The Transportation Impacts of Mixed Land-Use Neighborhoods

Report 95.7

Washington State Transportation Commission
Innovations Unit

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Prepared for
Washington State Transportation Commission
Olympia, Washington

June 1995

Editor	Stephanie MacLachlan
Report Design	Mary Catherine Snyder
Technical Graphics	Duane Wright
Printing	Washington State Transportation Center (TRAC) University of Washington, Seattle

Printed on Recycled Paper

Production Run 1 (20)

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Executive Summary

Over the past 30 years, a notable change in land use has been the growth of residentially oriented suburban neighborhoods located some distance from employment and service centers. Linked with this growth are increasing levels of traffic congestion, air pollution, and a general disenchantment with suburban living. These negative impacts have focused attention on the potential transportation benefits of traditionally oriented neighborhoods characterized by more diverse land use development patterns. Developers and planners have suggested that mixing land uses can reduce automobile dependency by making more goods and services available within walking and short driving distances.

This research used a two-day travel diary and demographic survey of 900 households in three Puget Sound neighborhoods characterized by two or more distinct land uses. This data set was then compared with detailed household travel data collected throughout King County by the Puget Sound Regional Council (PSRC). Both data sets used similar survey forms and were collected and coded by the same contractor. The data were adjusted for compatibility and compared to see whether the travel behavior of residents of mixed-use neighborhoods was significantly different from the travel behavior of residents in King County neighborhoods that featured more homogenous land use patterns.

The comparison of the data set determined that individuals from two of mixed land use neighborhoods in Seattle traveled fewer miles per day than did other individuals. Partially because of goods accessibility, these mixed-use residents had shorter trips, drove less, and walked more than individuals from other areas in the county.

The third mixed-use neighborhood was transitional between a mixed-use area and a more suburban location. As a result, survey respondents' average daily mileage from this area was typically higher than the other mixed-use neighborhood, but tended to be lower that of people from the inner and more suburban zones in King County.

Examination of mode choice within the mixed-use neighborhoods demonstrated that individuals would frequently walk for shopping and personal purposes when a household was within a few blocks of a commercial street. This rate of walking, however dropped off rapidly with increasing distance from the commercial street. Report findings also suggest that these and other walk trips resulted in reduced levels of driving.

In both the King County and mixed-use data sets, a notable number of all trip chains included a work stop. The length of the work trip also showed a consistent relationship with the length of shopping and personal trips. These results suggest that work trips and, by extension, work locations, are an important determinant of daily travel. Future research on mixed land use should consider the effects of the work site and the work trip.

Acknowledgments

The authors gratefully acknowledge the support of the Washington State Transportation Commission, and the many people and organizations in the public and private sectors who provided us with information. Valuable contributions to the final preparation of this report were made by the staff of the Washington State Transportation Center (TRAC) at the University of Washington.

Chapter 1. Introduction and Research Approach

Problem Statement

Over the past 30 years, a notable change in land use has been the growth of residentially oriented suburban neighborhoods located some distance from employment and service centers. Linked with this growth are increasing levels of traffic congestion, air pollution, and a general disenchantment with suburban life (Downs 1989 and Langdon 1994). These negative impacts have focused attention on the potential transportation benefits of traditionally oriented neighborhoods characterized by more diverse land use development patterns (e.g., Bookout 1992a, 1992b). Developers and planners have suggested that mixing land uses can reduce automobile dependency by making more goods and services available within walking and short driving distances. The new interest in mixed land use represents an about-face with regard to the basic assumptions that have shaped urban development patterns over the past 20 or 30 years.

While interest in mixed-use development is on the rise, only a handful of studies have explored the transportation implications of this type of development. Existing studies typically contain only general information on the demographic characteristics and travel patterns of inhabitants of mixed-use areas. This project sought to address at least part of this gap in the literature. The researchers used a two-day travel diary and demographic survey of 900 households in three greater Seattle area neighborhoods characterized by two or more distinct land uses. This detailed data set was then compared with detailed household travel data collected throughout King County (the county within which the three neighborhoods are located) by the Puget Sound Regional Council (PSRC). Both data sets used similar survey forms and were collected and coded by the same contractor. The data were compared to see whether the travel behavior of residents of mixed-use neighborhoods was significantly different from the travel behavior of residents in King County neighborhoods that featured more homogenous land use patterns.

Study Objective

This report documents Phase II of a study that closely examined three mixed-use neighborhoods. Phase I's primary goal was to quantify the nature of the mixed-use neighborhoods and to inventory and summarize residents' travel patterns within and outside their neighborhoods. Phase I results are summarized in a report by the Innovations Unit of the Washington State Transportation Commission entitled *Travel Patterns In Mixed-Use Neighborhoods* (Zemotel et al.1993).

This report documents the next phase of the mixed-use neighborhood study. The first objective of Phase II was to explore the mixed-use neighborhood data and to describe the trip-making characteristics of these neighborhoods' inhabitants in more detail. This objective entailed analysis of factors such as travel mileage, vehicle sharing characteristics, transit use, and destination locations. The second study objective was to compare the mixed-use travel data to regional travel data obtained from the Puget

Sound Regional Council's (PSRC) 1990 travel panel survey.

The goal of the research described herein was to explore the following issue: do people in neighborhood with goods and services available just around the corner travel less than people in other more homogenous neighborhoods? This study, unlike previous research on mixed land areas, approached this question using detailed, empirical travel data collected *specifically* to explore the travel characteristics of mixed-use neighborhood inhabitants. The travel data were designed to be compatible with similarly detailed county level travel survey data from the PSRC. This resulted in the ability to compare and contrast, relatively free of confounding factors, the travel patterns of mixed-use neighborhoods with other areas. Thus, this research project was explicitly designed to collect data on mixed use and to address an empirical gap in previous research.

The following categories of quantitative analysis were examined in detail as part of this research:

Travel Distances. The use of transportation modeling output, Geographic Information Systems (GIS) software, and a U.S. Census-derived computer file of the county street network allowed for calculation of a number of important spatially-oriented travel statistics. Most relevant was the ability to estimate the trip mileage of survey respondents, both individually and as households, from original survey data by estimating travel routes on the street network. The travel distance procedures also resulted in the ability to accurately calculate distances for short trips.

Demographics. Household and individual demographic characteristics were compiled to identify any correlation to observed travel patterns in each of the study neighborhoods.

Multi-Purpose Trips. Many people schedule their activities by combining several trips into a single, sustained journey or chain. Analyzing the number, length, and type of chains, as well as the characteristics of the trip maker, shows how people organize their travel for efficiency, especially around work trips.

County Comparisons. The mixed-use survey form was designed to be compatible with the county travel diary administered by the PSRC. This allowed the exploration of the difference in travel characteristics between non-mixed-use areas and mixed-use areas by comparing the PSRC's data to the neighborhood data.

Intra-Neighborhood Analysis. Each of the three mixed-use neighborhoods included areas with concentrations of retail and other service establishments. This research explored the travel patterns of households at various distances from these areas, and attempted to determine the extent to which proximity to commercial opportunities and services affected the use of modes other than the auto, and in particular whether walk trips replaced vehicle trips for short-distance travel.

In addition, preliminary analyses of several other issues were performed. The initial results of these analyses are contained in comprehensive technical appendices.

Analysis Limitations

This analysis has several potential limitations. Since the research is based on survey data, there is the possibility of inaccuracy due to response bias. The research is also dependent on the comparison of the PSRC panel survey data with the mixed-use neighborhoods data. While the design of survey forms was similar, the two surveys were conducted two years apart, increasing the possibility of some incompatibility between the data sets. In addition, the two data collection efforts used different respondent selection procedures, and the mixed-use survey form was more comprehensive, resulting in other possible limitations when comparing information between data sets.

Report

The remainder of this report is divided into five chapters.

Chapter 2: Literature Review. The research literature concerning empirically oriented analyses of neighborhoods with mixed land use characteristics is summarized. This review identifies the scarcity of quantitative analyses of neighborhood travel behavior, particularly as they relate to land use characteristics.

Chapter 3: The Data Sets. This section discusses the two data sets used for the study. First, a brief review of the data collection methodology is given. Since the subsequent analysis of the data set requires specific knowledge of trip locations (origin and destination), the process by which those locations are derived from the survey responses and computer coded (also known as the geocoding process) is discussed in detail. The PSRC data set used for regional comparisons is also discussed. This discussion concludes with a comparison of the mixed-use and PSRC data sets; several differences between the data sets are highlighted.

Chapter 4: Research Methods. This chapter reviews the techniques and issues associated with processing the data and preparing them for computer analysis.

Chapter 5: Findings. The mixed-use data and the panel survey data are then analyzed statistically and spatially. The major findings resulting from the comparison of these data sets are then discussed. The findings are also compared to other studies.

Chapter 6: Summary and Future Research. The results of this research are summarized, and the conclusions are presented. These findings suggest support for the hypothesis that the characteristics of mixed-use neighborhoods are correlated with residents' travel behavior; they also suggest areas where additional analysis would be valuable.

Appendices. Additional data analysis and technical information about the research data are documented in a several technical appendices.

Chapter 2. Literature Review

Freidman, Gordon, and Peers (1992), in *The Effect of Neotraditional Design on Travel Characteristics*, attempted to estimate neotraditional neighborhoods' potential effect on travel by comparing older traditional communities with newer suburban tract developments[1]. Carried out in the San Francisco area, the study was based on travel data collected in 1980. Five traditional communities developed prior to World War II were selected. The neighborhoods were characterized by a mixed-use downtown commercial district, a gridded street network, and a mixture of both residential and non-residential uses. These existing traditional communities thus functioned as a proxy for neotraditional neighborhoods. In contrast, suburban communities included in the survey had developed since the 1950's and tended to have segregated land uses, a hierarchical roadway system consisting of primary arterials and local feeder streets, and a concentration of roadway access at a few points. In an attempt to control for income differences, the wealthiest and poorest households in each neighborhood were eliminated from the study. Travel data for selected households were then compared. The findings revealed that suburban areas generated 23 percent more trips than the traditional neighborhoods; households in the suburban areas had a higher drive-alone rate (68 percent) than those in traditional neighborhoods (49 percent); the walk mode split for the traditional neighborhood was 112 percent of the suburban communities; and transit's share of trips for the traditional communities was 17 percent compared to 5 percent for the suburban communities.

The authors cited their study findings as a strong indication that traditional neighborhoods have characteristics that result in fewer automobile trips. Based on the travel characteristics of traditional neighborhoods, the authors concluded that a newly created transit-oriented development would be less dependent on automobile travel than a conventional suburban development.

In *Traditional Neighborhood Development: Will Traffic Work?* (Kulash 1992), the author evaluated the travel performance of two theoretical development prototypes. One was a traditional neighborhood with densely gridded streets, and the other was a conventional suburban development with less dense, partially connected streets terminating in cul-de-sacs. Kulash modeled the traffic performance characteristics of these neighborhoods and determined that a gridded street network had capacity and speed characteristics comparable to those of the typical arterial/feeder network. While the traditional neighborhood inhabitants' trips had lower travel speeds, the trips were also shorter.

Explaining Urban Density and Transit Impacts on Auto Use (Holtzclaw 1991), was pro-

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[1] These neighborhoods have various labels in the literature including *neotraditional, traditional neighborhood developments*, and *transit oriented developments*. What these areas have in common with the mixed-use neighborhoods selected for this study is that they tend to be older than conventional suburban developments, they have land use heterogeneity, the street pattern is typically in a grid and they are frequently pedestrian oriented. A number of the documents reviewed in this chapter are contained in a compendium collected by Calthorpe Associates (1992).

duced as part of a legal action brought by several environmental organizations. This study analyzed data from several types of communities with varying densities and land use mixes. Odometer readings and trip logs were used to determine automobile mileage for each community. Holtzclaw concluded that as housing, population densities, and transit service increased, household vehicle-miles traveled (VMT) decreased. Specifically, he noted that annual VMT in a traditional community with neighborhood businesses and a moderate settlement density was found to be 50 percent lower than that of a "classic sprawling suburban bedroom community."

One study based on detailed travel survey data was *Getting Around in a Traditional City, A Suburban PUD, and Everything In-Between* (Ewing et al 1994). Six communities in Palm Beach County, Florida, were selected for study on the basis of their diverse development. The researchers concluded that households in the "sprawling" non-gridded suburban community composed mainly of single family homes had two-thirds more vehicle-hours than did a traditional gridded community with varied land use. Based on this relationship, and on travel characteristics of "in-between" communities, the authors concluded that higher density, mixed land use, and central location tended to be associated with reduced vehicle-hours of travel.

A Comparative Assessment of Travel Characteristics for Neotraditional Developments (McNally and Ryan 1993) evaluated travel differences between a conventional suburban community and a neotraditional community based on the street network. The authors noted that most mixed land use neighborhoods had highly connected streets while suburban areas, with segregated land uses, had street patterns that were hierarchical. This study used a planning model to examine the transportation performance of two hypothetical areas whose street systems replicated either suburban or neotraditional communities. In order to examine just the effects of the street network, the same land use mixes were used for both areas. The hypothetical suburban area's street pattern included arterials, feeders, and dead ends or cul-de-sacs, whereas the neotraditional area's network was gridded. The authors concluded that the same level of activity in both areas would result in greater congestion and longer trip lengths in the suburban street system pattern. Thus, the gridded street design common to many mixed-use areas may influence travel patterns.

Commuting in Transit Versus Automobile Neighborhoods compared the commuting characteristics of residents from older transit neighborhoods with those living in newer suburbs (Cervero and Gorham 1995). Twelve traditional neighborhoods in the San Francisco and Los Angeles areas were selected based on their historical proximity to street car lines and gridded street patterns. These areas were paired with nearby suburban neighborhoods that had been developed independent of transit considerations and had a more random street pattern. The process attempted to match median household income and transit service levels. The comparison of these pairs suggests that neighborhood design does affect the work trip and the levels of trip generation. Suburban residents tended to travel more, drive alone to work more frequently, and to use bicycles and walk less. The effects of neighborhood type on transit use were less clear, with some suggestion that density had greater effect on transit use in the transit-oriented neighborhood than in the auto-oriented neighborhoods. The authors also found that traditional neighborhoods in Los Angeles surrounded by freeway-oriented suburbs tended to remain auto dependent.

Regional Versus Local Accessibility: Implications for Non-work Travel examined local and regional accessibility for a case study in the San Francisco area (Handy 1993). This study focused on suburban areas (defined mainly as other than highly urbanized San Francisco). The study related shopping trip distances to levels of local and regional accessibility for a set of large zones. Accessibility was calculated using a gravity model and was based in part on the location of commercial activity. The study's major conclusion was that higher levels of both regional and local accessibility could be associated with shorter average shopping distances, but not trip frequency. This implies that an area with closer shopping opportunities and better accessibility (such as a mixed land use neighborhood) may have lower levels of travel. The study also suggests that for regional trips external to a neighborhood, the neighborhood type may not matter. This study demonstrated that the relationship between accessibility and travel is complex, and that a neighborhood's *regional* as well as *local* situation may be relevant.

