (active transportation) to proceed at longer duration or higher frequency or under different conditions than otherwise possible”. A complex set of interrelations between transit service, transit use, the built environment, socio-economics characteristics, travel opportunities and limitations (such as restricted car availability and transit dependence), as well as preferences and time availability, were presented in the thesis. Given my results, I suggested that the catalyst effect was plausible as I was able to empirically verify the criteria established in the introduction and theory chapter.

Transit-dependent riders were found to practice more active transportation than choice riders. This result, coupled with the moderating effect of transit use in the relationship between built environment and physical activity, suggested the exploration of processes occurring earlier along the causal pathway of preferences, choices and choice limitations in housing location. Circumstances and necessary trade-offs may have limited a respondent’s ability to locate near public transit. Not all respondents were able to harness the benefits of public transit use and they may have been forced to accept less than optimal conditions for transit use. Lower income transit-dependent riders were potentially more vulnerable to these circumstances, as evidenced by the fact they walked more than their choice rider counter-parts. Results presented in chapter 4 suggested that a transit-housing mismatch might have occurred for some respondents because of conflicting preferences, housing opportunities (lack of single family housing) and financial restrictions prevented respondents from locating in areas well served by transit.

Researchers must consider how different theoretical frameworks can help understand the complexities and diversity of issues associated with public transit. Transportation planning and public health literatures provided theoretical frameworks, a body of existing empirical evidence, and impetus for policy actions. The ecological model of active living (Sallis et al., 2006) is the dominant theoretical underpinning and helped shape the research questions and provided a flexible framework adapted to the outcomes of interest. In this framework, both active transportation and transit use are behaviors influenced by individual characteristics as well as by the surrounding built environment and transportation policies. Economic theory of consumer choices with respect to transportation (Ben-Akiva and Lerman, 1985; Meyer and Miller, 2001) was also used to assess transit use as a choice. Concepts of time use (Michelson, 2005), time restriction and activity displacement (Sturm, 2004) were used to analyze and discuss differences in lifestyles. The influence of preferences, opportunities, inclinations and obligations on travel choices and housing choices were drawn from psychosocial theory applied to transportation (Stradling et al., 2000; Gärling et al., 2002; Scheiner, 2006). Looking at public transit use from a physical activity perspective provided distinct evidence on the lifestyles associated with public transit use. Theory on travel disadvantage (Lucas, 2004; 2006; Sanchez and Brenman, 2007; Sanchez, 2008; Sanchez and Brenman, 2008) helped identify groups of interest such as transit-dependent riders.

These last few words are devised to link the analyses conducted in the empirical chapters, explain their theoretical relevance, show their innovativeness and limitations, and suggest prospects for future research. In the last section, the results are placed in the current policy context and given relevance for distinct interest groups and levels of governmental and non-governmental organizations.

7.1 Why conduct this research?

Although not mentioned explicitly in each chapter, many contemporary planning and sustainability issues make up the backdrop for the resulting analyses and justified the current research. Discussions over climate change, and transportation-related greenhouse gas emissions, rising fossil fuel price, urban traffic congestion and urban redevelopment all call for the development and expansion of public transit infrastructure and increases in public transit use (Cervero, 1998; TRB, 2001; Ewing et al., 2007). Investments in physical transit infrastructure can contribute towards increasing ridership, a reduction in auto use and in vehicle Kilometers traveled. Equally important is to gain a better understanding of transit riders and their personal and household characteristics, lifestyles, perceptions and constraints in order to increase the modal share of public transit, and enhance the experience of current users.

The analyses presented in this thesis can provide evidence to health authorities on the potential health benefits associated with transit use. Health authorities have turned to promoting moderate forms of physical activity achievable through everyday activity. This is because many North Americans do not practice any form of physical activity through leisure or sports, and because the dose-response curve between physical activity and health benefits does not display a lower threshold (meaning that even small amounts of moderate physical activity can generate health benefits) (USDHHS, 1996; USDHHS, 2008). Walking is the most important potential source of moderate physical activity. As lack of time is considered a strong barrier to the practice of physical activity, enabling individuals to build physical activity into their daily lives has been considered an effective way to improve population health. Health authorities can use the results presented here in two ways: By using social marketing to promote transit use and its health benefits (Maibach, 2003) and by directly addressing transportation and planning authorities, planners and decision-makers to influence decisions regarding transportation investments and changes to the built environment. These will be discussed below.

The analyses also improve our understanding of transit use, of the lifestyles associated with different groups of transit users and of the connection between housing and transit use and its implication on transit access. This information may help transit agencies tailor transit systems that make transit use more pleasant to the user, and more attractive to those not using it. These two objectives have been established by the Transportation Research Board and have been disseminated to professionals through the Transit Capacity and Quality of Service Manual (TRB, 2003). Planners can also draw lessons from this research by acknowledging the importance of ensuring that various types and price range of housing are available near transit corridors. Section 7.8 provides more specific policy implications.

Below, a brief review of each of the core empirical chapters is focused on presenting results, comparing data particularities and providing some justification for the combination of hypotheses presented in each chapter. This summary provides an opportunity to integrate findings and discuss their joint implications.

7.2 Transit-housing match and transit use (Chapter 4)

A more recent trend in research on the relationship between neighborhood built environment and non-motorized transportation is to attempt to control for the self-selection of individuals in neighborhoods that matched their preferences for certain types of travel (Cao et al., 2006; Handy et al., 2005; 2006; Frank et al., 2007; Schwanen and Mokhtarian, 2005a; 2005b). Chapter 4 begins with the premise that transit users, because of the scarce distribution of transit service in North American cities, must attempt to self-select into neighborhoods that support their travel preference in order to gain convenient access to transit service. However, because of economic constraints and required trade-offs between neighborhood and housing characteristics, some potential transit users may not be able to locate in preferred neighborhoods with transit access. The work of Schwanen and Mokhtarian (2005b) has begun addressing this issue using the concept of neighborhood dissonance, the idea that some people live in neighborhoods that do not support their travel choices.

In chapter 4, precursors of transit use and active transportation were assessed through an analysis of the inclinations and choices along the causal pathway that lead to transit use and non-motorized transportation. The chapter provided an exploration of the long-term process of housing location and its relationship to transit use. Individuals and households have competing needs and desires that ultimately lead them to identify a location for their home. Even in the presence of low quality transit service, respondents that wanted to locate near transit used transit at a similar rate as those that actually located near good transit. These results provide an explanation for the considerable differences in walking between choice and dependent riders and between transit commuters living in high and low walkability environments. Some transit users are not able to locate near good transit service.

The development and integration of transit service measures to the NQLS data for the Seattle metropolitan region allowed an assessment of the relationship between neighborhood walkability, as defined in the NQLS study design, and public transit service. Strong associations were found between transit service and walkability. Walkability was therefore considered synonymous with higher quality transit service in the other papers. More specific research designs would be required to disentangle the effect of walkability from that of transit service on transit use and active transportation.

7.3 Commuting and objective physical activity (Chapter 5)

In chapter 5, survey items on commuting patterns of employed individuals working outside of home were used. The proportion of trips to work taken by transit during the past month was separated into frequent and infrequent transit commuters, as well as non-users. The outcome of interest, a physical activity indicator, was developed using records from accelerometers deployed with the survey. This objective measure had the advantage of being less subject to reporting biases, and provided a portrait of overall activity levels over a week. The drawback of using accelerometer measures was the lack of details on the purpose of the activity (e.g. active transportation vs. leisure). Accelerometer records can, however, measure intensity, and be separated into bouts of light, moderate or vigorous physical activity (Freedson et al., 1998).

A first challenge to the catalyst hypothesis was that public transit potentially moderates the relationship between the built environment and physical activity. The characteristics of the survey, random sampling within neighborhoods of either high or low walkability, allowed for an effective test of this by enabling the comparison of transit users to non-users within neighborhood of high and low walkability. Independent of neighborhood walkability, transit users recorded more physical activity than non-users. Both frequent and infrequent transit commuters were positively associated with accelerometer measure when controlling for neighborhood walkability, household income and car availability. There was evidence of a moderating effect of transit use in the relationship between the built environment and physical activity since transit use increased the amount of physical activity in both neighborhoods, but not equally. The differences in physical activity between commuters and those not commuting by transit was greater in low walkability neighborhoods.

The idea that transit use may be a catalyst for walking is partly based on the assumption that transit users often walk to services near their home and near their place of work and therefore adopt an active lifestyle beyond the walk to transit. Indeed, even an avid transit user is likely to want to minimize the amount of traveling they do by transit by instead taking advantage of the destinations and services available near home and frequent destinations. Evidence of this is provided in chapter 5 through a comparison of transit users and non-user's number of days walked to different destinations and services from home and from the workplace. The analysis provides evidence that transit commuters not only increase their physical activity by walking to transit, but they also walked more both within their neighborhoods and near their workplace to access services. Again, the difference in walking to services between transit commuters and those not commuting by transit was greater in low walkability neighborhoods. Evidence of a more active lifestyle brought forth by non-motorized transportation was presented as a potential mechanism for transit users' higher physical activity levels.

Another issue that could be detrimental to the catalyst hypothesis is that people actually chose to use transit because they enjoyed physical activity to begin with. The addition of a self-reported attitudinal item on enjoyment of moderate physical activity provided no evidence of such confounding effect. Transit users were just as likely as non-users to enjoy moderate physical activity. That is, there was no evidence that individuals decided to use transit just because they enjoyed moderate physical activity. This also supported the plausibility of the independent effect of transit use on active transportation.

7.4 Transit use, transit dependence and self-reported physical activity (Chapter 6)

In chapter 6, self-reported measures of four different types, or domains, of physical activity (active transportation, leisure, home-based and work-based physical activity) were used. This data, albeit self-reported and therefore of lower quality than accelerometer measures, allowed the separation of active transportation from other forms of physical activity to confirm that active transportation had a stronger association with transit use than other domains of physical activity. The concept of activity displacement was used to evaluate if transit riders spent less time participating in leisure physical activity as a result of having spent more time in active transportation. The use of physical activity categories also allowed an analysis of the allocation of active time for two groups of transit users. Transit-dependent and choice riders were separated based on car availability to identify differences in active transportation and in the mechanisms influencing its practice.