Summary

The studies reviewed generally support the view that higher density areas with a more traditional street grid and relatively diverse land uses tend to have lower levels of automobile use. However, most of the studies just described either used hypothetical data or used data from a variety of sources to assign trip distances to study neighborhoods. Few of the studies collected data to specifically examine mixed-use neighborhoods, or had data at the individual trip level. This research project, which was explicitly designed to collect data on mixed-use areas, and on individual trips, begins to address this empirical gap in the literature.

Chapter 3. The Data Sets

Introduction

This project was based on two data sets. First, a mixed-use neighborhood data set was collected by the Washington State Transportation Commission's Innovations Unit in November of 1991 as part of this study. Second, the Puget Sound Regional Transportation Panel Survey, conducted from September through November 1989 and obtained from the PSRC, was used as a reference dataset. To enhance the validity of comparisons between the two data sets, the Innovations Unit data collection effort was designed for compatibility with the PSRC's panel survey methodology.

While this chapter focuses on the data collected from the mixed-use neighborhoods, the data collection methodology for both data sets is discussed briefly. The mixed-use data required considerable preparation for analysis, and the steps of this process are documented herein. Since both data sets are compared, differences between the mixed-use data set and PSRC data set are discussed.

The Mixed-Use Data

The mixed-use neighborhood data set was obtained from a series of two-day travel diaries completed by survey participants in November of 1992. Over 1,620 individuals in 900 households in the Kirkland, Wallingford, and Queen Anne neighborhoods in the greater Seattle region responded. The Phase I project report contains detailed information concerning the data collection methodology, characteristics of the study neighborhoods, and some preliminary data analysis (Zemotel et al. 1993).

Neighborhood Descriptions

Neighborhoods were selected for study because they had more than one distinct land use (residential as well as other uses), and because each was located in an area that offered a range of transportation mode alternatives.

Queen Anne, which is a few miles north of downtown Seattle, was the smallest of the three study areas (figure 1). The study area was roughly 0.5 miles by 0.7 miles, centered on Queen Anne Avenue, a busy shopping street with supermarkets, banks, restaurants and retail shops. The rest of the study area was residential with a few scattered retail and office facilities. Queen Anne's streets form a grid pattern. The location of the respondent's households is shown in figure 2.

Wallingford is west of Interstate 5, a few miles north of downtown Seattle, and west of the University of Washington (figure 3). The study area was approximately 0.75 miles by 1.25 miles long. The neighborhood's land use is diverse, with recreational outlets, residential uses, and a variety of retail and commercial buildings. The main shopping area is along Northeast 45th Street and, to a lesser extent, along Stoneway Avenue North. The street pattern forms a grid. The location of the study households is shown in figure 4.

Kirkland is a suburban neighborhood bordered by Lake Washington on the west and Interstate-405 on the east. The study area was the largest and extended for 1.25 miles by 0.5 miles (figure 5). The area includes a renovated downtown and a mix of housing types. Kirkland's shopping and commercial facilities are somewhat more scattered than those of the

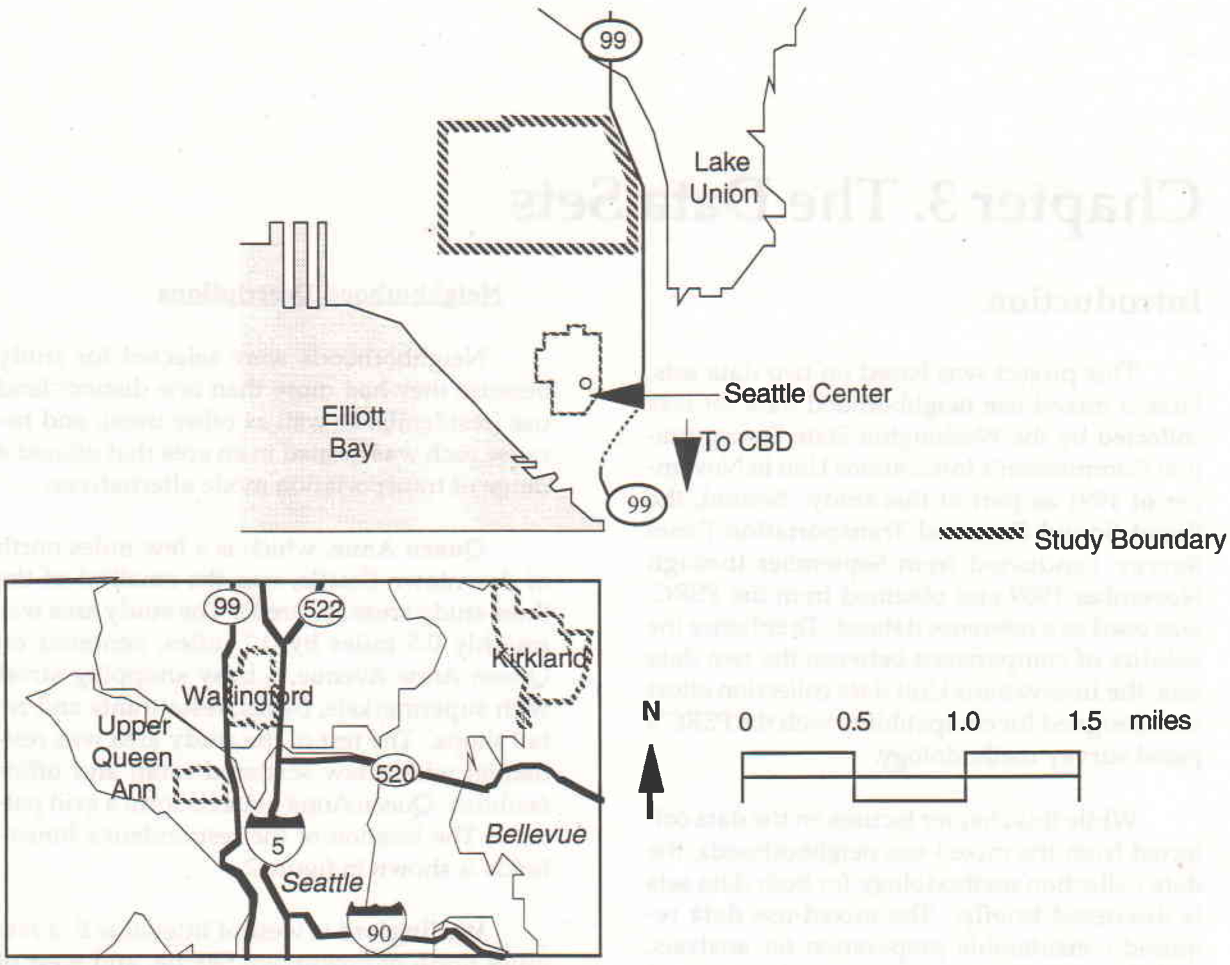

Figure 1. Queen Anne Vicinity Map

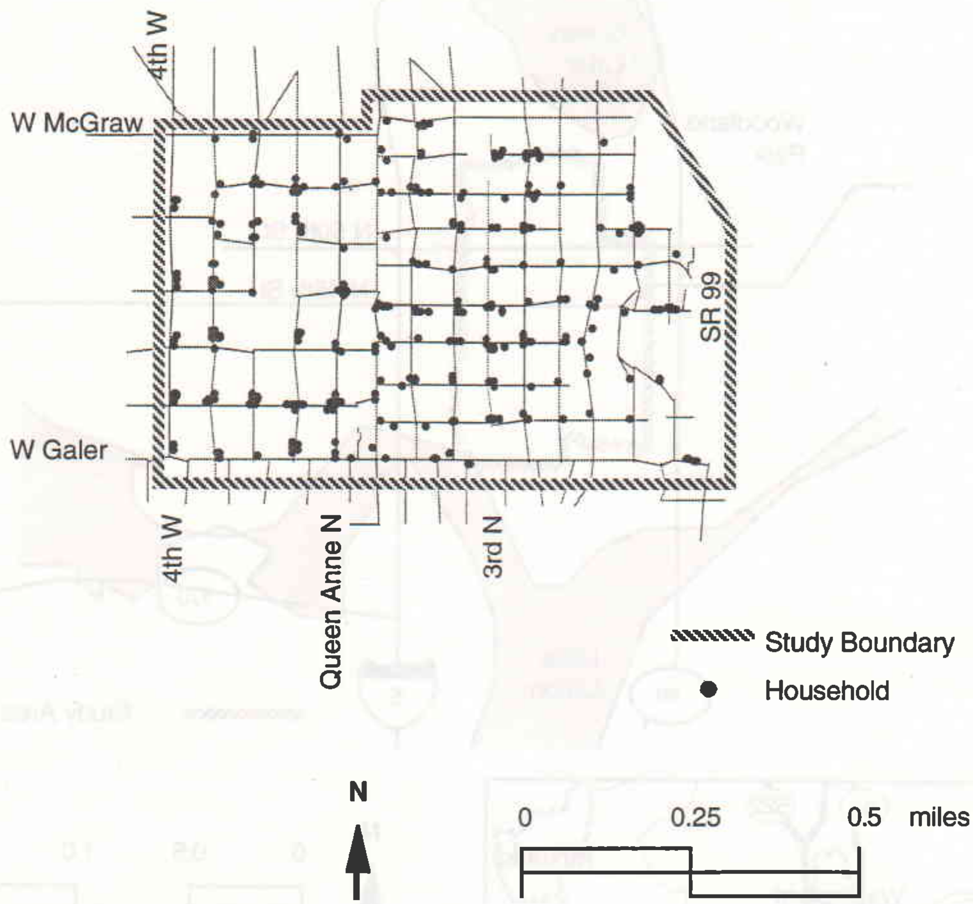

Figure 2. Queen Anne household map

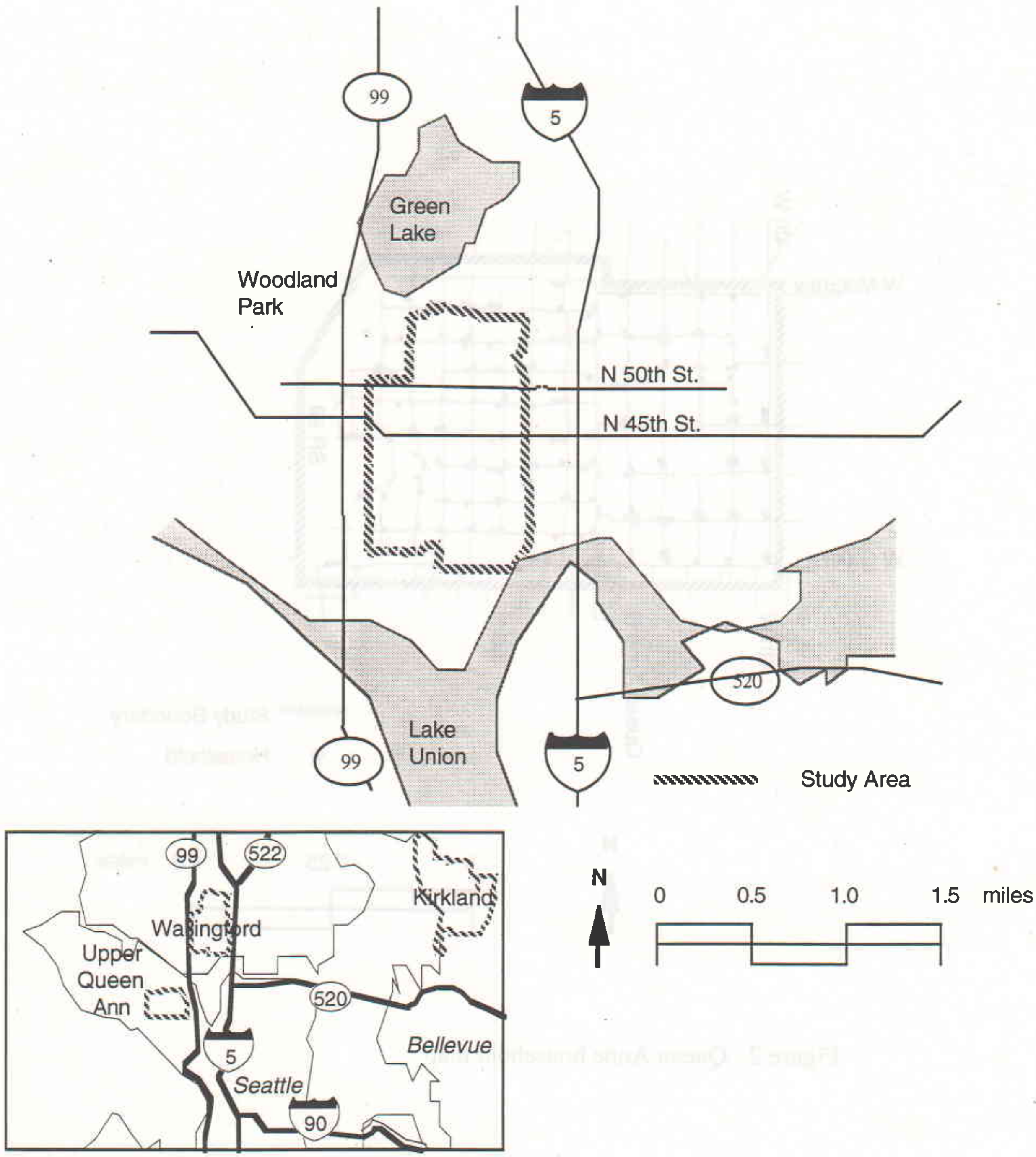

Figure 3. Wallingford vicinity map

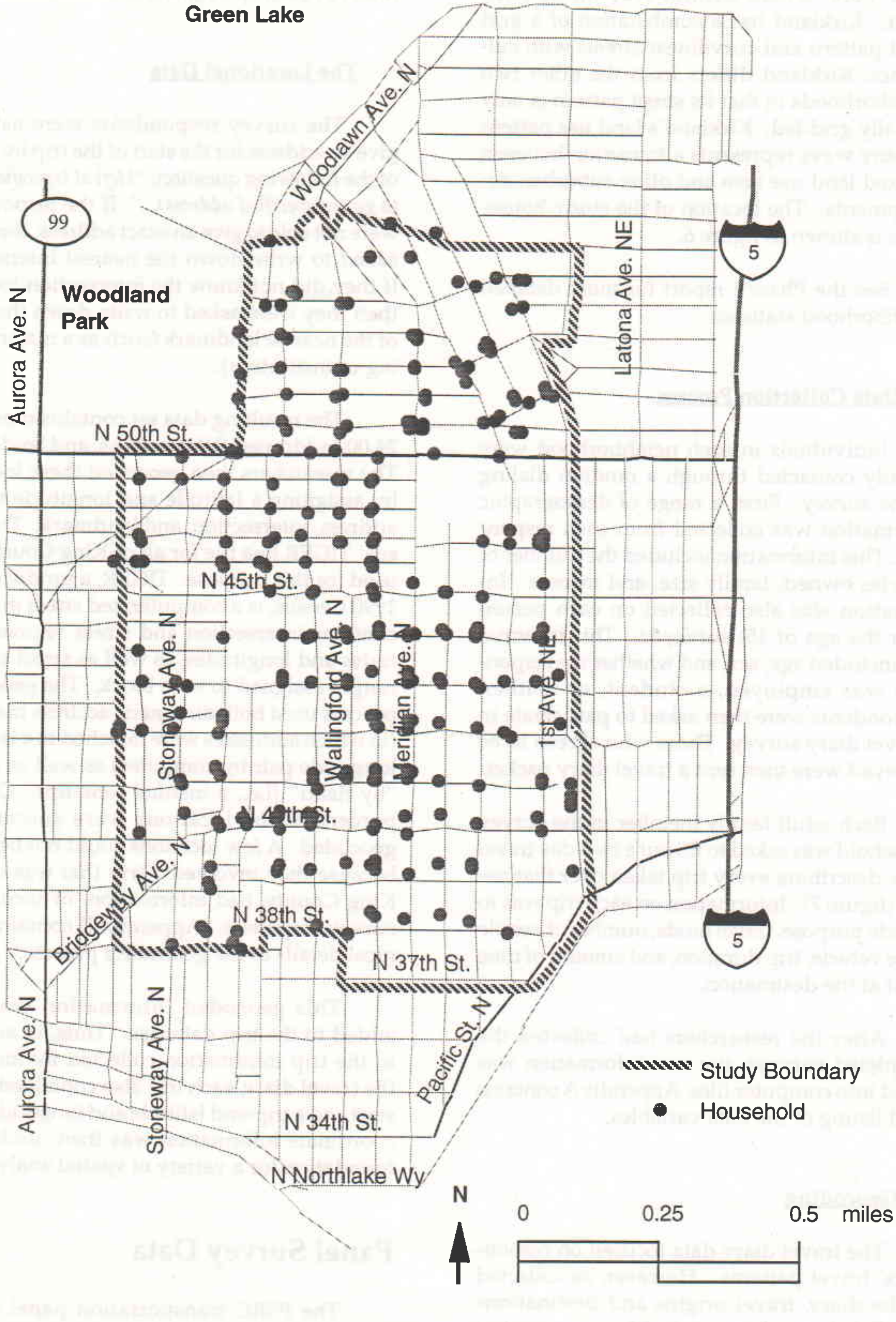

Figure 4. Wallingford household map

other study neighborhoods, but there are concentrations along Central Way and at the downtown 'core' where Central Way meets Lake Street. Kirkland has a combination of a grid street pattern and curvilinear streets with cul-de-sacs. Kirkland differs from the other two neighborhoods in that its street pattern is only partially gridded. Kirkland's land use pattern in many ways represents a transition between a mixed land use area and other suburban developments. The location of the study households is shown in figure 6.

See the Phase I report for more detailed neighborhood statistics.

Data Collection Process

Individuals in each neighborhood were initially contacted through a random dialing phone survey. First, a range of demographic information was collected from each respondent. This information included the number of vehicles owned, family size, and income. Information was also collected on each person (over the age of 15) surveyed. This information included age, sex, and whether the respondent was employed, a student, or neither. Respondents were then asked to participate in a travel diary survey. Those who agreed to be surveyed were then sent a travel diary packet.

Each adult family member in the survey household was asked to fill out a two-day travel diary describing every trip taken over that period (figure 7). Information on each trip was to include purpose, travel mode, number of people in the vehicle, trip duration, and amount of time spent at the destination.

After the researchers had collected the completed surveys, the raw information was coded into computer files. Appendix A contains a full listing of the data variables.

Geocoding

The travel diary data focused on respondents' travel patterns. However, as collected on the diary, travel origins and destinations were listed as only a set of addresses, an intersection, or the name of a landmark. To make these data usable, the researchers had to translate these locations to a map coordinate system. This involved geocoding, a process that is briefly described below. The purpose of the geocoding was to assign a latitude and longitude to each trip origin and destination.

The Locational Data

The survey respondents were asked to give an address for the start of the trip by means of the following question: *"I left at (specified time) to go to (specified address)..."* If the respondents were not able to give an exact address, they were asked to write down the nearest intersection. If they did not know the intersection location, then they were asked to write down the name of the nearest landmark (such as a major building or institution).

The resulting data set contains more than 24,000 addresses, intersections, and landmarks. The researchers then geocoded these locations by assigning a latitude and longitude to each address, intersection, and landmark. The Census' TIGER line file for all of King County was used for this purpose. TIGER, a product of the 1990 Census, is a computerized street map that contains intersection and street segment latitudes and longitudes, as well as street address ranges assigned to each block. The geocoding process used both automatic address matching (in which addresses were matched to a latitude-longitude pair by computer) as well as coding "by hand" (i.e., a manual look-up). Over 96 percent of the locations were successfully geocoded. A few locations could not be coded because they involved a trip that was outside King County, bad information, or incomplete survey responses. Appendix B contains technical details of the geocoding process.

This geocoded information was then added to the trip database. Thus, in addition to the trip information collected by means of the travel diary, each trip also contained a trip-start and a trip-end latitude and longitude. This coordinate information was then used as the foundation for a variety of spatial analyses.

Panel Survey Data

The PSRC transportation panel survey was used as the source of comparative county-level travel characteristics. Since the PSRC data collection effort was started before the mixed-use survey project was initiated, the PSRC sur-

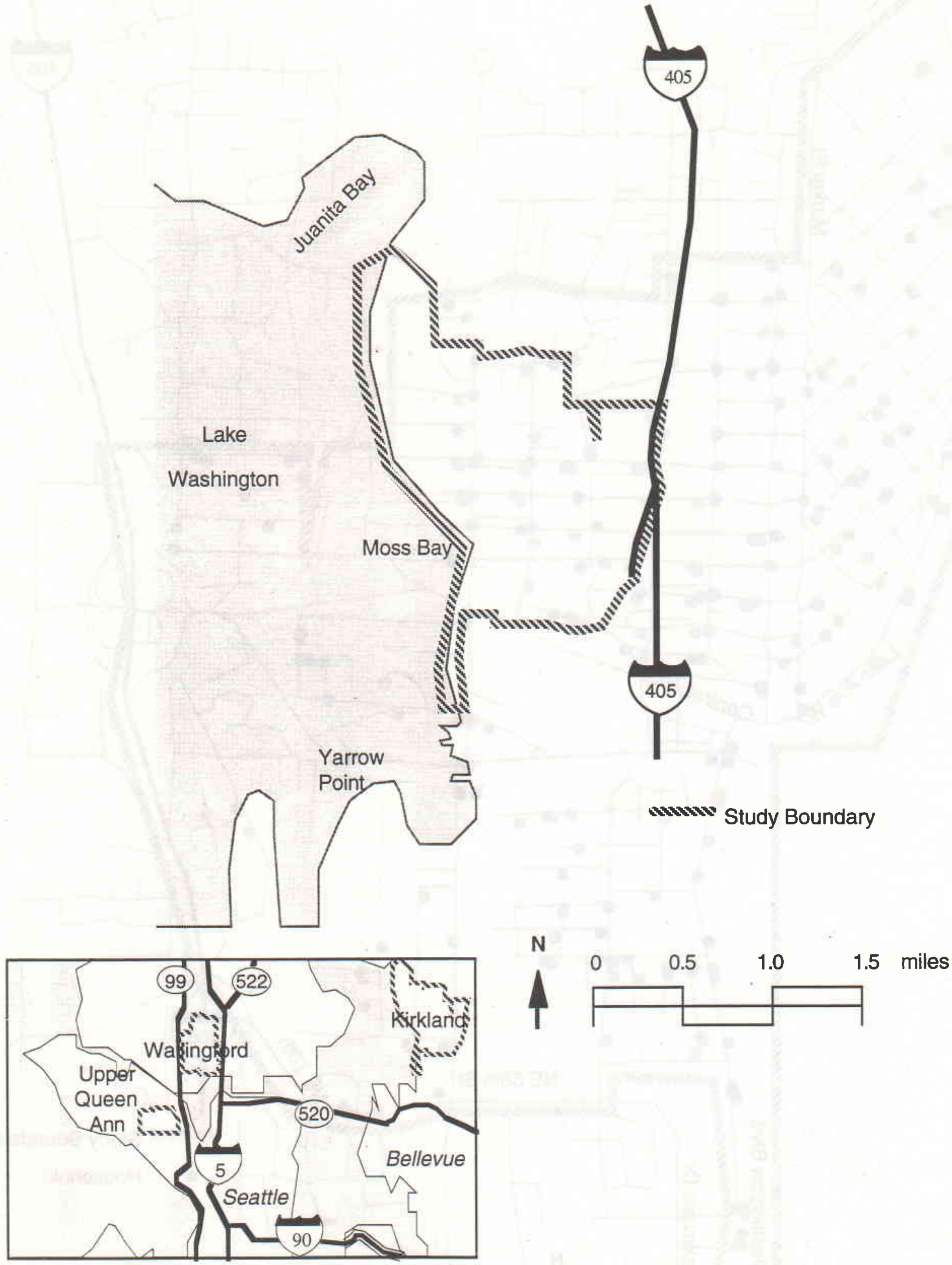

Figure 5. Kirkland vicinity map

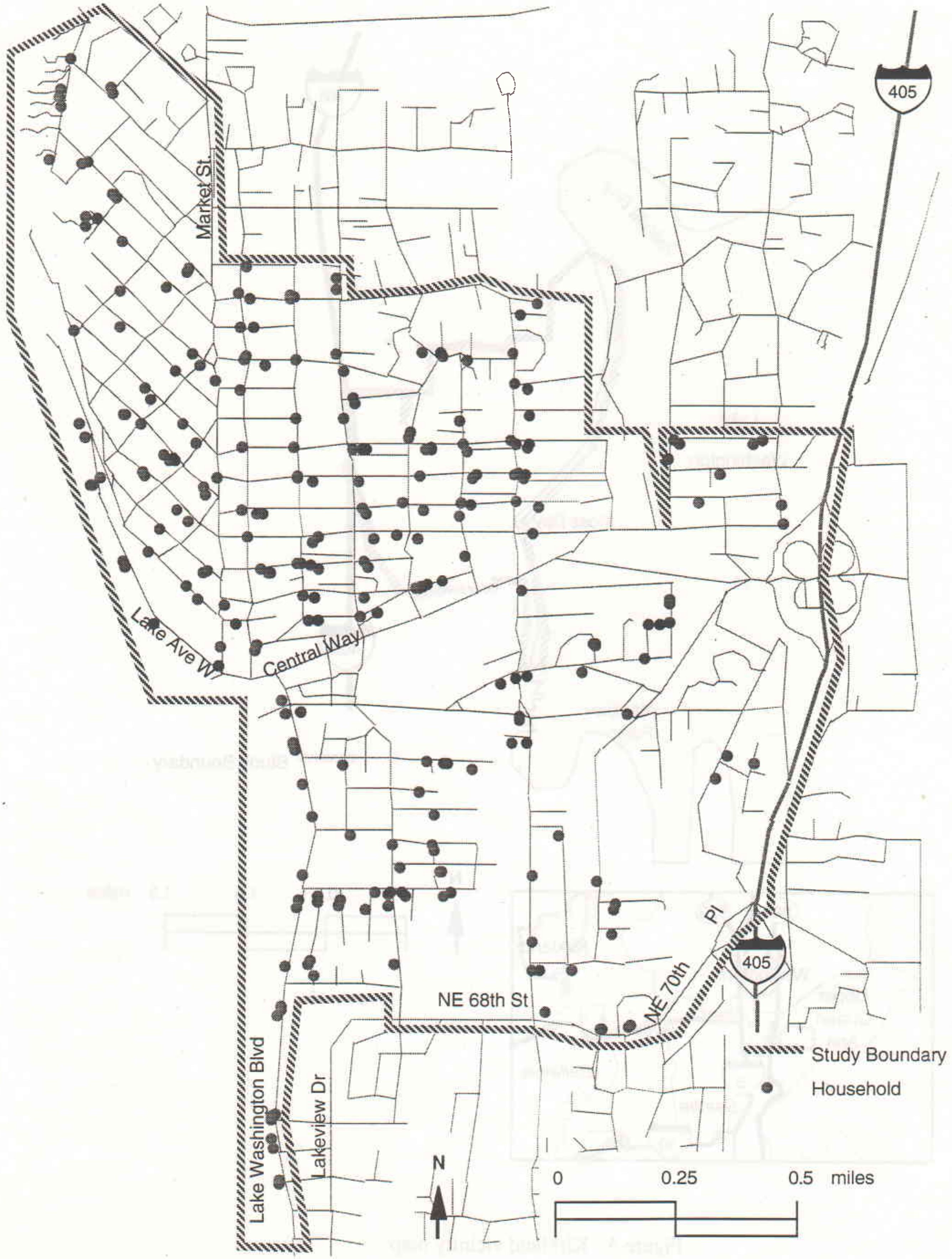

Figure 6. Kirkland household map

UNIVERSITY OF WASHINGTON TRANSPORTATION PANEL
1992 Travel Diary

1 I STARTED THE DAY AT:

address ______________________
or cross streets ______________________
city ______________________

THINGS TO REMEMBER:

* Fill out the diaries for the days indicated.
* Remember to also record each return trip to home or work.
* The last entry should be your home, or where you were at 1 a.m.
* When household members travel together, each should record the trip.

IF YOU DID NOT GO ANYWHERE ON THIS DAY PLEASE CHECK HERE: ☐

	I LEFT AT:	TO GO TO:	I GOT THERE AT:	REASON FOR TRIP (work/school/visit/recreation/etc)	HOW? (car/truck/van/walk/bicycle/bus/taxi/etc.)	Driver or Rider?	How many total in group?	WHO? (relationship of persons with you)
2	am or pm	address: or cross streets: city:	am or pm			D R		
3	am or pm	address: or cross streets: city:	am or pm			D R		
4	am or pm	address: or cross streets: city:	am or pm			D R		
5	am or pm	address: or cross streets: city:	am or pm			D R		
6	am or pm	address: or cross streets: city:	am or pm			D R		
7	am or pm	address: or cross streets: city:	am or pm			D R		
8	am or pm	address: or cross streets: city:	am or pm			D R		
9	am or pm	address: or cross streets: city:	am or pm			D R		

Use the back of sheet for additional trips.

Figure 7. Survey Form

vey was used as the basis for the design of the mixed-use survey.

The PSRC panel survey was a major effort aimed at collecting data on the effect of transportation conditions and demographic characteristics on household travel behavior in urban areas. The PSRC panel survey covered the four counties of the Puget Sound region and was conducted over time in several waves. Three waves had been completed at the time of this report, but, to control for household changes, only the information from King County in the first wave, conducted in September through November 1989, was used for this study. The data used for this study involved 663 households making almost 12,000 trips. Detailed information concerning the survey methodology is available from Murakami and Watterson (1992). Appendix C contains a listing of the information in the PSRC data sets.