As in chapter 5, evidence of higher active transportation were found for both transit-dependent and choice riders, but transit-dependent riders reported more active transportation than their choice counter-parts. No evidence was found of activity displacement for any of the studied groups whether non-users or choice and dependent transit riders. The processes and mechanisms associated with the practice of different types of physical activity were found to be different depending on whether a person was a choice or a dependent rider. For example, a longer walk to public transit stop for transit-dependent riders was associated with more active transportation. In such circumstances, choice riders would more likely drive to a park-and-ride to access transit. The results were used to support the argument that to choice riders, more walking is likely a lifestyle choice based on inclination to walk, while for transit-dependent, it may very well be a constraint associated with their travel limitations and necessities.

To complement the analysis of the practice of physically activity as an issue of time use and allocation of time, this analysis included a self-reported measure of lack of time to assess how lack of time could influence the practice of different types of physical activity for each groups. The trade-off between active transportation and leisure time physical activity was more apparent for transit-dependent riders than for choice riders. As lack of time was reported as being more important barrier to physical activity, active transportation reduced slightly for both choice and dependent riders. However, leisure physical activity reduced considerably more for dependent riders than for choice riders, suggesting that other activities in their lives – perhaps longer travel time – would constrain the practice of physical activity.

An interesting feature provided by the survey design was the ability to assess regional differences in physical activity by comparing Baltimore and Seattle. The differences between regions with respect to associations between transit use or transit commute and physical activity, as measured by accelerometers or self-reported measures, were quite modest and never significant. This suggests that the behavioral mechanisms presented in this thesis could be similar in other urban areas of the US. The results found in the analysis justify the reproduction of these analyses in other settings and the development of alternative approaches to the categorization of transit-dependent and choice riders.

7.5 Implications of chapter 5 and 6 and association with chapter 4

The field of planning has traditionally drawn from many theories and frameworks to produce evidence useful to policy making. Most often, these theories have not been integrated or considered jointly. Planners and planning researchers can, through their unique expertise, contribute to the creation of evidence of interest to other fields. In chapter 5 and 6, evidence that can be used in the creation of public health messages on the physical activity benefits of public transit use was provided. Both chapters seek to raise awareness in the public health field for the production of social marketing messages that combine healthy and sustainable living recommendations. Additionally, the evidence provided here can be used by public health agencies to positions themselves with respect to urban development and transportation policies.

Social marketing approaches are typically conceived as an intermediary between education and enforcement and can be used when the target market is neither prone nor resistant to the behavior being promoted and may voluntarily adopt the behavior. “Social marketing can be used to elicit behavior change in [these] populations by increasing the perceived benefits, reducing the perceived barriers, or in other ways improving the opportunities to adopt the recommended behavior, thereby enhancing the perceived value of the recommended behavior” (Maibach, 2003, p.115). Education may suffice when the population is prone to a behavior, and enforcement may be required when a population is resistant to a behavior. While it may be argued that the US population is largely resistant to a mode shift, policy-makers will likely not support enforcing the use of public transit, when it is available, for its health or environmental benefits. Using the evidence presented in this thesis, public health authorities may decide to engage in social marketing for public transit use by discussing its potential health benefits. Such an activity could potentially result in increased transit ridership without any additional investments from transit agencies.

Addressing social marketing messages to the population is not the only way that can be used to support public transit. Communication across institutional divides can also be used to provide public health support for transit infrastructure development to policy and decision-makers. This was clearly exemplified in the metropolitan region of Montreal, Quebec, where an annual report published by the public health department focuses on a specific theme each year. In 2006, the focus was on the health effects of urban transportation (DSP, 2006). The benefits of active transportation and the increased inactive time associated with car use were presented for their health benefits. This report, targeted to the population, was accompanied by issue papers submitted to hearings on highway projects. By doing so, the public health department have acted as advocates for change in urban transportation planning and built environment interventions that enabled the adoption of healthy travel behaviors, and the reduction of air pollution and traffic accidents. The benefits of public transit were not discussed for lack of evidence at the time. Information provided in this thesis would likely be appealing to a public health organization engaged in increasing active transportation and reducing auto use.

Chapter 4 and chapter 6 are distinctly associated in that the evidence produced can inform theory, research and policies on travel disadvantage. Social inequalities are of interest to both public health and urban transportation planning, because in both cases, lower income populations are worst off than wealthier populations. This is true for numerous health outcomes, as well as for mobility and access to employment and leisure opportunities. The introduction of the distinction between transit-dependents and choice riders in associations with active transportation suggests limitations that some may face in locating near transit service. Why would that be the case? In order to address this in more details, the process of housing location with respect to access to public transportation was explored in chapter 4. in this analysis, an exploration of whether respondents were able to locate in housing that enabled them to use transit was proposed. In turn, whether the satisfaction with the quality of the service actually led respondents to use public transit was analyzed.

To achieve the goal of increased transit use and to reap its physical activity benefits, planners and public health authorities must ensure that those wanting to use transit are able to find a home located in an area that supports transit use as well as provide other desired necessities and amenities. The results presented in chapter 4 provided evidence that not all respondents were able to locate in places that enabled their transit needs. As a result, those living in neighborhoods with lesser access to transit were found to have a lower propensity to use transit, even if they wanted to. This was however not statistically significant. Such a finding provides explanation for the higher physical activity levels of transit users in low walkability (chapter 5), and for the higher active transportation of dependent riders in chapter 6.

7.6 Theoretical and research implication

The study of the relationship between physical and the built environment brought forth discussions on the joint history and perspectives shared by the fields of transportation planning and public health – some of the first zoning ordinances were based on public health concern over the quality of air in highly populated areas (Schilling, 2005; Frank and Engelke, 2003; Frumkin et al., 2004). Chapter 4 was targeted to a planning and land use journal, Chapter 5 was accepted in September 2010 in a public health journal, the Journal of Physical Activity and Health and chapter 6 is targeted for submission to a transportation journal. Targeting chapter 6 to a transportation journal is justified by the need for improved communication across disciplines that share common interests. Growing interest in non-motorized transportation in transportation circles, and clear public health guidance on the importance of walking—a form of moderate physical activity—form the basis for renewed collaborations between the two fields (Sallis et al., 2004). Research on physical activity and the built environment now provides a clear theoretical and policy link. Some authors debate whether this is justifiable and desirable and whether planners should prioritize public health goals over environmental and social goals (Laurian, 2006). The perspective that was proposed in this thesis was rather to explore how both fields may generate complimentary evidence in an interdisciplinary effort with strong potential for co-benefits in an austere fiscal environment. The social goal of reducing travel disparities and the environmental goal of reducing motorized transportation can be, to a certain extent, reconciled.

Not so long ago, the field of planning drew inspiration from the knowledge and frameworks developed by other fields. Friedman (1987) provides extensive discussion of the sources of inspiration for planning theory, ranging from economics, public administration, management and sociology, to history and engineering. Now a science in itself, with a broad set of lines of policy inquiry, tools and acquired knowledge, the field of planning can, through the theoretical and empirical research produced, provide a contribution to knowledge development in other fields. Health authorities and researchers have been interested in learning about the perspectives that can be provided by urban and transportation planners (Sallis et al., 2004). Planning perspectives and expertise reinforces the measurement of built environments and the analysis of its correlation with physical activity, to the benefit of physical activity research. With transit use as a key focus of the thesis, elements of the travel behavior framework were used to augment the ecological model of active living. Concepts, such as transit dependence and transit-housing mismatch, that were not previously considered in physical activity frameworks, are a good example of the contribution urban transportation planning can provide to this research.

Many theories can serve to explain the use of transit, its associated health and social benefits and the process by which one accesses public transit. By looking at active transportation time as both a health benefit and a hindrance to transit use (through the negative influence of distance to transit stops), an attempt was made to join the concerns and frameworks of public health and transportation. This may help understand health inequalities as well as inequities in access to transportation, a known determinant of health. By analyzing time spent performing different types of physical activity, implications for transit-dependent lifestyles were identified. Longer transit access time, a reduced amount of motorized transportation, and a greater trade-off in the practice of leisure physical activity distinguished transit-dependent from choice riders. This analysis revealed social equity implications associated with access to transit. Indeed, the chapter concludes that those most needing to access transit can be located far from transit stops and stations, or in areas with less transit options and therefore have to walk longer distances to access the transit network. While health practitioners may see this additional walking as a health benefit, the choice framework used by transportation planners considers walking distance to transit as an impedance to transit use for those individuals (TRB, 2003), as well as a problem of distribution in access to transit (Schaeffer and Sclar, 1980; Lucas, 2004; Sanchez and Brenman, 2007). As such, the evidence detailed in empirical chapters provided a good example of how the theories and frameworks of both fields may have led to conflicting interpretations (Lachapelle, 2009). Considering both the ecological model of active living and the choice framework applied to transportation may increase behavioral realism in the study of travel and physical activity behavior.

7.6.1 Limitations and future research

Quantitative empirical analysis on public transit use and more broadly on travel behavior has largely relied on travel surveys and census data. Using a survey designed collaboratively by health, psychology and planning researchers has provided a number of benefits, as well as limitations. Prospects for future research that address these limitations are also presented.

Using a survey instrument designed for purposes not typically assessed in transportation planning research provided a distinct perspective on travel. First and foremost in the case of the present thesis, was the impact of perceptions and attitudes towards physical activity, time use and housing location. Also, differences in how travel and travel restrictions may influence the practice of other activities (in this case, the data only allowed us to observe domains of physical activity) brings a fresh perspective to the assessment and characterization of transit dependence. Analyzing physical activity patterns across population groups provided interesting and original insights into the lifestyles and limitations of transit-dependent riders. Activity-based travel survey or time use surveys could generate more detailed accounts of the use of time for travelers with distinct characteristics. Although the NQLS survey provided ample opportunities to explore the underlying mechanisms that support the relationship between transit use and physical activity, the design of the study by neighborhoods of high and low walkability and income is inherently unrepresentative of the spectrum of land use and socio-economic conditions found in the study regions. Nonetheless, this design enables a thorough assessment of the processes and mechanisms that may influence the studied behaviors. Care is taken in not overusing these results for their direct policy implications. Furthermore, it is a stated limitation of chapter 5 to focus specifically on employed individuals and not have data on the young and the old, three important markets for transit. Future study on the relationship between transit use and walking would gain from assessing these specific groups.