Chapter 4. Research Methods

Introduction

A goal of this study was to explore in detail the travel characteristics of the mixed-use neighborhood inhabitants. This chapter discusses the process necessary to prepare the data for analysis. To explore the travel characteristics in detail, the initial dataset had to be expanded to include supplementary information. Specifically, it was important to

- compute a model-derived roadway travel distance between each trip start and trip end
- develop a distance measurement to compensate for the inaccuracy of model-derived distances for short trips
- categorize the data by household type, income, trip purpose and trip mode
- verify short, unrecorded transit access trips
- create a supplementary bus stop and bus route data base
- add the locations and nature of commercial establishments in the study areas
- adjust for differences between the mixed-use and the PSRC panel survey data sets
- create a variety of geographical variables concerned with distances and zones for different levels of analysis
- explore the possibility of vehicle overcounting due to travel in the same vehicle by two or more survey respondents

Each of these areas is discussed in the following sections.

Distance Calculation

Objective: compute roadway travel distance between each trip start and trip end.

The trip distances used for this study were initially computed based on travel distances as output from the PSRC's transportation model. These distances, which were based on a computerized trip distribution, were derived from a mathematically expressed link and node network that approximates actual streets and intersections. The model network attempted to incorporate the effects of real world travel considerations such as speed limits, lane capacity, and congestion. However, because of practical limits, the model network was a representation of the region's higher level street system.

Trip distances were calculated based on a zone structure that was superimposed over the region. Distances were computed between each pair of zones using the street network model described above, and put into a look-up table. Each survey trip's start and end location was then assigned to the particular zone that contained it, and the trip distance was computed referring to the look-up table. Trips that started and ended in the same zone (intra-zonal) were assigned a fixed distance based on the distance between the center of that zone and 0.7 times the network distance to the center of the nearest adjacent zone.

Initially, the PSRC and mixed-use data distance calculations differed in that PSRC trips were coded to a coarser zone structure based on census tracts, while the mixed-use trips used a somewhat finer zone structure based on TAZs (Traffic Analysis Zones). Since the PSRC and mixed-use distances were to be compared and a modified distance look-up table was created. Distances in the modified table were recalculated using a common census tract based zone structure. This look-up then was used to add trip distances to both the PSRC panel data and the mixed-use data.

As a rough check of the reasonableness of these distances, the distances calculated based on the model derived look-up tables were compared to a GIS derived shortest path distance. A multiple regression analysis showed an r-squared of 0.96, suggesting that the look-up distances were close to that of the shortest available path.

Accuracy of Short Trip Distance

Objective: develop a distance measurement to compensate for the inaccuracy of model-derived distances for short trips.

Empirical evidence suggests that measurement error in network-generated model distances can be considerable (Talvitie and Dehghnai 1979). Of particular concern is the transportation models' ability to calculate shorter trips, given that travel mileage calculations are based on trip between zones and based on a simplified street network which eliminates many of the lower-level short streets. This potential inaccuracy of model-derived short trips was especially relevant for this study, since the mixed-use neighborhood data included information on trips on bicycle or on foot that involved shorter travel distances.

As a check on the accuracy of short distance values, the model network-generated trip distances were compared to trip distances obtained via the GIS's shortest path function using the TIGER street network. All the model-based trips of three miles or less was selected. The distance of these same trips was then recalculated using the shortest path calculation. Comparison of these two methods of calculating distance revealed that the model-derived trip distances over-estimated trip distances. The analysis of travel distances are included in Appendix D.

Because of the distance inaccuracy for shorter trips, a new trip distance variable, called TRUEDIST, was developed to increase the accuracy of distances in the mixed-use data. This variable uses a combination of two methods of calculating distances. Model- based trip distances, from the look-up table described previously, were used for all trip lengths greater than 2.0 miles. However, if the travel distance was equal to or less than 2.0 miles, that model-based distance was replaced with a distance calculated based on the shortest path. The assumption behind this process was that individuals tended to travel the most efficient and shortest path for short distances. For longer distances, travelers were expected to be more likely to divert to a freeway, with the result that the trip may be longer but faster; this is the situation that a model-based distance computation is designed to capture.

Household Type and Income

Objective: create categories for household type, income, trip purpose, and trip mode.

Both data sets contained data concerning the number and ages of the household members and the number of children. This information was used to create a household type variable with eight categories. The categories and number of households for the PSRC-King County and mixed-use data sets are in Table 1.

When assigning each household to a type, some category types were given precedence over others. Any household with children, regardless of size or age of the adults, was placed in one of the first two categories. If a household had no children, household category was determined first by the size of the household and then by age. Thus, a two person household with one person older than 65 years of age would be placed in the two adults, 65 years or older category. This assignment procedure resulted in 8.4 percent of the households in the King County data and 11.4 percent of the households in the mixed-use data being classed as *a two or more adults 65 years or older household*. This raised a concern that a household with members that were both over and under 65 years of age might be obscured by the classification procedure. However, analysis of the data determined that only a small percentage of all senior households contained members younger than

Table 1. Number of Households by Category

Household Category	PSRC (King)	Mixed
1. any children under 6 years of age	114	113
2. any children between ages 6 and 17	99	93
3. one adult under age 35	34	77
4. one adult between ages 35 and 64	75	139
5. one adult 65 years or older	29	77
6. two or more adults under age 35 years	91	149
7. two or more adults between ages 35 and 64	161	154
8. two or more adults 65 years or older	56	103
Total Households	**659**	**905**

65 (for the King County data it was 2.7 percent and for the mixed-use data it was 2.3 percent). Many of these households involved a situation where one spouse was just over 65 and the other just under 65.

Households were also classified by income. Both the mixed-use neighborhood and panel survey data had a variety of variables that concerned household income. Because it was a common category break for both data sets, a stated yearly income of $35,000 was use to separate low and high income household.

Serve Mode

Objective: verify short, unrecorded transit access trips.

A review of the travel diary data revealed that a number of transit trips were supposedly begun from a home location. Further examination of the data revealed that, even though survey recipients were asked to record all trips including short walks to transit, they occasionally failed to note very short "access" trips of this type.

To explore the significance of these "serve mode" trips, access trips already in the data set were first identified. Thus, any trip that was a walk mode and was linked to a transit trip was classified as a *serve mode* trip. An in-house program was then developed to identify missing serve mode trips. The program used the following logic. If a respondent's trip start was home and the mode of that trip was transit, it could be assumed that an intervening, short walk to a bus stop had occurred. A dummy serve mode trip was then inserted into the data set. This logic was also applied for trips home from transit.

Transit Stop

Objective: create a supplementary bus stop and bus route data base.

Transit stop information obtained from the regional transit agency was added to the GIS software. These data consisted of the latitude and longitude information for each bus stop in King County. The data were accurate as of 1992 and included route numbers. This information allowed analysis of transit accessibility.

Commercial Establishments

Objective: add the locations and types of commercial establishments in the study areas.

The accessibility to commercial goods and services by the mixed-use neighborhood households was of considerable interest. As a result, a data set of commercial addresses was developed for the mixed-use neighborhoods. Sources for the address information included local phone books and site visits. This information was geocoded so that each establishment was assigned a coordinate-based location and was labeled with the establishment type (groceries, auto repair, etc.).

Adjustments of the Data Sets

Objective: adjust for differences between the mixed-use and PSRC data sets.

The mixed-use data survey was designed to be similar to the existing PSRC panel survey. The information for both surveys was collected and coded by the same contractor and the surveys were completed at roughly the same time of year (though three years apart). However, there were some differences between the data sets. Principally, the mixed-use data collected more detailed information than did the panel survey. The differences and their adjustments were as follows:

Trip Duration. The PSRC data set asked respondents to include all trips of five minutes or longer. The mixed-use data set had no such restriction; this was eight percent of all trips and 45 percent of all pedestrian trips. To compensate, any comparison of the PSRC and mixed-use data removed all trips under five minutes.

Weekdays. The PSRC data covered only weekday travel while the mixed-use data set included some weekend travel. Therefore, the mixed-use data were limited to weekday travel trips when comparing the two data sets. An initial exploration of the data indicated that the PSRC survey contained more Tuesdays, Wednesdays, and Thursdays than it did Mondays and Fridays. The mixed-use data were more evenly spread throughout the week.

Sampling Techniques. The PSRC data were stratified to add additional transit households beyond those gathered by random sampling techniques (Pendyala, Konstadinos and Goulias 1991). The PSRC's first wave data for King County included a total of 1330 households, of which 1195 were randomly selected. Approximately 100 households were added to the panel survey precisely because these households used transit for the majority of their work trips. This resulted in a 10 percent rate of oversampling of transit-oriented households. In contrast, the 900 households in the mixed-use data set were selected completely randomly.

Fortunately, partial data regarding the selection process for each PSRC household were available. Use of several in-house programs allowed for the identification of most of the randomly selected households and the creation of a modified panel survey data set with only randomly selected data.

Trip Purposes. The mixed-use survey was coded with a greater range of trip purposes than were the PSRC data. For comparison of trip purposes across data sets, common aggregate purpose categories were created. Table 2 shows these categories.

Trip Mode. The mode used to make each trip was coded similarly for the mixed-use and PSRC data. For analyses of trip modes across data sets, common aggregate mode categories were created. Table 3 shows these categories.

Geographical Variables

Objective: create a variety of geographical variables concerned with distances and zones for different levels of analysis.

Because this study was driven by the geographical location of households, the analysis

Table 2.Trip Purpose Categories

Common Category	Included Panel Survey Categories	Included Mixed-use Survey Categories
Work	Work	Work, Work related Business
Shop	Shopping	Shopping
School	School, College	School, College
Personal	Visiting, Free time, Personal	Professional Services, Family/Personal Business, Church, Visit Friends, Pleasure Trip, Other Social Recreational, Eating or Drinking
Appointments	Appointments	Work-related appointment, Personal Appointment
Home	Home	Home

process required development of a number of distance and zonal variables. For the mixed-use neighborhoods, *commercial* and *transit stop* distance variables were created. The commercial variable indicated the straight-line distance from each survey household to the nearest concentration of retail and eating establishments. Figures 8 through 10 show the concentrations of commercial locations for the three mixed-use neighborhoods. The transit stop distance was similar to the commercial distance except that it measured the distance from each household to the closest transit stop.

The researchers added a variable to the PSRC data set that indicated where a household was located within King County. Three geographic zones were created based on when the cities or census places in the county were initially developed, and were spatially represented as rings around the Seattle CBD (figure 11). The first zone is *Seattle City,* and it includes any household within the limits of the City of Seattle. This zone includes 232 PSRC survey households and overlapped with the mixed-use neighborhoods of Queen Anne and Wallingford. The next zone is an *inner* ring, and about 30 cities surrounding Seattle that were developed in the 1940's, 50's and early 60's. This ring includes 183 households from the PSRC data. The zone includes the Kirkland mixed-use neighborhood. The *outer* ring includes both newer suburban developments and the remaining rural and incorporated portion of King County. This zone includes 248 survey households and 30 cities and census places.

For a finer analysis of the data, several analysis zones within the City of Seattle were created. A zone consisting of north Seattle was selected to facilitate comparison of the mixed-use households of Queen Anne and Wallingford with similar, nearby households in the PSRC data set. North Seattle encompasses the two

Table 3. Trip Mode Categories

Common Category	Included Panel Survey Categories	Included Mixed-use Survey Categories
Car	Car, Carpool, Vanpool, Taxi, Motorcycle	Car, Truck, Van, Carpool, Vanpool, Taxi, Motorcycle
Transit	Bus, Paratransit, School Bus	Bus, Paratransit, School Bus
Walk	Walk	Walk
Bike	Bike	Bike

Seattle mixed-use neighborhoods and includes about half of the City of Seattle. Also, in order to examine the influence of the region's major employment location, the Seattle CDB was selected. Figure 12 shows the location of these zones.

A summary of demographic characteristics of the mixed use neighborhoods only and several King County analysis zones are shown in Table 4. The three mixed use neighborhoods are similar except Kirkland, which has a higher median age and considerably lower residential density. With the exception of income, North Seattle is much like Queen Anne and Wallingford. Inner and Outer King County are also similiar.

Carpooling Over-Count

Objective: explore the possibility of vehicle over-counting due to travel in the same vehicle by two or more survey respondents.

Carpool over-counting occurred when two survey respondents from the same household (typically spouses) made a trip in the same vehicle but each recorded that trip on their individual survey form. The situation was of interest because it potentially could lead to over-counting of vehicle trips and vehicle miles of travel (VMT). Carpool over-counting was identified by determining which trips in the mixed-use data set had the same origin, destination and similar departure time.