It is commonly understood that the poorest, most marginalized populations do not tend to participate in survey research, out of lack of time, disbelief that the results will improve their situation, or out of general mistrust in the elitist academic institutions. This low level of access to information on the most marginalized populations should be recognized in most research that does not specifically targets them, and is of paramount importance in the study of transit dependence. In future research, transit dependence could be explored by developing different and more specific forms of categorization, for example using information on preferences for transit use, or automobile use. Indeed, the measures used in chapter 5 were limited to the identification of transit dependence using information on driver's license and car ownership. As such, identifying individuals who may have foregone car ownership even though they could afford it because they did not enjoy driving was not possible. A person may be transit-dependent by choice. Many additional research opportunities can be inspired by the analyses presented throughout this thesis.

Strengthening the evidence presented in this thesis will likely require reproducing the results using data source that planners are more familiar with, such as activity-based travel surveys. Travel survey designs are evolving and the inclusion of items on attitudes, preferences and trade-offs will likely become more prevalent in the near future. Travel survey design has also entered an era of more accurate measurement of walking and cycling as non-motorized forms of transportation which enables research on trip chaining behaviors and the combination of multiple modes of transportation (Krizek, 2003). Understanding the links between motorized and non-motorized modes will likely gain from these endeavors. Much of the results presented in this thesis should be reproduced using instruments that are more representative of entire metropolitan areas, or at a national level. Travel surveys conducted in each regions of the US are widely available from the Metropolitan Travel Survey Archive (http://www.surveyarchive.org/, Accessed on November 2, 2010), and many regions make their surveys directly public to the research community. At a national level in the US, the National Household Travel Survey (http://nhts.ornl.gov/, Accessed on November 2, 2010), provides a solid opportunity to verify some of the results across regions and across metropolitan regions of the US. No equivalent is found in Canada for such national level transportation data. Health-based surveillance data could also be of use, but no know survey currently asks questions on transit use. The research presented in this thesis may be used to argue for the value of identifying transit users in health surveillance surveys.

Panel surveys, by following the same groups of individuals over time could provide the strongest evidence of activity displacement and of how travel restrictions like transit dependence impacts the allocation of time for other activities. The theory formulated in this thesis through the concept of catalyst is inherently causal. Only a rigorous longitudinal design will allow the clarification of the relationships hypothesized on and identified in this thesis. Nonetheless, cross-sectional evidence provides an excellent starting point to explore relationship and expand the theoretical framework. The Puget Sound Transportation Panel Survey (http://www.psrc.org/data/surveys, Accessed on November 2, 2010) provides one opportunity to assess information on how respondents have changed their travel patterns over time. In Canada, the city of Toronto has also developed the Toronto Travel-Activity Panel Survey, that could be used to track changes in travel and active transpotation over time (http://www.civil.engineering.utoronto.ca/research/transport/subpages/ilute.htm , Accessed on November 2, 2010).

Nevertheless, there exists a need for developing more specific survey tools specifically directed at the relationship between transit use, walking and physical activity behavior. There is a clear need for the design of a solid intervention study that would assess the motorized and non-motorized travel behavior of residents of an area before and after the implementation of transit improvements. A major challenge will be to coordinate the timing of funding sources, survey deployment and actual building and opening of the transit improvement. Along with travel and physical activity behavior, such survey instrument should include more specific items on perceived characteristics of the transit system, and of motivators and deterrents to transit use. The survey items available in the NQLS nonetheless formed a solid basis to produce innovative evidence.

Geographical Information Systems and Global Positioning System technology will also be important tools in the next ten years to more precisely describe walking, transit access, travel and the settings in which these take place. Finally, qualitative research on transit users may provide human-scale stories of the plight and benefits of public transit use for different types of users.

7.7 Policy implications

The research presented in this thesis was targeted to four specific policy audiences: **public health authorities, transportation and transit planner, urban planners and public transit advocates**. A recent report to congress stated "Transportation, housing and energy can no longer be viewed as completely separate spheres with little or no coordination through the different levels of government" (HUD, 2008). The report included a recommendation to better coordinate transportation, energy and housing policies and programs. The **Department of Housing and Urban Development (HUD), the Federal Department of Transportation (DOT) and the Environmental Protection Agency (EPA)** have begun collaborating on policy issues that will contribute to enhancing the co-benefits of urban policies. This desire to improve communication between departments is not new. The Transportation Research Board suggested in a 2002 surface transportation environmental research report that: "The nation must find a way to deliver a transportation system that simultaneously promotes economic growth, adds to the health of communities and individuals, uses energy efficiently, is inclusive, and enhances the natural and built environments" (TRB, 2002; Page 2). By exploring the inability to locate near public transit for low-income segments of the population, and by presenting the distinct lifestyles of choice and dependent transit riders, the results of chapters 4 and 6 provided evidence that transportation systems can be more inclusive. The assessment of physical activity and active transportation presented in Chapters 5 and 6 provided evidence of the benefits of public transportation in improving the health of communities and individuals.

The statements formulated in HUD and TRB reports have recently become reality with the development of the **Interagency Partnership for Sustainable Communities** (P4SC http://www.p4sc.org/, Accessed on August 13, 2010), between the Federal DOT, EPA and HUD. Intensification of communication and collaboration between agencies and Federal coordination of funding between each agencies should enable improvements in access to affordable housing, the creation of more transportation options for individuals as well as a reduction in transportation costs for American households. The EPA's contribution and oversight should ensure that these objectives are met while simultaneously protecting the environment in communities and helping to address the challenges of climate change.

As part of the Partnership for Sustainable Communities, six guiding "livability principles" will be used to coordinate transportation and housing investments and environmental protection " Fostering the concept of livability in transportation projects and programs will help America's neighborhoods become safer, healthier and more vibrant" (DOT secretary LaHood in News Release: http://www.hud.gov/news/release.cfm?content=pr2009-06-16.cfm, Accessed on August 13, 2010). The principles are:

- **Provide more transportation choices** to decrease household transportation costs, reduce oil dependence, improve air quality, reduce greenhouse gas emissions and promote public health;
- **Promote equitable, affordable housing**, by expanding housing choices for all people to increase mobility and lower the combined cost of housing and transportation;
- **Enhance economic competitiveness** through reliable and timely access to employment centers;
- **Support existing communities**, by investing in transit-oriented, mixed use development;
- **Coordinate policies and leverage investments** by aligning federal policies and funding;
- **Value communities and neighborhoods**, invest in healthy, safe and walkable neighborhoods.

With respect to these principles, some results of this thesis are worth pointing out and speak more specifically to the first, second, fourth and sixth principle. It should be recognized that that public transit users develop lifestyle strategies where they use motorized transportation less, and walk more frequently to nearby destinations in their neighborhood and place of employment to complete errands. It should also be recognized that lower income individuals use public transportation the most, and that some individuals favorable to transit use are unable to find a location where they can use public transit, and as a result may be “pushed” into owning a car and driving more, with resulting increases in energy use and Greenhouse Gas Emissions (GHG’s), Finally, low-income individuals are often transit-dependent because they cannot afford the additional burden of a car, and as a result of limited affordable housing near transit, they end up having to travel greater walking distance to get to transit and to utilitarian destinations.

While the current partnership should be welcomed and considered a major step in US urban policies, the content of this thesis attests to the need for a fourth partner in thin the P4SC partnership. Collaborating and coordinating policies with the **Department of Health and Human Services (DHHS)** could improve the attainment of health benefits from transportation and urban development projects, and the attainment of existing objectives with respect to inclusiveness and social equity. The combination of analyses presented in this thesis supports the idea that the four policy spheres of transportation, environment, housing and health could effectively “Speak with one voice” and attain greater co-benefits.

Public health authorities can use the research provided in this thesis for two main purposes. First, as stated earlier, to design and distribute social marketing messages to individuals to induce health-enhancing lifestyle changes, in this case the use of public transit and second, to support knowledge transfer and cross-silo collaboration in policy-making. Public health authorities may frame their policy recommendations to regional transportation planners and public transit agencies with respect to the provision and distribution of public transit service based on the health benefits that may be associated with these infrastructures. Public health authorities, with their strong emphasis on the health issues associated with lower-income population, could add a valuable voice to the discussion and help target investments where they can reach these populations. The wealth of empirical evidence on associations between neighborhood design and motorized and active transportation produced in recent years and the specific presentation of transit dependence in this thesis will give public health authorities much clout in these discussions. Improving the quality or quantity of public transit service does not ensure that people will use it. At an aggregate level, a larger share of the population may shift from car use to public transit, but, only the ones making this shift may actually harness the physical activity benefits. For this reason, information on the health benefits of transit use must be communicated to the public, in conjunction with advocacy for better transit infrastructures.

The provisions of the federal partnership should enable many opportunities for metropolitan areas to improve current housing and public transit provision jointly. Federal funding for transportation and housing projects are typically administered at the local level by **Metropolitan Planning Organizations (MPOs)**, who are responsible for creating a shared vision of the metropolitan area. MPOs are comprised of elected officials from municipal governments, transit agency representatives and state Department of Transportation officials. MPOs roles are to create a setting where metropolitan actors can develop Long Range Transportation Plans (LRTP), evaluate the value of alternative projects based on their merits, and develop Transportation Improvement Programs (TIP) devised to allocate scarce resources in a fiscally-constrained environment. MPOs are also expected to ensure public participation in program and project elaboration and development. Hence, while a large share of the funding will come from the federal government, much of the required changes will be carried out by MPOs. They already have many of the tools, processes and actors required to develop interagency partnerships at the metropolitan and municipal level. These required changes will not be done without the consent of the American population, who in many cases may be reluctant to the idea of mixed-income housing and public transit use. Public participation processes will have a key role in informing the population of the current state, collecting information on the desires, priorities, and vision of constituents, and in elaborating concrete context-sensitive solutions.

Transit advocates have been interested in the links between transportation, public health and social justice noting for example issues of access and of housing needs near transit (Reconnecting America, 2007a; 2007b). A public transit advocacy group from Vancouver, BC describes their role through the following statement. “The Vancouver Bus Riders Union represents the mass transit and public health needs of the transit-dependent. The Bus Riders Union fights to put the needs of transit-dependent people, overwhelmingly working class, and disproportionately people of color, at the center of public policy” (Vancouver Bus Rider Union Web Site, http://bru.vcn.bc.ca/about, Accessed on December 10, 2009).

Seattle's Transit riders union advocates for transit equity, which they define as "ensuring that all riders in all areas are well served" (Transit riders union http://www.transitriders.org/, Accessed on July 6, 2010). Baltimore's Transit Riders Action Council also has a transit equity committee (http://www.getontrac.org/, Accessed on July 6, 2010). The evidence produced as part of this thesis can provide evidence and help substantiate the public health and social inequity concerns of transit advocacy groups.

For **public transit planners**, there are many challenges that must be simultaneously tackled in order to improve the living conditions of urban dwellers. Increasing the provision, quality and distribution of public transit across urban areas has been promoted as a means of protecting the environment, reducing household travel costs, reducing dependence on fossil fuels, improving the quality of life and increasing economic efficiency. For any given project, it may not be feasible to attain each of these benefits. Creating a clear conversation about the goals of specific public transit projects will help make the process more transparent, accepted, and likely more successful (Walker, 2008). These goals could be increased ridership, improved service to current riders, or improved distribution of transit service across the region for equity purposes. Decisions regarding spatial distribution of transit service have often been focused on developing new high quality rails in wealthy neighborhoods (Grengs, 2002), thereby reducing funding for bus service in central areas inhabited by low income populations.

Public transit planners will find interest in discovering a different facet of the choice and dependent transit rider divide. At a time where transit agencies should be looking into expanding their service and ridership to be consistent with energy and climate change policies, understanding why even some of the poorest transit users may consider and often do use a car should be considered useful insights. Overly long walks to transit stops, and inability to locate near transit must be addressed to retain even low-income riders and to attract potential markets. Collaborating with Public Health Authorities may help them better understand the concerns of transit advocates and attain goals of social and environmental justice.

Results of the physical activity analyses in chapter 5 and 6 can be observed with two distinct perspectives: first by considering the physical activity benefits in themselves and second, by looking at active transportation as an indicator of lifestyles under constraints of low income and restricted car ownership. The second perspective rather reflects concern for access and provides new evidence on the burden of transit dependence. Considering only transit use in itself as a correlate of active transportation may obscure considerable differences between transit user groups. There exists considerable variation in active transportation between choice riders and transit-dependent riders, between frequent and infrequent commuters and between transit users residing in high and low walkability neighborhoods. These variations are an expression of the socio-economic situation of individuals, their practice of active transportation, of leisure activity, their ability to locate in places where good transit is available and their use of public transit. Mismatched pro-transit households are in a situation where any improvements in their financial conditions will likely result in a mode shift to automobile. Such loss of a near market should be considered unacceptable for a transit agency.

Understanding the physical activity benefits of public transit provides a clearer sense of the lifestyle implications of transit use. Providing the option for a physically active lifestyle for certain groups of the population willing to forego a car is in line with both public health and environmentalists' objectives. However, not considering the important burden of walking for those not having choices contradicts goals of equity. Furthermore, the physical activity perspective on transit use described in this thesis may inform transit providers about the pedestrian segment of a transit trip, which relates to the neighborhood, and requires increased collaboration with urban planners. The fact that public transit users take significantly more walk trips to services and destinations near the home and the workplace is a good example of how transit service and walkable, mixed-use neighborhoods support each others and enable an alternative lifestyle to car dependence.

Urban planners at the **MPO** and **municipal** level will be required to collaborate and coordinate with transit agencies in developing the land uses that support transit use, and in ensuring that provision for diverse housing enable users and potential users to access local destinations by walking. A large share of the public transit user market consists of low-income groups, whose housing and transportation needs consume an important part of their income. Federal programs aimed at funding transit projects will now be mandated to be aligned with housing programs, providing an important opportunity to address the key issue of the limited ability of potential transit riders to take on transit use in a favorable housing context. Transit service is already typically more available in high walkability areas, but there are transit users in low walkability areas, which have fewer opportunities for accessing services and destinations. In places with high walkability with sparse public transit, public transit should be intensified, and in low walkability areas where good public transit is found, care should be taken in providing services and destinations that can increase the ability to carry out activities within walking distance. Some of these transit users may drive to park-and-ride facilities, while others may live in a suburban area served by a nearby transit line. Intensifying the development of mixed-use and mixed-income housing near existing transit lines should also be done away from the city center, where lower land value makes housing typically more affordable. As high walkability environments and quality transit service commend a premium on housing costs, policy tools such as location efficient mortgages should be developed in existing high walkability neighborhoods. Location efficient mortgages enable people to take on a larger mortgage on their home purchases with the assumption that they will save on transportation costs by not relying as much on automobiles (HUD, 2008).

Some transit users' ability to locate in neighborhoods where good transit can be found was compromised by financial or household constraints, and by competing preferences and desires. Social equity research on transportation often focuses on accessibility to employment and ability to participate in labor market. Participation in undesired active transportation, and limited housing opportunities near public transit are two other expressions of social exclusion that must be understood to improve the living conditions of lower-income groups. The health, environmental, economic and social equity benefits of public transit can only be attained if all income groups can find housing in places that jointly maximize access to transit and to local destinations, so as to reduce the need for motorized transportation.

Combining theoretical frameworks, sources of data, and research questions from different fields has allowed me to develop innovative evidence completing existing knowledge on active living and travel disadvantage. Cross-disciplinary approaches are challenging to researchers that have been trained in fields with clear and defined boundaries of inquiry, and as such, are subject to severe questioning and critique. The uneasy questioning of existing assumptions and beliefs is however, I believe, the avenue where most creative and progressive research will take place in the next few decades. The policy orientation that the current US administration is taking clearly shows the need for crossing the boundaries of disciplines and policy realms. I hope that this thesis will be considered part of this great endeavor called interdisciplinarity.