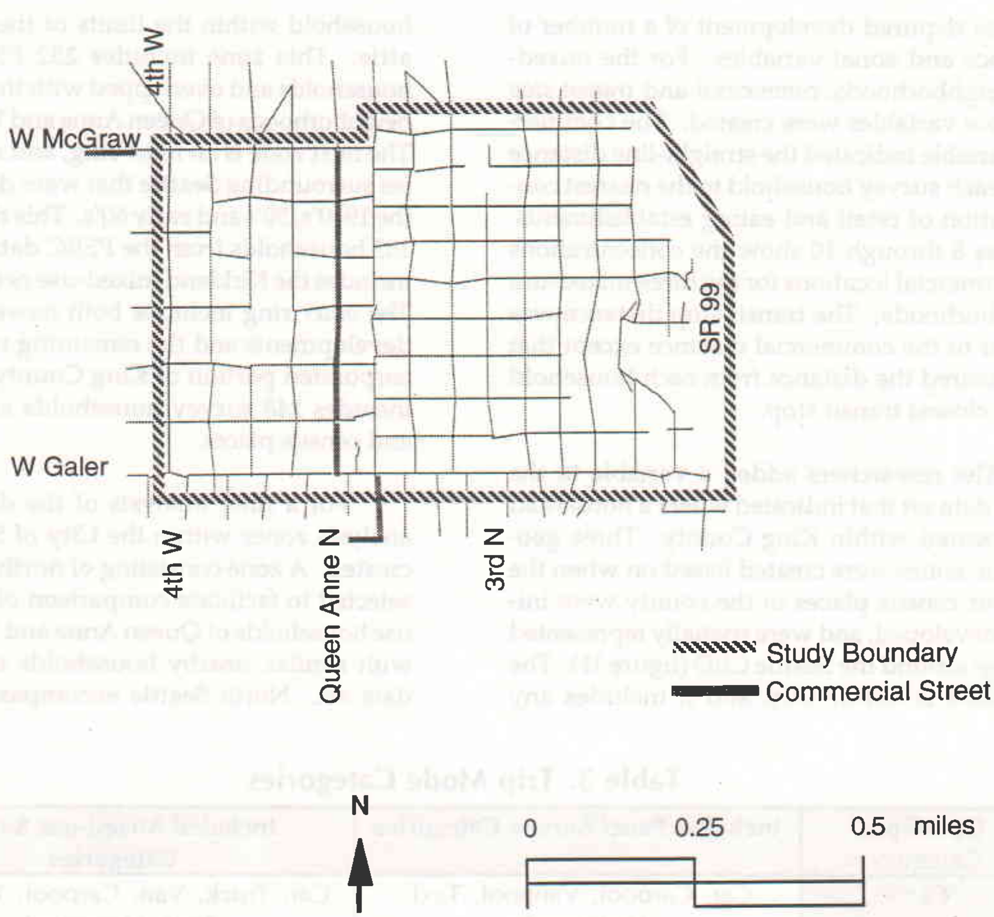

Figure 8. Queen Anne commercial locations

Figure 9. Wallingford commercial locations

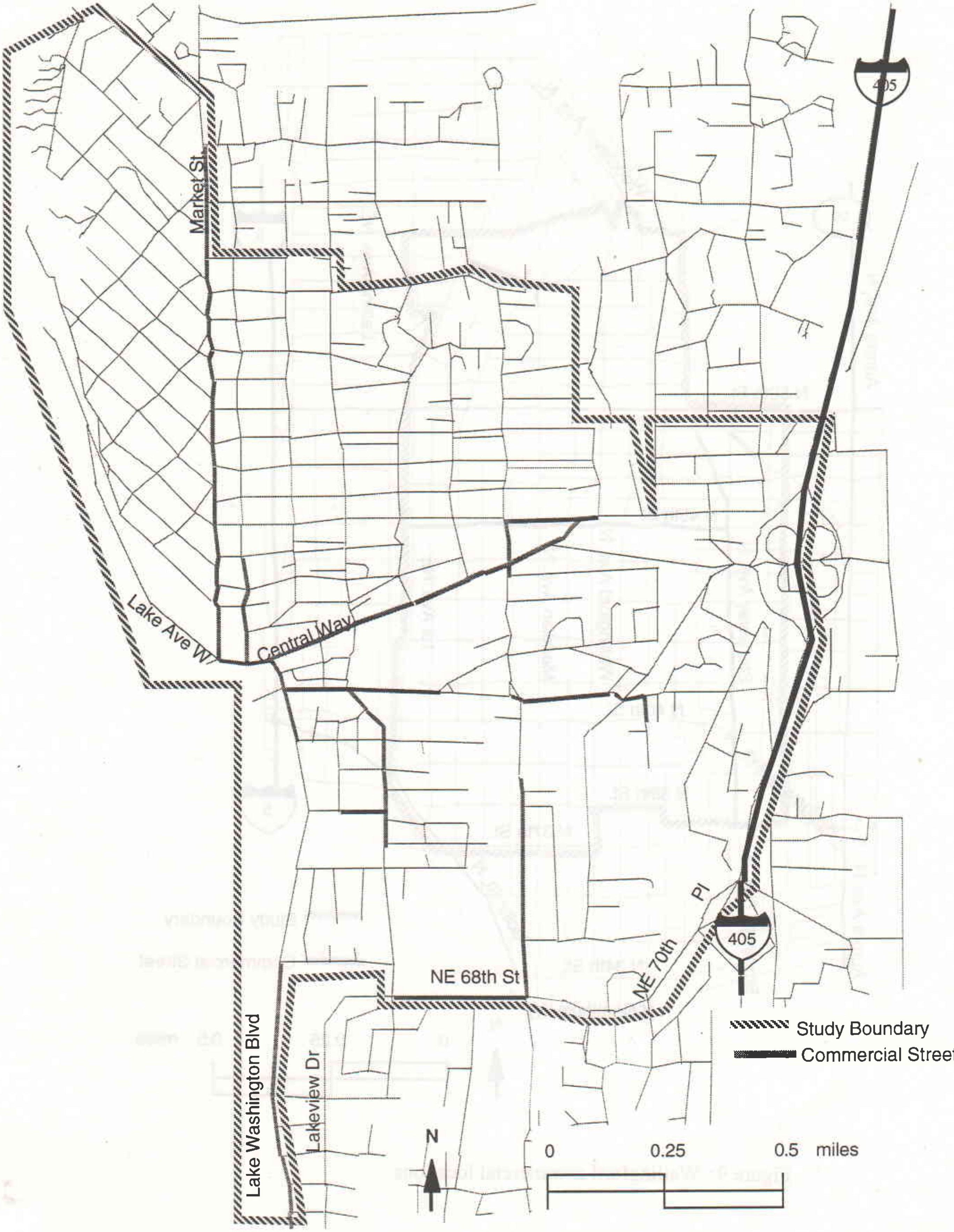

Figure 10. Kirkland commercial locations

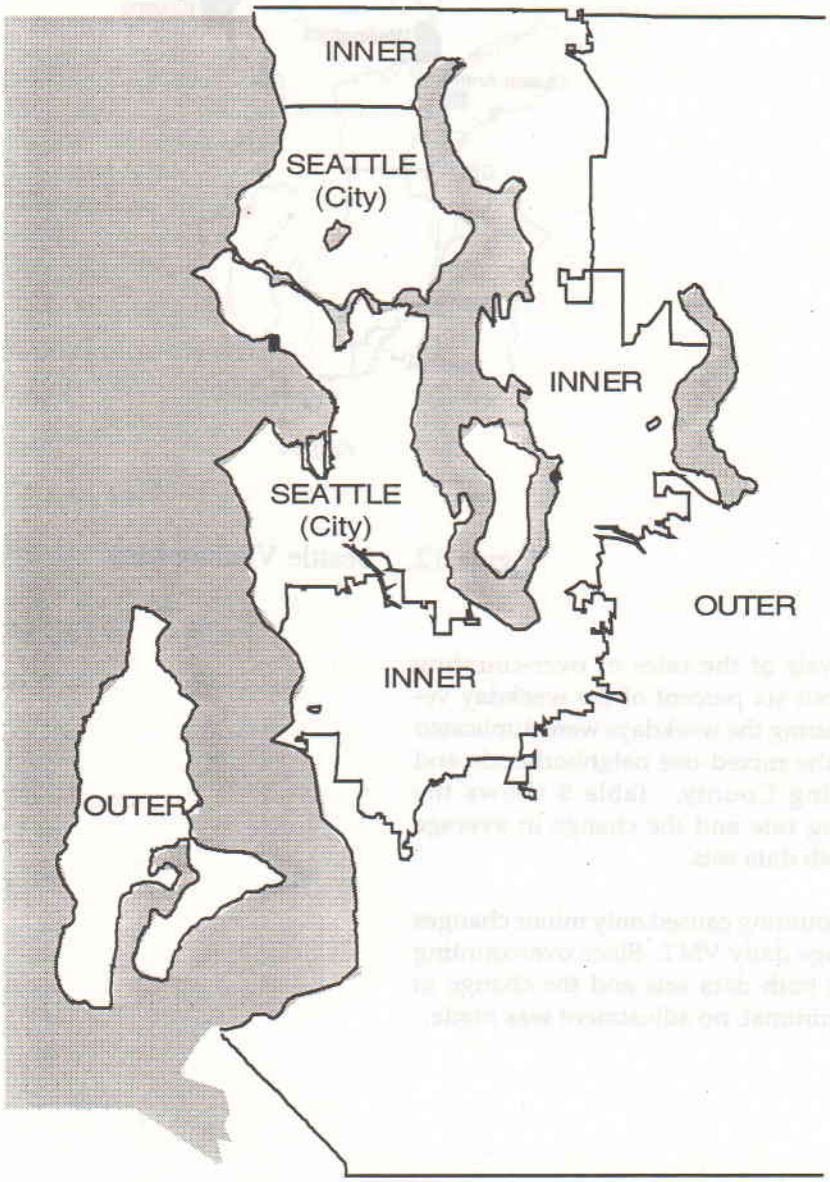

Figure 11. Analysis zones

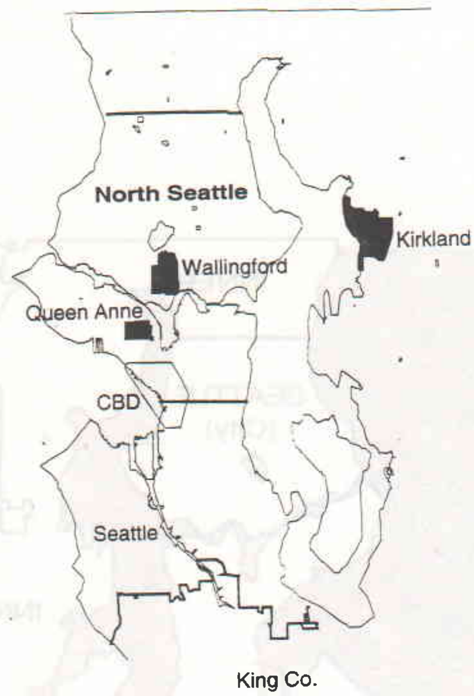

Figure 12. Seattle Vicinity Map

Analysis of the rates of over-counting showed about six percent of the weekday vehicle trips during the weekdays were duplicated in each of the mixed-use neighborhoods and areas in King County. Table 5 shows the overcounting rate and the change in average VMT for both data sets.

Overcounting caused only minor changes in the average daily VMT. Since overcounting occurred in both data sets and the change in VMT was minimal, no adjustment was made.

Table 4. Summary of Household Characteristics

Location	Average Household Size	Average Number Employees/ Household	Average Number of Vehicles/ Household	Median Age of Persons over 15	Percent Income over $35.000	Gross Density
Queen Anne	2.2	1.4	1.7	39	67%	7.6
Wallingford	2.1	1.3	1.6	37	56%	7.2
Kirkland	2.0	1.0	1.9	47	61%	3.1
All King County	2.5	1.3	2.1	37	51%	-
North Seattle	2.2	1.2	1.8	37	41%	-
Inner King County	2.5	1.4	2.1	35	56%	-
Outer King County	2.7	1.4	2.2	37	55%	-

Table 5. Respondents in Same Vehicle Overcounting (Weekdays)

	Overcounting Rate	Change in Average Daily VMT per person*
Mixed-use Neighborhood		
Queen Anne	5.5%	-1.7%
Wallingford	6.1%	-1.4%
Kirkland	7.0%	-0.2%
PSRC		
Seattle City	8.8%	-0.2%
Inner King	8.5%	1.3%
Outer King	9.6%	1.0%

* These change can be + or - depending on the contribution of the over-counted individuals to the total VMT.

Chapter 5. Data Analysis

In this chapter, travel characteristics of the inhabitants of the mixed land use neighborhoods are explored. The measure of travel most commonly used is *average daily travel mileage per person.* This figure expresses the average per-person mileage of all trips made in one day, based on all the survey respondents that fit into the category of interest. Since most respondents filled out a two-day travel diary, trips were typically averaged across these days.

The analysis begins by examining the general travel characteristics of the survey respondents. The relationship between household income, household category, respondent's age and gender, and the average daily mileage traveled is explored. The section also looks at transit, walk and bicycle trips.

Since most urban travel involves multi-purpose trips, the next section focuses on trip chaining behavior. Given the importance of nearby destinations to the neotraditional concept, an identification of trip stops that were close to each respondent's household was also completed.

Work travel, which involves the greatest percentage of daily trips, is given separate consideration. This analysis looked at work chains, chain lengths, and work locations.

The data analysis then looked at the neighborhood-level travel patterns of the mixed-use respondents. This section examined the pattern of trips generated by local commercial establishments and bus stops.

Finally, the trip length and travel characteristics of the mixed-use households and PSRC's King County households were directly compared. The analysis involved a number of household and income categories and analysis zones.

Note: Each analysis in this study that compares the mixed-use data set with the PSRC data set was adjusted for compatibility. Since the PSRC data did not include trips under five minutes, only mixed-use weekday trips of more than five minutes duration were included in comparisons.

The results of this analysis are summarized. At the end of the chapter, the analysis results are compared to other similar studies.

General Travel Characteristics

Age

Both the mixed-use and PSRC's surveys inquired about survey respondents' ages. Table 6 compares average daily travel mileage per person for each survey in eight age categories.

In both the mixed-use neighborhoods and in King County, individuals of middle age had the greatest daily travel mileage. For the mixed-use data, this group includes those between the ages of 45 to 54. For King County, the age with the greatest daily travel was the slightly younger group, including those between 35 to 44 years. For both the mixed-use neighborhood and for King County, teenagers (15-17 years) had the lowest average daily miles of travel followed by seniors (65+ years). Across the two data sets, the King County respondents consistently traveled more miles per day than did their counterparts in the mixed-use neighborhoods.

Table 6. Average Daily Mileage per Person by Age Group

	Mixed-use	(n)	King County	(n)	% diff
15 - 17	15.8	56	22.4	78	42.0%
18 - 24	20.0	171	31.9	174	59.6%
25 - 34	20.9	691	33.0	540	58.3%
35 - 44	20.2	824	34.1	594	68.9%
45 - 54	23.5	438	31.7	441	34.9%
55 - 64	21.8	246	29.5	271	35.0%
65 - 98	18.8	430	24.1	235	28.6%
all ages	20.7	2871	31.3	2343	51.3%

(n) = number of daily person-trips

Table 7. Average Daily Mileage per Person by Income (weekdays)

	Household Income Less Than $35,000 a Year	(n)	Household Income More Than $35,000 a Year	(n)	% Diff
Queen Anne	15.2	263	19.1	724	20.7%
Wallingford	15.3	342	17.1	582	10.6%
North Seattle	20.8	283	24.6	258	16.0%
Kirkland	23.3	291	30.3	581	23.0%
Seattle City	16.2	481	20.4	446	20.7%
Inner King County	23.6	284	29.8	429	21.0%
Outer King County	33.8	378	34.7	607	2.6%

(n) = number of daily person trips

Income

Table 7 shows the daily average mileage per person related to annual household income. The households were classified by low or high income with income of $35,000 as the dividing point.

For both the mixed-use neighborhoods and in King County, individuals from the lower income households traveled less per day. Differences between lower and higher income individuals ranged from 2.6 percent (a mile a day) in the outer zone of King County to 23 percent (7 miles day) for the Kirkland neighborhood. PSRC survey respondents who lived in outer King County had daily mileage that was high regardless of their income category.

The two mixed-use neighborhoods in the City of Seattle (Queen Anne and Wallingford) also had considerably lower daily mileage per person than did the north Seattle households. The inhabitants of the City of Seattle, as a whole, had travel mileage that was similar to that of the two Seattle mixed-use neighborhoods. The Kirkland respondents' mileage was about the same as those in inner King County, perhaps reflecting Kirkland's combination of mixed-use and suburban characteristics.

Household Category

A detailed analysis of mileage was completed by examining travel as it related to household category. The use of household categories attempted to remove any effect that household size and type may have on daily travel patterns. Table 8 shows the results.

While a few cells in Table 8 must be used with some caution because of small sample sizes, several patterns are visible. For both data sets, households with young children showed high rates of daily travel. In the King County data, households with older children also traveled a greater number of miles per day. In the mixed-use neighborhoods, individuals from households with two middle-aged adults trav-

Table 8. Average Daily Travel Person Mileage per Household Category (weekdays)

Household Category	Mixed use	(n)	King County	(n)	Difference
with children under 6	22.34	422	36.59	428	38.9%
children between 6-17	20.42	410	33.4	434	38.9%
one adult under 35	22.07	139	27.98	64	21.1%
one adult 35 - 64	19.93	248	25.82	142	22.8%
one adult 65+	18.59	128	24.02	52	22.6%
two adults under 35	19.05	554	30.37	357	37.3%
two adults 35 - 64	22.62	626	31.5	656	28.2%
two adults 65+	18.77	343	23.19	200	19.1%

(n) = number of daily person trips

eled as many miles per day as did individuals from households with small children. In both data sets, the lowest mileage was found in households with individuals 65 years or older. Across the data sets, King County respondents traveled more per day than did those from the mixed-use neighborhoods.