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Appendices

Appendix 1 Additional Tables and Figures

Figure A.1 Frequency of public transit commute in King County neighborhoods

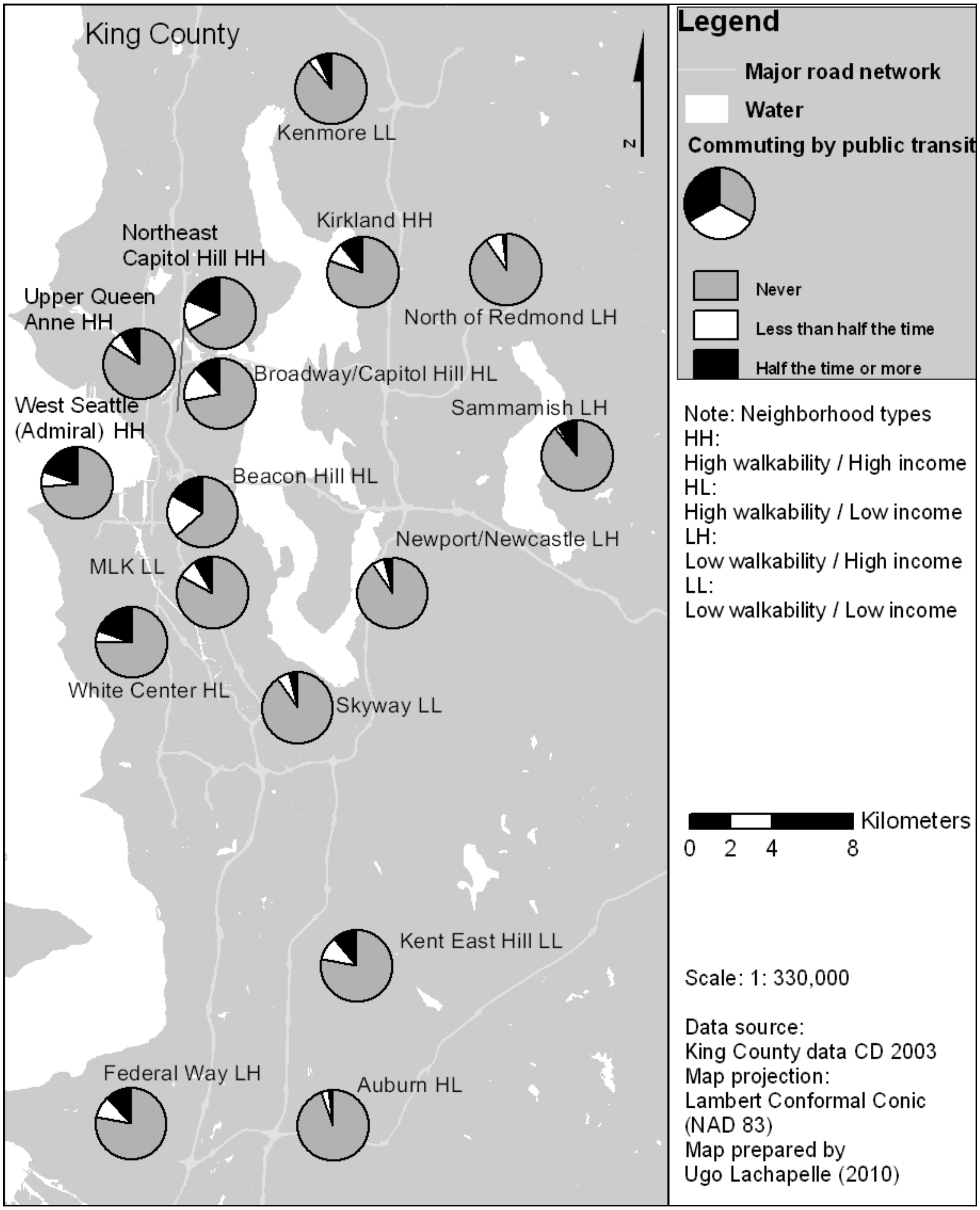


Figure A.2 Date first survey received

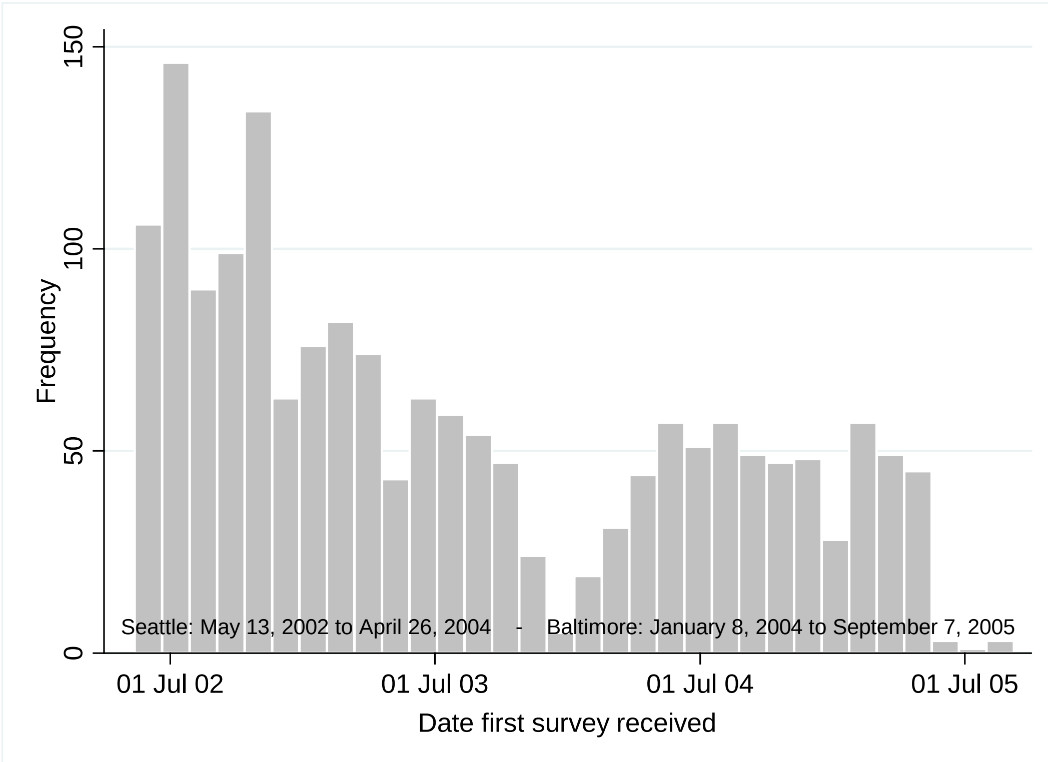


Table A.1 Pearson correlation coefficients for 1000 meter buffer measures of transit service, distance to features and walkability

	Lines/area	Express lines/area	Number of lines	Number of express lines	Transit cross-roads	Number of stops per area	Number of stops	Mean distance to 3 nearest park-and ride	Distance to nearest neighborhood centers	Mean distance to 5 nearest neighborhood centers	Distance to nearest stop	Walkability index
Lines/area	1.000											
Express lines/area	0.455	1.000										
	0.000											
Number of lines	**0.963**	0.472	1.000									
	0.000	0.000										
Number of express lines	**0.914**	0.494	**0.944**	1.000								
	0.000	0.000	0.000									
Transit cross-roads	0.282	0.181	0.336	0.217	1.000							
	0.000	0.000	0.000	0.000								
Number of stops per area	**0.632**	0.422	**0.714**	**0.592**	**0.612**	1.000						
	0.000	0.000	0.000	0.000	0.000							
Number of stops	**0.587**	0.457	**0.717**	**0.605**	**0.573**	**0.964**	1.000					
	0.000	0.000	0.000	0.000	0.000	0.000						
Mean distance to 3 nearest park-and ride	0.336	0.243	0.401	0.446	0.066	0.485	**0.505**	1.000				
	0.000	0.000	0.000	0.000	0.019	0.000	0.000					
Distance to nearest neighborhood centers	-0.280	-0.070	-0.321	-0.232	-0.397	**-0.504**	-0.477	-0.243	1.000			
	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000				
Mean distance to 5 nearest neighborhood centers	-0.394	-0.363	-0.444	-0.384	-0.354	**-0.591**	**-0.590**	-0.389	**0.830**	1.000		
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
Distance to nearest stop	-0.306	-0.331	-0.349	-0.241	**-0.515**	**-0.575**	**-0.536**	-0.064	0.429	0.386	1.000	
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.000		

	Lines/area	Express lines/area	Number of lines	Number of express lines	Transit cross-roads	Number of stops per area	Number of stops	Mean distance to 3 nearest park-and ride	Distance to nearest neighborhood centers	Mean distance to 5 nearest neighborhood centers	Distance to nearest stop	Walkability index
Walkability index	**0.734**	0.434	**0.821**	**0.747**	0.452	**0.861**	**0.867**	**0.591**	-0.398	-0.496	-0.490	1.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

Note: correlation coefficients above [0.5] are bolded.

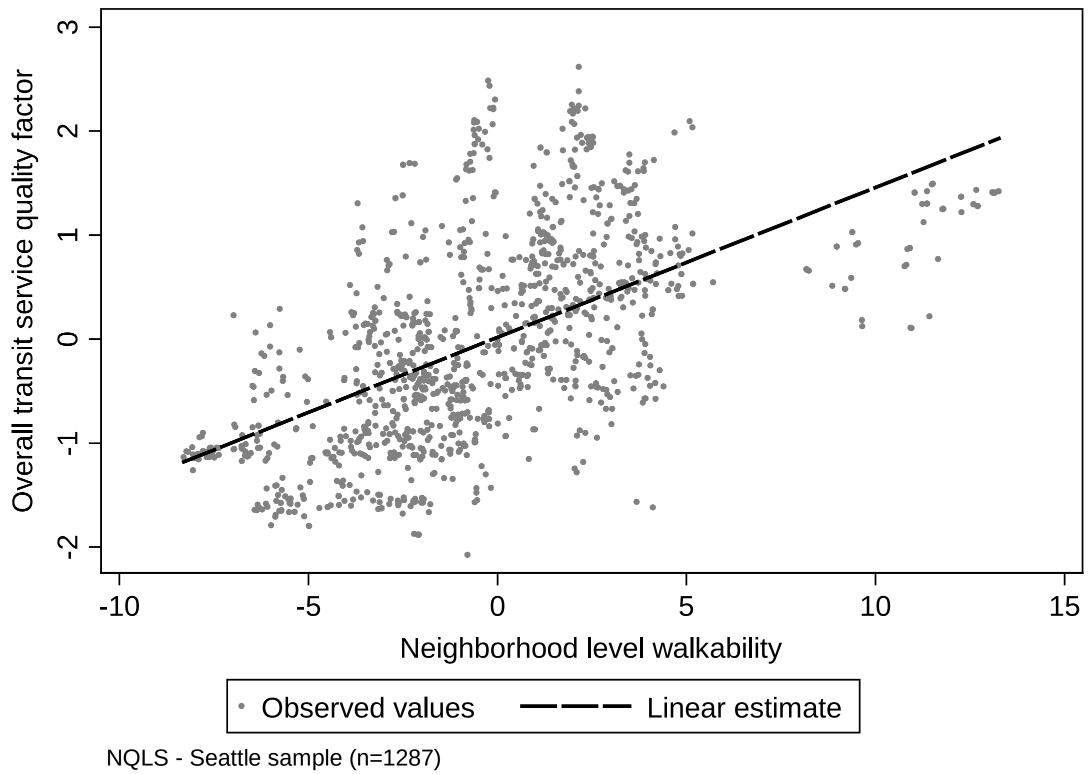
Table A.2 Pearson correlation coefficients for 500 meter buffer measures of transit service, distance to features and walkability

	Lines/area	Express lines/area	Number of lines	Number of express lines	Transit cross-roads	Number of stops per area	Number of stops	Mean distance to 3 nearest park-and ride	Distance to nearest neighborhood centers	Mean distance to 5 nearest neighborhood centers	Distance to nearest stop	Walkability index
Lines/area	1.000											
Express lines/area	0.367	1.000										
	0.000											
Number of lines	**0.663**	**0.523**	1.000									
	0.000	0.000										
Number of express lines	0.469	**0.840**	**0.608**	1.000								
	0.000	0.000	0.000									
Transit cross-roads	0.322	0.192	**0.631**	0.188	1.000							
	0.000	0.000	0.000	0.000								
Number of stops per area	0.361	0.167	0.605	0.137	**0.631**	1.000						
	0.000	0.000	0.000	0.000	0.000							
Number of stops	0.202	0.198	**0.659**	0.163	**0.673**	**0.913**	1.000					
	0.000	0.000	0.000	0.000	0.000	0.000						
Mean distance to 3 nearest park-and ride	-0.090	0.022	0.045	0.040	0.223	0.314	0.391	1.000				
	0.001	0.430	0.106	0.152	0.000	0.000	0.000					
Distance to nearest neighborhood centers	-0.105	-0.129	-0.247	-0.105	-0.210	-0.380	-0.395	-0.243	1.000			
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000				
Mean distance to 5 nearest neighborhood centers	-0.071	-0.255	-0.310	-0.215	-0.254	-0.444	**-0.510**	-0.389	**0.830**	1.000		
	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
Distance to nearest stop	-0.192	-0.241	-0.410	-0.203	-0.296	**-0.548**	**-0.540**	-0.064	0.429	0.386	1.000	
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.000		

	Lines/area	Express lines/area	Number of lines	Number of express lines	Transit cross-roads	Number of stops per area	Number of stops	Mean distance to 3 nearest park-and ride	Distance to nearest neighborhood centers	Mean distance to 5 nearest neighborhood centers	Distance to nearest stop	Walkability index
Walkability index	0.151	0.055	0.490	0.070	**0.523**	**0.646**	**0.754**	**0.591**	-0.398	-0.496	-0.490	1.000
	0.000	0.048	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

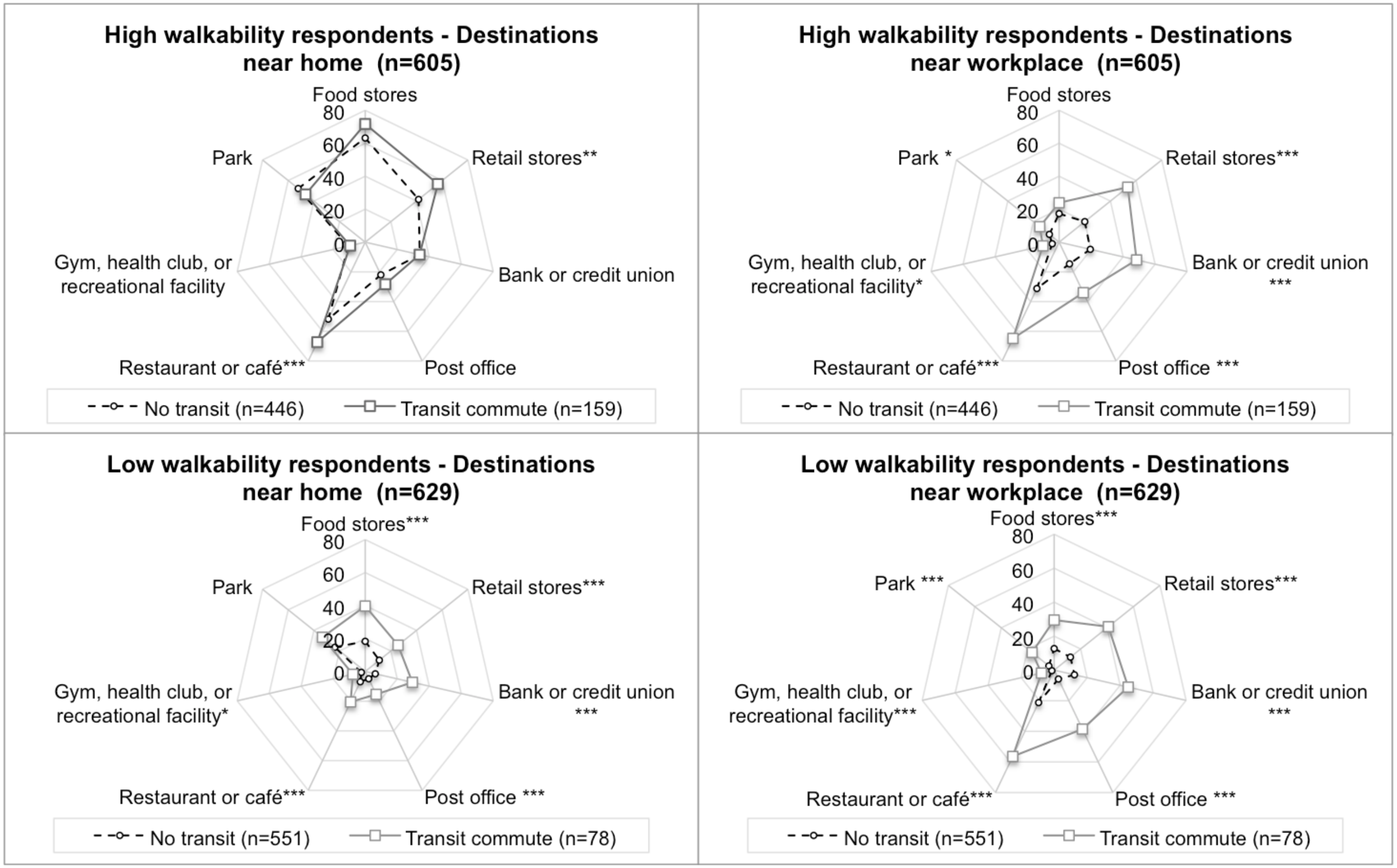
Note: correlation coefficients above[0.5] are bolded.

Figure A.3 Relationship between transit service quality factor and neighborhood walkability (Seattle)



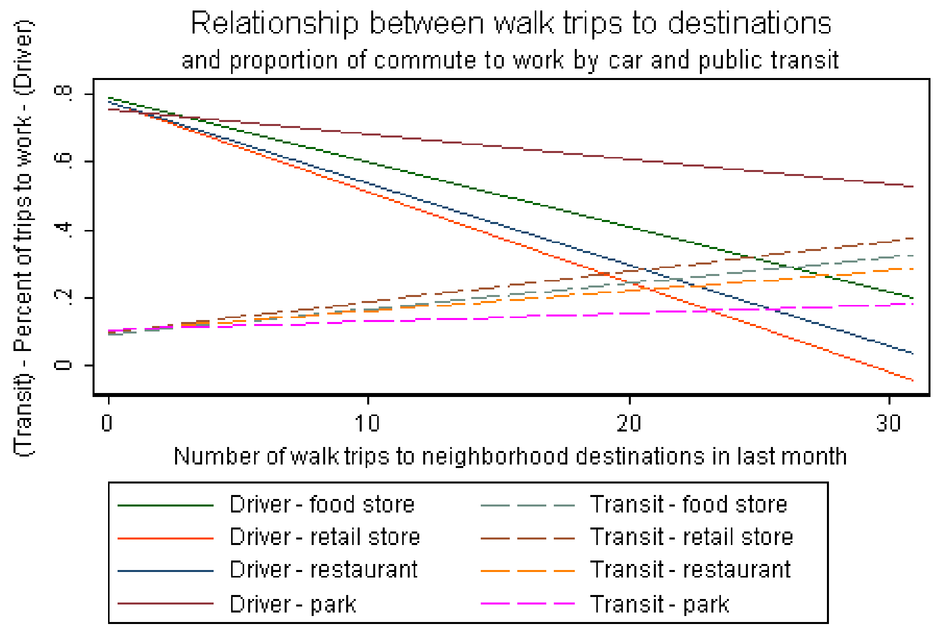
Note: There is an overall positive relationship between the transit service quality factor and the continuous measure of neighborhood walkability. The isolated cloud of points at the high walkability end of the distribution with transit service values bellow the linear estimate is made up of the residents of Broadway/Capitol hill, the highest walkability, low income neighborhood. The quality of transit service in that neighborhood could potentially improve regional accessibility for people living there that chose, or are forced, into a largely non-motorized lifestyle.

Figure A.4 Walking to neighborhood and workplace destinations by transit commute categories and home neighborhood walkability



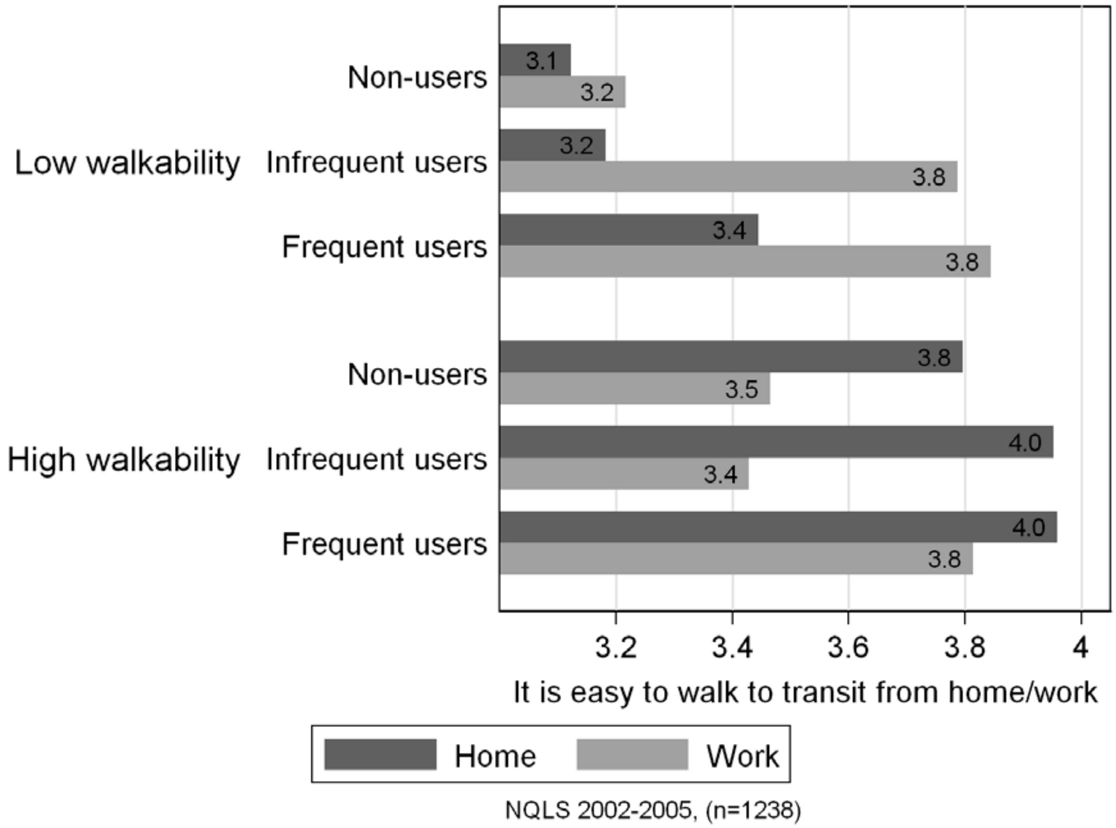
Note: Transit commuters walk more frequently than those not commuters to services near home and particularly near the workplace. Near home, the difference between transit commuters and their counter-parts in days walked to services is greater in low walkability neighborhoods. Overall, respondents walked more to restaurants, food stores and parks near home, and more to restaurants, banks and post offices near the workplace.

Figure A.5 Relationship between days walked to neighborhood destinations and proportion of commute to work by car and public transit



Note: In this Figure, rather than plotting the commute categories used in chapter 5, the proportion of all commute trips taken by public transit or driving is used on the vertical axis and the reported number of days walked to four selected destinations is used on the horizontal axis. The estimated linear relationship may not be an accurate and reliable way of estimating effect, but show an overall inverse relationship between walk trips and proportion of commute trips by driving, and a positive relationship between walk trips and proportion of commute trips by transit.

Figure A.6 Ease of access to transit at home and at work by commuter type



Note: Perceived access to transit near home is considerably higher in high walkability neighborhoods, and always slightly higher for transit commuters. Perceived access to transit near work is higher for those commuting by public transit, and not influenced, as expected, by neighborhood walkability near home. In high walkability neighborhoods, infrequent users perhaps only commute by transit part of the time because their ease of access to transit near home is counter-balanced by lower ease of access to transit near the workplace.