Gender

Table 9 shows the average daily trip mileage by sex for both automobile and bus modes. Some of the transit information should be interpreted with caution because of small sample sizes.

As shown in the table, men typically traveled more miles per day, both in cars and on transit, than did women. In automobiles, men from the mixed-use neighborhoods traveled 1.9 miles more per day than women. This difference was 3.5 miles per day for King County. For transit riders, men in the mixed-use neighborhood traveled 1.4 miles more per day than women. This difference was only 0.4 miles for King County.

Transit Use

Table 10 shows the relationship between transit and non-transit users in terms of daily mileage using several modes. Because of concerns about the accuracy of short trips, walk and bike mileage for the mixed-use data was calculated using the combined shortest path/model output distance variable (TRUEDIST) discussed in Chapter 4. Because this variable could not be developed for the King County (PSRC) data, their walk and bike mode data are not included.

Table 10 clearly shows that transit riders made much less use of automobiles than did non-transit riders. What is notable is the magnitude of the differences. In both the mixed-use neighborhood and in King County, non-transit users had about three times greater daily automobile mileage than did transit users. The mixed-use respondents who used transit also walked more, but bicycled less, than the non-transit riders. Since almost all transit trips require a walk trip to a bus stop, the increased level of walking is a reasonable finding.

Table 9. Average Daily Mileage per Person by Sex (weekdays)

	Automobile					Bus				
	Male	(n)	Female	(n)	% diff	Male	(n)	Female	(n)	% diff
Queen Anne	19.3	420	17.5	433	9.4%	7.9	60	6.6	99	16.6%
Wallingford	18.2	351	16.5	447	9.0%	6.6	65	6.3	82	5.3%
Kirkland	28.5	394	26.2	469	8.2%	22.4	19	14.2	39	36.5%
Mixed Use	22.1	1165	20.2	1349	8.6%	9.2	144	7.8	220	15.3%
King County	32.8	1048	29.3	1179	10.9%	14.6	91	14.2	138	2.5%

(n) = number of daily person trips

Table 10. Transit and Non-Transit User Average Daily Mileage

Location and User	Average Daily Mileage			
	Transit	Auto	Walk	Bike
Mixed: non-transit user	0	19.52	0.47	0.09
Mixed: transit user	7.93	6.03	0.81	0.02
King: non-transit user	0	28.91	n.a.	n.a.
King: transit user	13.76	9.74	n.a.	n.a.

Travel to Transit Stops

Since the mixed-use data set was in a GIS package, an analysis of each household's distances to the nearest transit stop was possible. The mixed-use inhabitants' households were not far from a bus stop; the average straight line distance from a transit stop for all households is was only 0.08 mile (420 feet or slightly less than a standard city block). Looking only at mixed-use households that included a person that used transit, the average distance to a bus stop was slightly farther, at 0.10 miles. Since these distances are straight line distances, the actual walk distance would be longer.

One area of interest is the relationship between the location of a nearby transit stop and the level of bus ridership, as well as the level of automobile use. Figure 13 shows cumulative bus and automobile use as a function of distance from a transit stop for the Queen Anne and Wallingford neighborhoods. Kirkland was not included because of low rates of transit use overall.

As shown in the graph, all bus and automobile users lived within 0.2 miles of a transit stop. One half of all transit users lived within 0.06 miles (320 feet) of a transit stop and 50 percent of all automobile users lived within 0.07 miles (370 feet) of a transit stop. This information indicates that both transit and automobile users have almost equal access to transit stops. This suggests that transit use in these mixed neighborhoods, especially as an alternative to automobile, is probably not related to accessibility of transit stops. However, this analysis has several limitations. One is that the distance is a straight line, and actual walk distances would be farther. The other limitation is that the distances used are to the nearest transit stop. The nearest stop, however, may not be served by a route that takes individuals where they want to go. Factors such as schedule convenience and the ability to transfer are also relevant, but are not accounted for in this analysis.

Bicycle Use

In the mixed-use neighborhood 94 weekday trips (0.9 percent) were by bicycle, while in King County 40 trips were by bicycle (0.3 percent). The breakdown of bicycle trips by purpose is shown in Table 11.

Table 11. Bicycle Trips by Purpose

Bike	Work	Shop	School	Personal	Appoint.	Home
Mixed Use	21.7%	7.5%	9.2%	25.0%	0.0%	36.7%
King County	20.0%	7.5%	2.5%	30.0%	0.0%	40.0%

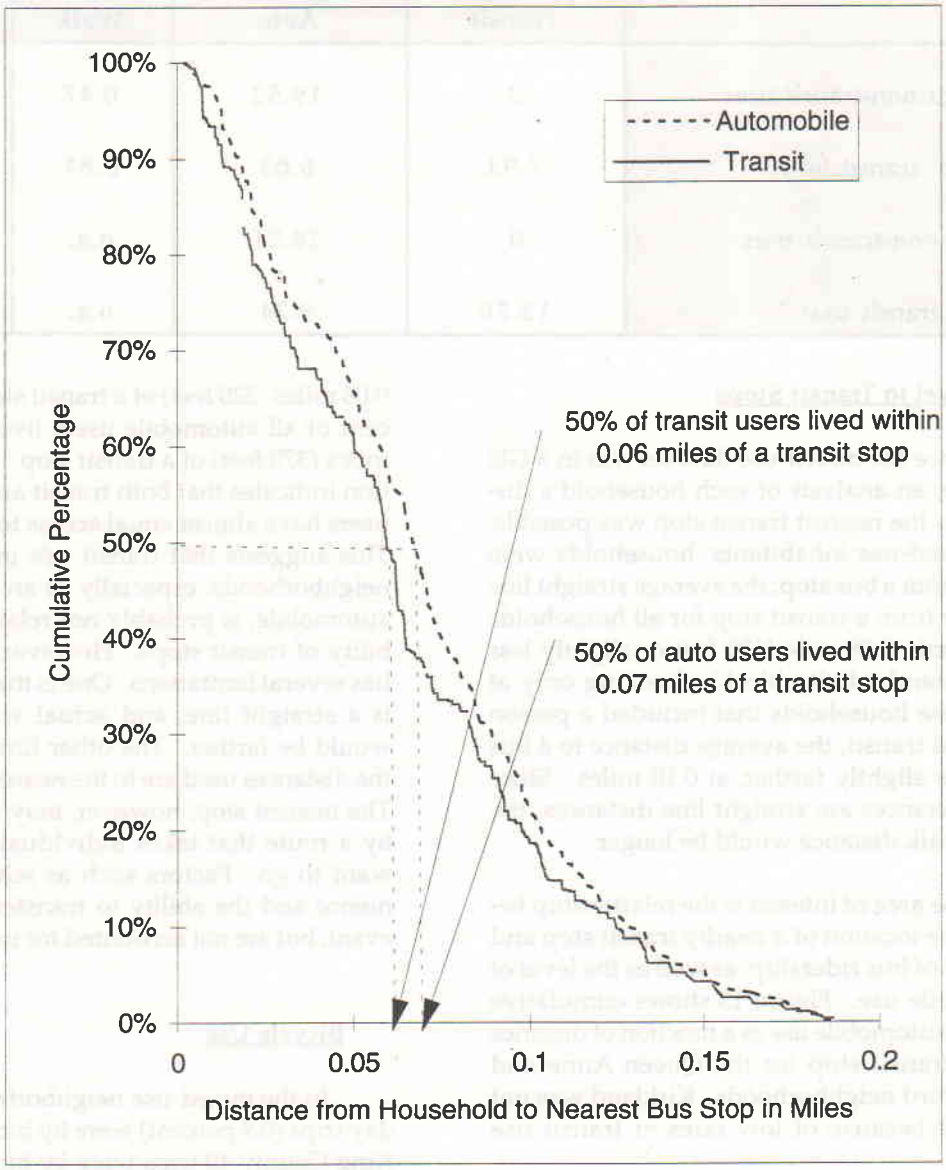

Figure 13. Cumulative Auto, Transit Use Based on Household Distance from Nearest Transit Stop for Queen Anne and Wallingford

Table 12. Bicycle Trips by Income Level

Bike	Income < $35,000	Income > $35,000
Mixed Use	52.5%	47.5%
King County	70.0%	30.0%

Other than to return to home, the most common use of the bicycle was for personal purposes, followed by work purposes. Bicycle use categorized by income is shown in Table 12.

While bicycle use in the mixed-use neighborhood is about the same for both income levels, King County bicycle users show a tendency to come from lower income households.

Pedestrian Trips

In the mixed-use neighborhoods 1581 trips (16.0 percent of all trips) were by pedestrians. For King County 536 trips (4.5 percent of all trips) were by pedestrians. Caution must be used when comparing the rates of walk trips between the King County and the mixed-use data sets. This is because many walk trips are short; the King County data respondents were requested to ignore all trips of less than five minutes, while the mixed-use respondents were instructed to include all trips. For that reason, all comparisons between the two data sets in this study removed trips of less than five minutes duration; however, the King County survey respondents' subjective estimates of travel time could have caused errors to accrue for trips of approximately five minutes. The King County respondents, under instructions to ignore trips under five minutes, may have loosely interpreted which trips fit this category; this may have resulted in over- or under-counted walk (and other short) trips. The mixed-use respondents, on the other hand, were told to include all trips. Their survey results would be less prone to individual interpretation of what constituted a five-minute trip.

The breakdown of weekday pedestrian trips by purpose is shown in Table 13.

Other than to return home, walk trips in both data sets were most often for personal purposes. Interestingly, the second most common purpose for walk trip in the mixed-use data set was for shopping, but in King County it was for work purposes. This suggests that more shopping opportunities are within walking distance for the mixed-use residents.

The percentage of walk trips by income is shown in Table 14.

In the mixed-use neighborhoods, the higher income households showed a greater rate of walking, while in King County the opposite was the case.

Multi-purpose Trips

In today's urban areas, most travel is multi-purpose; individuals combine trip purposes and stops. The following analysis quantifies the nature of multi-purpose chained trips by defining a multi-purpose trip (a chain) as a series of trips (or links) between stops. A chain was identified as any trip that started or ended (that is, the trip was anchored) at the location

Table 13. Pedestrian Trips By Purpose

Walk	Work	Shop	School	Personal	Appoint.	Home
Mixed Use	12.8%	19.5%	1.7%	34.3%	0.8%	30.9%
King County	21.1%	12.7%	3.5%	34.7%	3.0%	25.0%

Table 14. Pedestrian Trips by Income Level

Walk	Income < $35,000	Income > $35,000
Mixed-use	38.6%	61.4%
King County	54.6%	45.4%

of a respondent's home or work location. Thus, any link that started or ended at home or work would break a chain. A chain was also broken if the duration of a stop at any destination was greater than one hour. Based on this definition, the trips in each data set can be categorized by the number of stops per trip chain. The percentage of chains by the number of stops is shown in Table 15.

The three mixed-use neighborhoods' chaining behavior are similar. Slightly more than half of all chains contain a single link. These are mainly trips connecting home and work, or trips where travelers arrive at a stop and spend more than an hour there. About a quarter of the chains are two-link trips. This includes common trips such as dropping a child off at day-care on the way to work as well as going from home to do some quick grocery shopping and then returning. Almost a quarter of all the chains are composed of three or more stops. This indicates that a significant number of the trips taken by the mixed-use neighborhood respondents involve multi-purpose travel.

The King County data indicate that about three-quarters of all the chains are single-purpose trips that travel directly from home or work locations without any intervening stops. This suggests that King County residents have a lower rate of multi-purpose trips than do those living in the mixed-use neighborhoods.

The distribution of stops found in Table 15 can be examined in more detail by looking at the average number of links and chains per household per day. Table 16 shows the average number of links per household, while Table 17 shows the average number of chains.

As seen in the Table 16, the average number of links within each household type is similar for all locations. Across household types, those with children have the greatest number of stops per day, and households with one adult have the least.

Table 17 looks at the number of chains per day per household. Note that in this table a one-stop trip is also considered a chain.

The results from Tables 16 and 17 suggest that respondents from both the mixed use and King County neighborhoods have a similar

Table 15. Distribution of Number of Links in a Trip Chain (weekdays)

	1	2	3	4	5	6	7	8	9+
Queen Anne	61.2%	25.7%	7.8%	3.0%	1.3%	0.3%	0.4%	0.0%	0.1%
Wallingford	59.8%	26.7%	7.8%	3.3%	1.3%	0.4%	0.5%	0.1%	0.2%
Kirkland	56.7%	27.2%	8.8%	3.6%	2.0%	1.0%	0.2%	0.2%	0.3%
All King County	72.2%	17.7%	5.6%	2.3%	0.9%	0.4%	0.2%	0.1%	0.1%

Table 16. Average Daily Trip Links per Household

	Household Type			
	With child(ren)	1 Adult	2+ Adults	Senior
Queen Anne	12.9	5.2	10.8	6.9
Wallingford	11.5	5.3	10.4	6.9
North Seattle	10.7	4.7	10.6	7.2
Kirkland	11.4	5.2	11.6	7.0
Seattle	10.6	4.6	10.1	6.7
Inner	12.0	4.7	9.6	6.8
Outer	11.3	4.1	9.2	7.7

travel pattern in terms of the number of stops and the number of chained trips they make per day. This is reasonable considering that travel demands on individuals in any type of area should also be similar. Individuals still need to travel to shop for groceries or buy clothes—no matter where they live.

By combining Tables 16 and 17, the average number of trip links per chain can be derived; this ratio is shown in Table 18. The majority of all chains have one or two links or stops. Seniors have consistently more links per chain.

The nature of the survey respondents' chaining behavior can also be explored by analyzing the length of the trip chains as classified by the beginning or the ending link. For Table 19, the data from the three mixed-use neighborhoods are combined.

As seen in the table, for both the King County and mixed-use data, chains initiated or finishing at home are longer than those started elsewhere. Trips that end at work in the King County data are about as long as trips that end at home. However, in the mixed-use data, trips that end at work are notably shorter than trips that end at home. This suggests that mixed-use respondents make more stops coming from work than they do traveling to work.

Further investigation of chain length can be completed by examining the starting and ending purposes, as shown in Table 20.

For the mixed-use respondents, the longest chains are those that (1) begin and end at home; (2) begin at home and end at work; and (3) begin and end at other locations. The shortest chains are those that (1) begin at work and end at another purpose; or (2) begin at another purpose and end at work. This situation indicated that non-discretionary, work-based trips tend to be longer than more flexible, discretionary trips for other purposes (e.g., shopping, personal reasons) Why the longest chains are those that both start at home and end at home is uncertain. This category includes the greatest number of trips, and it probably includes many shopping trips from home wherein the respondent stayed less than one hour at the trip destination. Stops of less than one hour would not create a new chain.