Appendix 2 NQLS survey first wave[9]

ID # ______________________________

Survey 1

NQLS
NEIGHBORHOOD QUALITY OF LIFE STUDY

We need your help to make our study a success. Your candid answers to the items in this survey are very important to us. This will not take too long to complete. Remember….

- we want to know what you think,
- there are no right or wrong answers, and
- everything you tell us will be kept strictly confidential (secret).

And please….

- don't skip any questions and
- provide only one answer for each item.

If you prefer, call the office toll-free at 1-800-990-6757 and we can do some or all of the survey by phone.

A. Quality of Life

Please circle one answer.

1. In general, would you say that your health is
    1. Excellent
    2. Very good
    3. Good
    4. Fair
    5. Poor

2. All things considered, how satisfied are you with your life as a whole?
    1. Very satisfied
    2. Moderately satisfied
    3. No feelings either way
    4. Moderately dissatisfied
    5. Very dissatisfied

1

[9] Only pages with used survey items are included. A full copy of the survey instrument is available at: http://www.ipenproject.org/surveycore.htm, Accessed on February 17th, 2008

M. Reasons for moving here

Please rate how important each of the following reasons was in your decision to move to your neighborhood. For each reason, please circle a number between 1 and 5, with 1 = not at all important and 5= very important.

	Not at all important		*Somewhat important*		*Very important*
1. Affordability/Value	1	2	3	4	5
2. Closeness to open space (e.g. parks)	1	2	3	4	5
3. Closeness to job or school	1	2	3	4	5
4. Closeness to public transportation	1	2	3	4	5
5. Desire for nearby shops and services	1	2	3	4	5
6. Ease of walking	1	2	3	4	5
7. Sense of community	1	2	3	4	5
8. Safety from crime	1	2	3	4	5
9. Quality of schools	1	2	3	4	5
10. Closeness to recreational facilities	1	2	3	4	5
11. Access to freeways	1	2	3	4	5

Good Work! You completed the first section ....
Rest your eyes or take a 5 minute break

2. I enjoy the feeling I get while doing vigorous activities.

1	2	3	4	5
strongly disagree	somewhat disagree	Neutral	somewhat agree	strongly agree

3. I enjoy the feeling I get after doing vigorous activities.

1	2	3	4	5
strongly disagree	somewhat disagree	Neutral	somewhat agree	strongly agree

Questions about Moderate Physical Activity

Please use this definition for SECTIONS V and W.

"Moderate" physical activity includes activities like brisk walking, gardening, slow cycling, or dancing. A moderate physical activity is any activity that takes moderate physical effort and makes you breathe somewhat harder than normal.

V. Self Confidence for Moderate Physical Activity

This section is about doing moderate physical activity in different situations. For each item, **please mark how sure you are that you could do moderate physical activity in that situation**. Circle one answer for each item.

	I'm Sure I Cannot		Maybe I Can		I'm Sure I Can
1. Do moderate physical activity even though I am feeling sad or highly stressed.	1	2	3	4	5
2. Stick to my program of moderate physical activity even when family or social life takes a lot of time.	1	2	3	4	5
3. I will set aside time for regular moderate physical activity	1	2	3	4	5

W. Enjoyment of Moderate Physical Activities

Please use the above definition for moderate activities. Please circle one answer for each item.

1. I enjoy doing moderate physical activities.

1	2	3	4	5
strongly disagree	somewhat disagree	Neutral	somewhat agree	strongly agree

If I participate in regular physical activity or sports, then:

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
7. I will improve my health or reduce my risk of disease..............	1	2	3	4	5
8. I will do better at my job.................	1	2	3	4	5
9. I will feel more attractive..............	1	2	3	4	5
10. I will improve my heart & lung fitness	1	2	3	4	5

Y. Barriers to Regular Physical Activity

How often do the following prevent you from getting regular physical activity? Please circle one answer for each item.

	Never	Rarely	Sometimes	Often	Very Often
1. Self conscious about my looks when I exercise	0	1	2	3	4
2. Lack of interest in exercise or physical activity.	0	1	2	3	4
3. Lack of self-discipline	0	1	2	3	4
4. Lack of time	0	1	2	3	4
5. Lack of energy	0	1	2	3	4
6. Lack of company	0	1	2	3	4
7. Lack of enjoyment from exercise or physical activity..	0	1	2	3	4
8. Discouragement	0	1	2	3	4
9. Lack of equipment	0	1	2	3	4
10. Lack of good weather	0	1	2	3	4
11. Lack of skills	0	1	2	3	4
12. Lack of facilities or space	0	1	2	3	4
13. Lack of knowledge on how to exercise	0	1	2	3	4
14. Lack of good health	0	1	2	3	4
15. Fear of injury	0	1	2	3	4

AA. General information

Please print clearly.

1. Home address: ____
   Street   Apt/Suite

   ____
   City

   __________________   ______________
   State   Zip Code

2. Nearest street intersection to home: _______________ & _______________

3. Phone number: ________________________
   Area code   Number

4. Age: ________

5. Are you:

   1. Male ____
   2. Female ____

6. Are you of Hispanic, Mexican, or Latin American descent? 1. Yes ____ 0. No ____

7. Race (you can circle one or more):
   1. Caucasian
   2. African-American
   3. Asian-American
   4. Pacific Islander
   5. American Indian or Alaskan Native
   6. Other __________

8. Height: ____ feet ____ inches; **or** ____ centimeters

9. Weight: _______ pounds; **or** ______ kilograms

10. What was your highest education level completed? (please check one).
    1. Less than 7th grade ____
    2. Junior high/middle school ____
    3. Some high school ____
    4. Completed high school ____
    5. Some college or vocational training ____
    6. Completed college or university ____

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7. Completed graduate degree _____

11. How many people (including yourself) live in your household? _______ people

12. How many children under 18 live in your household? ________

13. What are the ages of the children living in your household (if any)?

a) _________ b) __________ c) __________ d) _________ e) _________ f) _________

14. What type of residence do you live in? (please circle one).

1. Single family house
2. Multi-family house
3. Apartment
4. Condominium/townhouse
5. Other _______________

15. Do you rent or own your home? 1. Own/buying _____ 2. Rent _____

16. How long have you lived at your current address? _____ year(s); ______ month(s)

17. Do you have a valid driver's license? 1. Yes _____ 0. No _____

18. How many driveable motor vehicles (cars, trucks, motorcycles) are there at your household? _______

19. What is your marital status? (please circle one).

1. Married
2. Widowed/divorced/separated
3. Single and never married
4. Living with partner

20. Approximate annual household income (please check one)

1.	<$10,000 _____	7.	$60,000-$69,000 _____
2 .	$10,000-$19,000 _____	8.	$70,000-$79,000 _____
3.	$20,000-$29,000 _____	9.	$80,000-$89,000 _____
4.	$30,000-$39,000 _____	10.	$90,000-$99,000 _____
5.	$40,000-$49,000 _____	11.	> $100,000 _____
6.	$50,000-$59,000 _____		

21. Email Address: ____

Appendix 3 NQLS survey second wave[10]

ID# ________________

Survey 2

NQLS

NEIGHBORHOOD QUALITY OF LIFE STUDY

We need your help to make our study a success. Your candid answers to the items in this survey are very important to us. This will not take too long to complete. Remember….

- we want to know what you think,
- there are no right or wrong answers, and
- everything you tell us will be kept strictly confidential (secret).

And please….

- don't skip any questions and
- provide only one answer for each item.

If you prefer, call the office toll-free at 1-800-990-6757 and we can do some or all of the survey by phone.

A. Quality of Life

Please check one answer.

1. In general, would you say your health is:
   - ❑ 1. Excellent
   - ❑ 2. Very good
   - ❑ 3. Good
   - ❑ 4. Fair
   - ❑ 5. Poor

The following questions are about activities you might do during a typical day.
Does your health *now* limit you in these activities? If so, how much?

2. **Moderate activities**, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf.
   - ❑ 1. Yes, limited a lot
   - ❑ 2. Yes, limited a little
   - ❑ 3. No, not limited at all

3. Climbing **several** flights of stairs.
   - ❑ 1. Yes, limited a lot
   - ❑ 2. Yes, limited a little
   - ❑ 3. No, not limited at all

1

[10] Only pages with used survey items are included. A full copy of the survey instrument is available at: http://www.ipenproject.org/surveycore.htm, Accessed on February 17th, 2008

12. During the *past 4 weeks,* how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?

1	2	3	4	5	6
All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time

B. Neighborhood Satisfaction

Below are things about your neighborhood with which you may or may not be satisfied. Using the 1-5 scale below, indicate your satisfaction with each item by placing the appropriate number on the line preceding that item. Please be open and honest in your responding. The 5-point scale is as follows:

1 = strongly dissatisfied
2 = somewhat dissatisfied
3 = neither satisfied nor dissatisfied
4 = somewhat satisfied
5 = strongly satisfied

How satisfied are you with…

(example) __3__the number of pedestrian cross-walks in your neighborhood
a. _____the highway access from your home.
b. _____the access to public transportation in your neighborhood.
c. _____your commuting time to work/school.
d. _____the access to shopping in your neighborhood.
e. _____how many friends you have in your neighborhood.
f. _____the number of people you know in your neighborhood.
g. _____how easy and pleasant it is to walk in your neighborhood.
h. _____how easy and pleasant it is to bicycle in your neighborhood.
i. _____the quality of schools in your neighborhood.
j. _____access to entertainment in your neighborhood (restaurants, movies, clubs, etc)
k. _____the safety from threat of crime in your neighborhood.
l. _____the amount and speed of traffic in your neighborhood.
m. _____the noise from traffic in your neighborhood.
n. _____the number and quality of food stores in your neighborhood
o. _____the number and quality of restaurants in your neighborhood.
p. _____your neighborhood as a good place to raise children.
q. _____your neighborhood as a good place to live.