As seen in both Tables 19 and 20, the chains completed by the King County inhabit-

Table 17. Average Daily Trip Chains per Household

	Household Type			
	With Child(ren)	1 Adult	2+ Adults	Senior
Queen Anne	7.8	3.5	7.1	3.5
Wallingford	6.7	3.4	6.6	3.7
North Seattle	7.6	3.3	7.5	4.5
Kirkland	6.6	3.5	7.1	3.6
Seattle	7.2	3.3	7.2	4.3
Inner	8.2	3.5	7.1	4.5
Outer	7.8	3.3	6.5	4.2

Table 18. Average Daily Trip Links per Chain per Household

	Household Type			
	With Child(ren)	1 Adult	2+ Adults	Senior
Queen Anne	1.66	1.47	1.52	1.96
Wallingford	1.72	1.57	1.57	1.87
North Seattle	1.41	1.42	1.41	1.61
Kirkland	1.72	1.49	1.64	2.09
Seattle	1.47	1.40	1.39	1.55
Inner	1.47	1.37	1.36	1.52
Outer	1.45	1.24	1.43	1.82

Table 19. Average Chain Length in Miles by Initial or Terminating Purpose

	Beginning				Ending			
	Mixed	*(n)*	King	*(n)*	Mixed	*(n)*	King	*(n)*
Home	7.8	*5309*	10.4	*3658*	7.5	*5292*	9.9	*3593*
Work	6.3	*1810*	10.2	*1828*	5.1	*1847*	9.4	*1850*
Other	5.5	*1791*	7.0	*2250*	5.3	*1771*	8.5	*2291*

(n) = number of person chains

Table 20. Average Chain Length by Initial and Terminating Purpose

	Home				Work				Other			
	Mixed	*(n)*	King	*(n)*	Mixed	*(n)*	King	*(n)*	Mixed	*(n)*	King	*(n)*
Home	8.3	*2795*	13.0	*873*	7.1	*1289*	11.4	*1194*	6.1	*1192*	6.9	*1509*
Work	5.9	*1121*	10.8	*1192*	5.3	*176*	12.2	*50*	3.4	*443*	6.1	*543*
Other	5.5	*1320*	8.7	*1525*	3.4	*303*	7.4	*573*	7.1	*148*	10.3	*193*

(n) = number of person chains

ants are longer generally than those of the mixed-use inhabitants, but they follow the same patterns between purposes. However, one difference is that discretionary trips by King County inhabitants that are from work to other destinations are relatively longer. This suggests that the King County inhabitants may be more likely to complete errands as they travel from work.

Trip Stops

Given the neotraditional movement's emphasis on trips to locations near the home, one analysis of interest is how many trip destinations are within a short distance from home. Table 21 is an examination of trip ends that are less than two roadway miles from each respondent's household.

This table clearly shows that the respondents in the mixed-use neighborhoods make almost twice as many trips to stops that are within two miles of home than do the King County respondents. The difference between the data sets is especially evident for trips less than one mile.

Work Travel

A number of studies have indicated that understanding urban daily travel behavior requires consideration of not only an individual's household location but also of their workplace location. Hanson, for example, using travel diary data from a Swedish city, concluded that many households' daily trips were tied to the journey to and from the work place (1980). Hodge, using travel diary data collected in King County, concluded that, "The journey to work remains a critical element of urban trip making, both as organizer of discretionary travel and household activities" (1991).

The following tables highlight the importance of the work trip in daily travel patterns and their role as part of multi-purpose trips. Table 22 shows the percentage of *links* that involve a work stop.

During the morning commute, more than one half of all trip links involved a work stop while about a third of all the evening commute trip links involved a work stop. The King County respondents' distribution of links per day is not notably different from that of the mixed-use respondents.

Table 23 shows the percentage of *chains* that involve at least one work stop.

If trip *chains*, involving a work stop are examined, as in table 20 above, the dominance of the work trip is more apparent. Between 40 and 50 percent of all daily trip chains include a work stop. During both the morning and evening commute, this percentage increases to over 50 percent.

The contribution of the work trip to daily travel can also be explored by looking at average mileage for both work and non-work chains. Table 24 shows length for work chains, and Table 25 shows length for non-work chains.

As seen in the table, except for the senior households category that tends to include retired individuals with few work trips, and small survey sample sizes, King County work chains are slightly less than twice the length of the mixed-use chains.

As shown in Table 25, the mixed-use residents' non-work chains had about 40 percent less mileage than those of King County. A comparison between Tables 24 and 25 shows that work chains typically have slightly lower mileage than non-work chains.

Table 21. Percent of Trip Stops by Distance from Households

	Distance of Stops from Household Location		
	1.0 Miles	1.5 Miles	2.0 Mile
Mixed Use	17.4%	25.4%	38.7%
King County	4.5%	11.6%	18.2%

Table 22. Percent of All Trip *Links* Involving a Work Stop (weekdays)

	All Day	AM[1]	PM[2]
Queen Anne	33.9%	53.4%	32.8%
Wallingford	30.7%	57.5%	36.6%
Kirkland	29.1%	55.7%	30.3%
King County	31.6%	50.8%	35.5%

[1] Any trip link that starts between 6 and 9 A.M. [2] Any link that starts between 3 and 6 P.M.

Table 23. Percentage of All Trip Chains Involving a Work Stop (weekdays)

	All Day	AM[1]	PM[2]
Queen Anne	48.4%	56.2%	57.6%
Wallingford	43.6%	59.3%	52.9%
Kirkland	41.9%	57.1%	50.9%
King County	44.8%	55.0%	51.9%

[1] Any trip chain that starts between 6 and 9 A.M. [2] Any trip chain that starts between 3 and 6 P.M.

Work Trip Ratios

The relationship of work trip mileage to that of shopping and personal trips can be explored by using a ratio. This was calculated in Table 26.

Table 26 can be interpreted by noting, for example, that for every mile of work travel completed by a Queen Anne resident, he or she traveled, on average, 0.57 miles for shopping purposes and 0.94 for personal purposes. The ratio of shopping trips to work trips is consistent for all locations. This implies that individuals with longer work trips also tend to have longer shopping trips.

The table also indicates that personal trips are longer than shopping trip. Again, there is noticeable consistency in the ratio among all the locations. Overall, the table demonstrates that, across locations, the length of the work trip is a good indicator of shopping and personal trip length.

Regional Work Trips

One concern when comparing the mixed-use and King County data was confounding effects due to different accessibility to Seattle's Central Business District (CBD). The CBD is a major employment center for King County and could be expected to attract a number of work trips. Both Queen Anne and Wallingford are close to the CBD; Queen Anne is about two miles and Wallingford four miles away. This proximity raised concerns that any average trip length for these two neighborhoods would be shorter than other locations simply because work trips to the CBD would reduce the average trip length. These shorter work trips potentially could obscure some of the transportation effects related to mixed land use.

As a means of investigating the CBD's capture of work trips, the location of each respondent's workplace was identified for both the mixed-use and King County data. Table 27 shows the percentage of work trips that remain

Table 24. Average Daily Trip Mileage per *Work* Chain

Household Type	Mixed		King County	
	Mileage	*(n)*	Mileage	*(n)*
With Children	4.9	*481*	9.2	*703*
1 Adult	4.8	*212*	7.1	*226*
2+ Adults	4.9	*706*	9.1	*912*
Senior	5.1	*61*	5.1	*45*

(n) = number of daily person chains

Table 25. Average Daily Trip Mileage per *Non-work* Chain

Household Type	Mixed		King County	
	Mileage	*(n)*	Mileage	*(n)*
With Children	6.0	*1182*	10.1	*1512*
1 Adult	6.4	*516*	8.5	*279*
2+ Adults	5.8	*1303*	10.1	*1412*
Senior	7.4	*403*	9.5	*470*

(n) = number of daily person chains

in the same areas as the household location, and those that travel to the Seattle CBD and to other zones.

It is apparent from Table 27 that the Seattle CBD is a significant generator of work travel for Queen Anne and Wallingford. The CBD also attracts the same level of work trips from the north Seattle zone. This finding is of particular relevance for this research because the north Seattle study area includes the Queen Anne and Wallingford neighborhoods. Because of the equal percentage of work trips traveling to the CBD from each of these areas, we conclude that differences in average trip lengths between these areas are probably not due to travel to the CBD.

Table 27 indicates that Seattle's CBD is a major location for work sites for King County's inner and outer zones. This is reasonable given the large size of these areas. However, as may be expected, most of the work sites for these two zones remained internal to the areas. The majority of the work locations for the Kirkland residents remain within the inner King zone.

Among the three mixed-use neighborhoods, approximately 10 percent of the respondents worked within the same neighborhood that they lived. This suggests that mixed-use areas do provide a few sources of employment for their inhabitants.

Household Location and Commercial Establishments

Since each mixed-use household address was geocoded to a latitude and longitude, it was possible to determine each household's distance from commercial streets. This information made it possible to relate travel behavior of individuals to the accessibility to local goods and services. Accessibility was measured by the straight line distance between each household and the nearest commercial street. Commercial streets were selected based on concentrations of establishment providing goods and services that would be used on a routine basis. This included grocery stores, convenience stores, restaurants, dry cleaners and drug stores.

One tenet of the mixed-use movement is that nearby commercial establishments reduce the need to drive. One test of this idea is to compare levels of walking for mixed-use residents living at different distances from commercial areas. Figure 14 shows the percentage of shopping trips that were completed on foot by households at five different distances from the commercial streets. This analysis includes only shopping trips that have at least one trip end within a census tract that includes the mixed-use neighborhoods.

Table 26. Ratio of Average Shopping/Personal Distances to Work Distance

Location	Shopping to work ratio	Personal to work ratio
Queen Anne	.57	.94
Wallingford	.57	.90
North Seattle	.63	1.15
Kirkland	.59	.91
City of Seattle	.59	1.12
Inner King County	.64	1.09
Outer King County	.60	.97

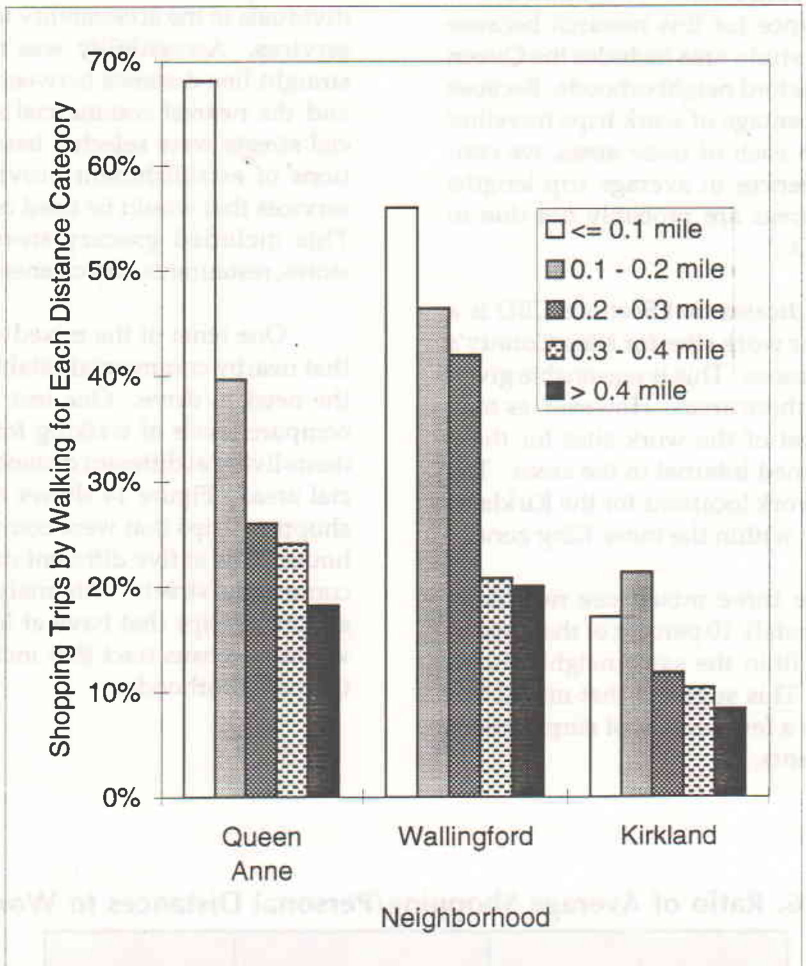

Figure 14. Shopping Trips by Walking Related to Household Distance from Commercial Streets

Table 27. Work Trip Destinations

Location	Within Neighborhood Location	To CBD	To North Seattle	To Inner King Co.	To Outer King Co.
Queen Anne	10.5%	30.9%	41.6%	11.5%	4.5%
Wallingford	10.4%	24.8%	46.4%	11.4%	5.2%
Kirkland	14.3%	11.6%	6.4%	52.9%	16.5%
North Seattle	-	31.0%	42.0%	8.4%	6.1%
Inner King	-	12.6%	9.2%	52.7%	10.5%
Outer King	-	6.8%	4.1%	31.0%	44.5%

In general, the figure indicates that the farther mixed-use inhabitants live from a commercial street, the less likely their shopping trips will be on foot (and more likely in an automobile). This trend is particularly noticeable for the Queen Anne and Wallingford data. Over 65 percent of the residents from Queen Anne and 50 percent of those from Wallingford, who also lived within 0.1 miles of commercial street, walked to shop. In contrast, less than 25 percent of those respondents who lived more than 0.2 mile from commercial establishments walked.

The Kirkland data showed a less obvious trend because of low numbers of walk trips and small survey sample sizes. Kirkland also had a more dispersed pattern of commercial activity than did the other two mixed-use neighborhoods, making any trends less obvious.

The same analytical process can be applied to recreation and personal trip purposes (figure 15). Personal and recreation purposes include eating and drinking, pleasure trips, and family/personal business.

As seen in the figure, the overall relationship between walking trips and distance is also noticeable for recreation/personal trips. Since many of these purposes involve commercial establishments, it is not surprising that this level of walking shows a similar trend to shopping purposes.

Travel Mileage and Mode

One of the goals of this research was to determine whether the three mixed land use neighborhoods had different travel characteristics than other, less diverse land use areas. Travel distance information from the PSRC's King County data was compared to data from the mixed-use neighborhoods. During this stage of analysis, an effort was made to control for sample bias. This was achieved by comparing travel mileage between similar household types and incomes. Because of low survey sample sizes, various categories were aggregated, and different analysis zones were used. Since north Seattle overlapped the Queen Anne and Wallingford study areas, these areas were frequently compared.

The average daily mileage by mode for both King County and the mixed-use respondents is shown in figure 16.

The average miles traveled per day was 15 for the mixed-use inhabitants and 27 miles for the King County inhabitants. When looking at both the transit and automobile modes, King County survey respondents had significantly longer daily travel mileage.

The choice of modes for all trips is examined in Table 28.