How many days in the ***past month*** have you done ***moderate physical activity*** or ***vigorous exercise*** in these places? *If none, put "0".*

k. ______ days Private swimming pool

l. ______ days School or school grounds

m. ______ days Shopping center or mall (e.g., mall walking)

G. Walking for Transportation

How many ***days in the past month*** have you walked to the following places from your home or work? *If none, put "0".*

	a. Days walked from home	b. Days walked from work
Example: Library	2	2
1. Food store		
2. Retail store		
3. School/Day care center		
4. Bank/credit union		
5. Post office		
6. Restaurant/Café		
7. Gym/health club/rec facility		
8. Park		
9. Public transportation/park and ride		
10. Work		

H. Biking

Do not count stationary biking.

1. How often do you bicycle, either in your neighborhood or starting from your neighborhood?
   - ❑ 0. Never (*skip to Question #3*)
   - ❑ 1. Less than once a week
   - ❑ 2. 1-2 times a week
   - ❑ 3. 3-6 times a week
   - ❑ 4. Every day

2. When you bicycle, how far do you normally ride? ______ miles

3. How often would you bike if you thought it was safe from cars?
   - ❑ 0. Never
   - ❑ 1. Less than once a week
   - ❑ 2. 1-2 times a week
   - ❑ 3. 3-6 times a week
   - ❑ 4. Every day

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3. Is your primary work:
   - ❑ 1. Indoors
   - ❑ 2. Outdoors
   - ❑ 3. Mixed indoors and outdoors

4. How many days in the past month or so (20 work days) did you go to work by:
   If none, put "0".
   a. ___ days Walking
   b. ___ days Biking
   c. ___ days Driving alone
   d. ___ days Carpool driver
   e. ___ days Carpool passenger
   f. ___ days Vanpool
   g. ___ days Bus
   h. ___ days Taxi
   i. ___ days Subway/Trolley

5. How long does it take you to walk from your parking space or transit stop to your primary workplace?

   ___ minutes **or** ☐ I do not drive or take transit to work.

You're making great progress!!!

Please indicate which of these items are available at your work. Please circle an answer for each item.

6.	Exercise facilities (e.g. workout room/gym, exercise equipment, walking path/PAR course)	1. Yes	0. No	8. Don't know
7.	Regular exercise programs (e.g. aerobic classes, team sports, walking groups, etc.)	1. Yes	0. No	8. Don't know
8.	Shower facilities that you can use	1. Yes	0. No	8. Don't know
9.	Lockers for clothes	1. Yes	0. No	8. Don't know
10.	Safe bicycle storage	1. Yes	0. No	8. Don't know
11.	An exercise specialist or activity coordinator available for employees	1. Yes	0. No	8. Don't know
12.	Policies that encourage exercise or biking	1. Yes	0. No	8. Don't know
13.	Employer provides paid time for you to exercise	1. Yes	0. No	8. Don't know

Your Physical Activity

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions are about the time you spent being physically active in the **last 7 days**. They include questions about activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport. Your answers are important.

Please answer each question even if you do not consider yourself to be an active person.

Q. JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Section P.

1. Do you currently have a job or do any unpaid work outside your home?

☐ **Yes**
☐ **No** *[If No, go to SECTION R: TRANSPORTATION]*

The next questions are about all the physical activity you did in the ***last 7 days*** *as part of your paid or unpaid work. This does not include traveling to and from work.*

2. During the last 7 days, on how many days did you do *vigorous* physical activities like heavy lifting, digging, heavy construction, or climbing up stairs *as part of your work*? Think about *only* those physical activities that you did for at least 10 minutes at a time.

_________ **days per week or** ☐ **none** *[If none, go to question 4]*

3. How much time did you usually spend **on ONE of those days** doing vigorous physical activities *as part of your work?*
______ **hours** _______ **minutes per day**

4. Again, think about *only* those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do *moderate* physical activities like carrying light loads *as part of your work?* Please do not include walking.

_________ **days per week or** ☐ **none** *[If none, go to question 6]*

5. How much time did you usually spend **on ONE of those days** doing moderate physical activities *as part of your work?*

______ **hours** _______ **minutes per day**

6. During the last 7 days, on how many days did you *walk* for at least 10 minutes at a time *as part of your work*? Please *do not* count any walking you did to travel to or from work.

________ days per week or ☐ **none**

[If none, go to SECTION R: TRANSPORTATION]

7. How much time did you usually spend **on ONE of those days** walking *as part your work?*

______ hours _______ minutes per day

R. TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies and so on.

1. During the last 7 days, on how many days did you *travel* in a motor vehicle like a train, bus, car or tram?

_________ days per week or ☐ **none** *[If none, go to question 3]*

2. How much time did you usually spend **on ONE of those days** *traveling in a car, bus, train or other kind of motor vehicle?*

______ hours _______ minutes per day

Now think *only* about the *bicycling* and *walking* you might have done to travel to and from work, to do errands, or to go from place to place.

3. During the last 7 days, on how many days did you *bicycle* for at least 10 minutes at a time *to go from place to place*?

__________ days per week or ☐ **none** *[If none, go to question 5]*

4. How much time did you usually spend **on ONE of those days** t *place to place*?

______ hours _______ minutes per day

5. During the last 7 days, on how many days did you *walk* for at least 10 minutes at a time *to go from place to place?*

_________ days per week or ☐ **none** *[If none, go to SECTION S: HOUSEWORK, HOUSE MAINTENANCE AND CARING FOR FAMILY]*

6. How much time did you usually spend **on ONE of those days** *walking from place to place*?

______ hours _______ minutes per day

S. HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the last 7 days <u>in and around your home</u>, like housework, gardening, yard work, general maintenance work, and caring for your family.

1. Think about *only* those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do *<u>vigorous</u>* physical activities like heavy lifting, chopping wood, shoveling snow, or digging *<u>in the garden or yard</u>?*

_________ **days per week or** ☐ **none** *[If none, go to question 3]*

2. How much time did you usually spend **on ONE of those days** doing vigorous physical activities *<u>in the garden or yard?</u>*

______ **hours** _______ **minutes per day**

3. Again, think about *only* those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do *<u>moderate</u>* activities like carrying light loads, sweeping, washing windows, and raking *<u>in the garden or yard</u>?*

_________ **days per week or** ☐ **none** *[If none, go to question 5]*

4. How much time did you usually spend **on ONE of those days** doing moderate physical activities *<u>in the garden or yard?</u>*

______ **hours** _______ **minutes per day**

5. Once again, think about *only* those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do *<u>moderate</u>* activities like carrying light loads, washing windows, scrubbing floors and sweeping *<u>inside your home</u>?*

_________ **days per week or** ☐ **none**

[If none, go to SECTION T: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY]

6. How much time did you usually spend **on ONE of those days** doing moderate physical activities *<u>inside your home?</u>*

______ **hours** _______ **minutes per day**

T. RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the last 7 days solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

1. *Not counting any walking you have already mentioned*, during the last 7 days, on how many days did you walk for at least 10 minutes at a time *in your leisure time*?

_________ **days per week or** ☐ **none** *[If none, go to question 3]*

2. How much time did you usually spend **on ONE of those days** walking *in your leisure time?*

______ **hours** _______ **minutes per day**

3. Think about *only* those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do *vigorous* physical activities like aerobics, running, fast bicycling, or fast swimming *in your leisure time*?

_________ **days per week or** ☐ **none** *[If none, go to question 5]*

4. How much time did you usually spend **on ONE of those days** doing vigorous physical activities *in your leisure time?*

______ **hours** _______ **minutes per day**

5. Again, think about *only* those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do *moderate* physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis *in your leisure time*?

_________ **days per week or** ☐ **none** [*If none, go to SECTION U: TIME SPENT SITTING]*

6. How much time did you usually spend **on ONE of those days** doing moderate physical activities *in your leisure time?*

______ **hours** _______ **minutes per day**

Once you are finished wearing the activity meter for 7 days*, mail this survey, the activity meter, and the activity meter log sheet back to us. Don't forget to use the return envelope we sent with the activity meter.*

- ✓ *Remember, the envelope should include 3 items:*
  - *the activity meter,*
  - *the activity meter log sheet,*
  - *and this survey.*

If you don't have the envelope we provided, mail to:
The Neighborhood Quality of Life Study
3900 Fifth Avenue, Suite 310
San Diego, CA 92103

Please feel free to give us a call if you have any questions.

Our** toll-free **number is 1-800-990-6757.

You can also email questions to nqls@projects.sdsu.edu or visit us on the web at www.nqls.org

For Office Use Only

Date mailed	________	Date entered	________
Date received	________	By	________
		Date entered	________
		By	________

Appendix 4 Certificate of approval

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Lawrence D. Frank	UBC/College for Interdisciplinary Studies/School of Environmental Health	H10-02277

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

CO-INVESTIGATOR(S):
Ugo Lachapelle

SPONSORING AGENCIES:
N/A

PROJECT TITLE:
PUBLIC TRANSIT USE AS A CATALYST FOR AN ACTIVE LIFESTYLE: MECHANISMS, PREDISPOSITIONS AND HINDRANCES

CERTIFICATE EXPIRY DATE: November 25, 2011

DOCUMENTS INCLUDED IN THIS APPROVAL:

DATE APPROVED:
November 25, 2010

Document Name	Version	Date
Protocol:		
Phd Research Prospectus_Lachapelle_2008-09-17c_SUBMITED	2008-09-17c	September 17, 2008
Consent Forms:		
Study consent form	V1	October 19, 2010
Questionnaire, Questionnaire Cover Letter, Tests:		
NQLS_2ndsurvey	N/A	September 11, 2010
NQLS_survey_1_08-09-03	N/A	August 9, 2003
Other Documents:		
Letter of authorization to use the data	V1_10-04-10	October 4, 2010
NQLS IRB original approval letter	N/A	August 29, 2001

Other:
The neighborhood Quality of Life Study (NQLS) web site contains information on the primary investigators, former links to access the survey as well as Frequently asked questions. http://www.nqls.org/ The International Physical Activity and the Environment Network (IPEN) web site contains information on protocol, sampling, recruitment, consent, questionnaires, cover letters and other project relevant information. http://www.ipenproject.org/

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

This study has been approved either by the full Behavioural REB or by an authorized delegated reviewer