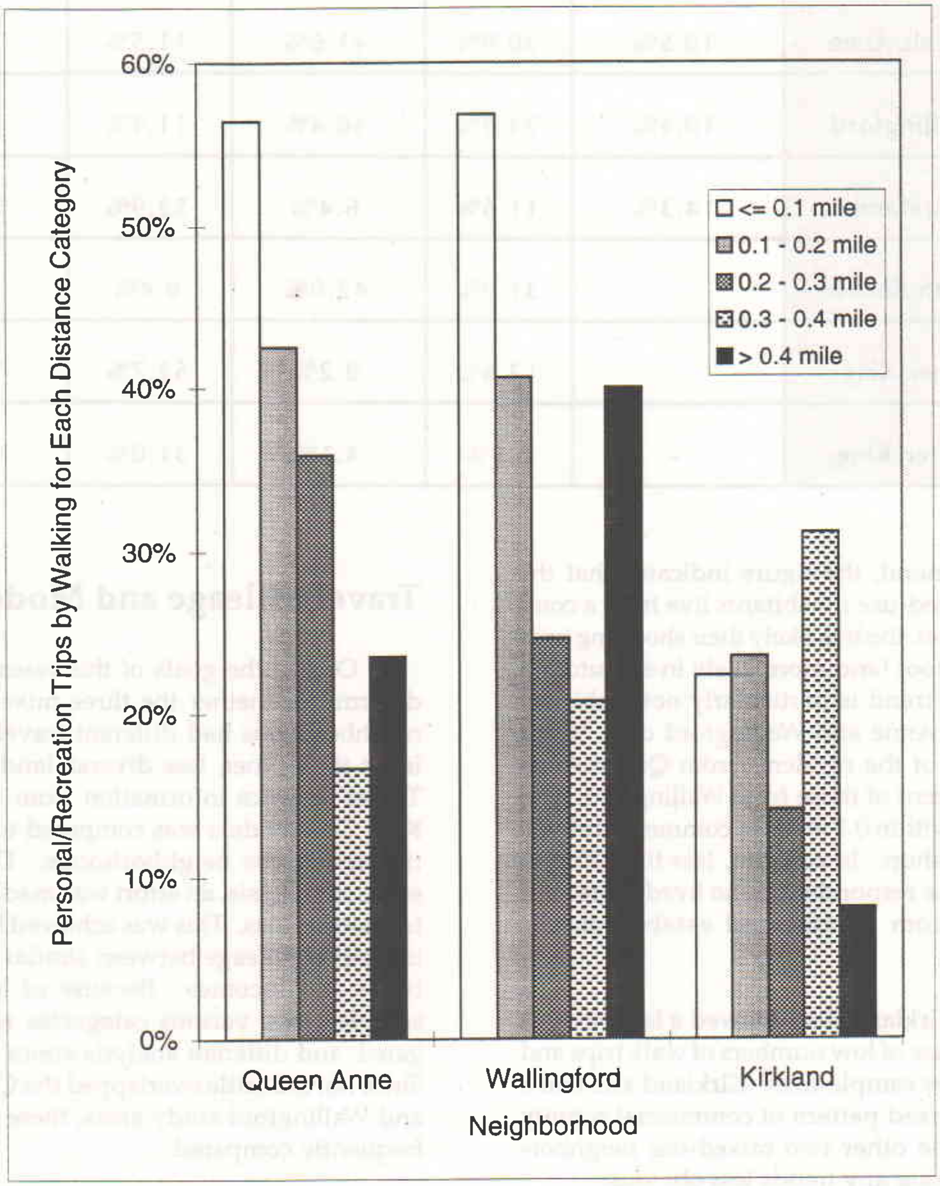

Figure 15. Personal/Recreation Trips by Walking Related to Household Distance from Commercial Streets

The table indicates that the Seattle mixed-use neighborhood residents drive less and walk more than those living in other locations. However, transit use in these neighborhood is not much different than other areas in Seattle. These findings support the hypothesis that mixed-use neighborhoods provide residents with more opportunities to walk to trip destinations.

Kirkland residents show a slightly lower automobile use rate and higher walk rate than the surrounding inner areas of King County. The location with the highest level of automobile use is outer King County.

Figure 17 compares average daily travel trip mileage by purpose for respondents from the mixed-use data set with those from King County.

As shown in figure 17, the mixed-use neighborhood inhabitants consistently traveled fewer average miles across all trip purposes. The greatest average daily mileage for the mixed-use neighborhoods was for work trips (9.2 miles). For the King County data, the greatest mileage (12.2) was for personal trips. The mileage may indicate that the mixed-use inhabitants have better (that is closer) opportunities for conducting personal, discretionary activities.

This average daily travel information can be subdivided by income. Since it was shown previously that daily mileage varies with household income, daily average mileage was separated into higher and lower income categories. Figure 18 shows the travel mileage for individuals from households with high and low incomes.

In figure 18 it can be seen that the King County residents travel more on average than do the mixed-use residents for each of the income categories.

A more detailed breakdown of the travel mileage data can be completed by location. Figure 19 shows some of the same data as above, but disaggregated into the three mixed-use neighborhoods and the three King County analysis zones.

The results depicted in figure 19 support some of the findings earlier in the chapter that individuals from households with children travel the most and those from senior households travel the least. In general, those who lived in mixed-use neighborhoods consistently traveled fewer miles than the respondents from the King County data set. In every case, the two Seattle mixed-use neighborhoods also had a lower average mileage than similar house-

Table 28. Mode Choice by Location

Location	Auto	Transit	Walk	Bike	Other
Queen Anne	71.7%	6.7%	20.0%	0.8%	0.8%
Wallingford	71.6%	7.7%	18.6%	2.0%	0.2%
North Seattle	82.1%	6.9%	9.0%	0.7%	1.4%
Kirkland	88.4%	2.9%	8.4%	0.0%	0.4%
Seattle City	82.4%	7.1%	8.3%	0.7%	1.4%
Inner	93.1%	2.7%	2.8%	0.1%	1.3%
Outer	93.3%	2.3%	2.5%	0.2%	1.7%

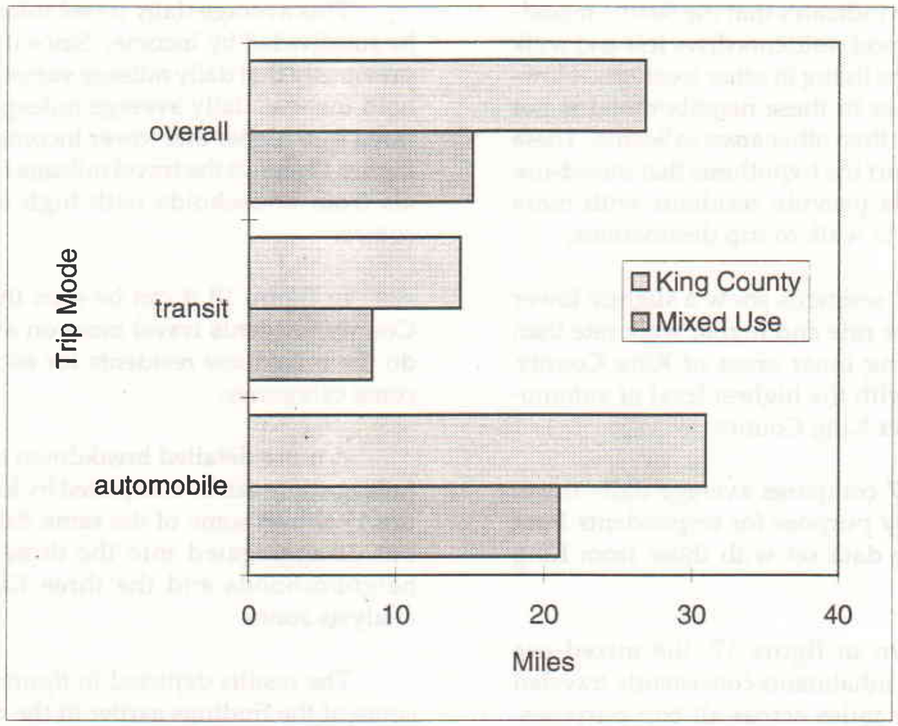

Figure 16. Average Daily Mileage per Person by Mode

Figure 17. Average Trip Mileage per Person by Purpose

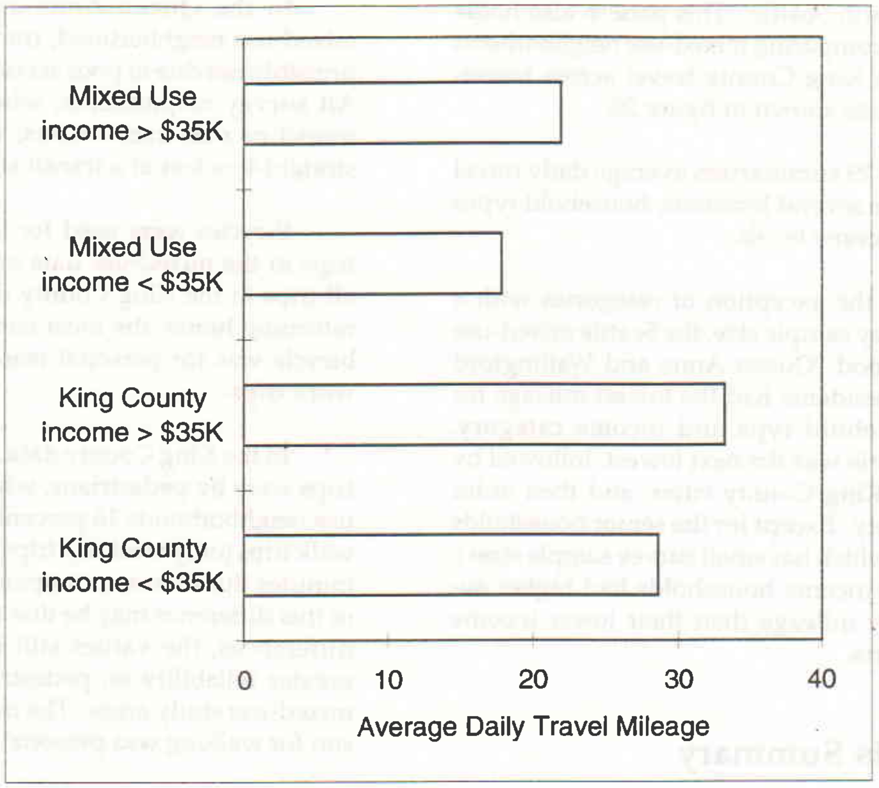

Figure 18. Average Daily Person Mileage for Households by Location and Income

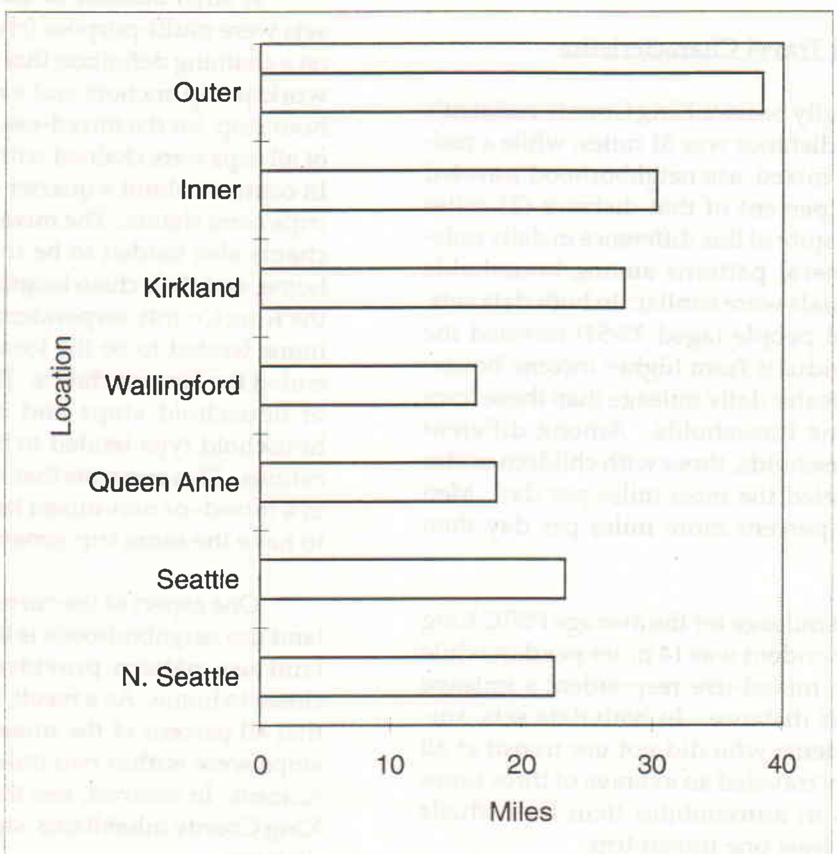

Figure 19. Average Daily Person Mileage by Household Location

holds in north Seattle. This pattern also holds true when comparing mixed-use neighborhood travel with King County travel across household types, as shown in figure 20.

Table 29 summarizes average daily travel mileage for several locations, household types and two income levels.

With the exception of categories with a small survey sample size, the Seattle mixed-use neighborhood (Queen Anne and Wallingford together) residents had the lowest mileage for each household type and income category. North Seattle was the next lowest, followed by the inner King County cities, and then outer King County. Except for the senior households category (which has small survey sample sizes), the higher income households had higher average daily mileage than their lower income counterparts.

Analysis Summary

The following section summarizes the main finding of this chapter.

General Travel Characteristics

On a daily basis, a King County resident's daily travel distance was 31 miles, while a resident from a mixed-use neighborhood traveled less 50 fifty percent of that distance (21 miles per day). In spite of this difference in daily mileage, the general patterns among households and individuals were similar. In both data sets, middle-aged people (aged 35-54) traveled the most. Individuals from higher income households had greater daily mileage than those from lower income households. Among different types of households, those with children under age six traveled the most miles per day. Men traveled 10 percent more miles per day than women.

Transit mileage for the average PSRC King County respondent was 14 miles per day, while the average mixed-use respondent's mileage was half this distance. In both data sets, survey respondents who did not use transit at all during a day traveled an average of three times more miles in automobiles than individuals who had at least one transit trip.

In the Queen Anne and Wallingford mixed-use neighborhood, transit non-use was probably not due to poor access to transit stops. All survey respondents, whether they were transit or non-transit users, were within 370 straight-line feet of a transit stop.

Bicycles were used for 0.9 percent of all trips in the mixed-use data and 0.3 percent of all trips in the King County data. Other than returning home, the most common use of the bicycle was for personal reasons followed by work trips.

In the King County data, 4.5 percent of all trips were by pedestrians, while in the mixed-use neighborhoods 16 percent of all trips were walk trips (only weekday trips of more than five minutes duration are compared). While some of this difference may be due to data collection differences, the values still indicate a much greater reliability on pedestrian travel in the mixed-use study areas. The most common reason for walking was personal business.

Multi-Purpose Trip Summary

A large number of the trips in both data sets were multi-purpose (chained) trips. Based on a chaining definition that included home and work as trip anchors and a maximum of a one-hour stop, for the mixed-use data about one half of all trips were chained with two or more stops. In contrast, about a quarter of the King County trips were chains. The mixed-use respondents' chains also tended to be to locations closer to home, and their chain lengths were shorter than the King County respondents. For both groups, home tended to be the location that started or ended the longest chains. The average number of household stops and chains per day by household type tended to be similar for all locations. This suggests that households, be they in a mixed- or non-mixed land use area, tended to have the same trip generation needs.

One aspect of the current interest in mixed land use neighborhoods is the idea that a mixed land use pattern provides trip destinations closer to home. As a result, this study's finding that 40 percent of the mixed-use respondents' stops were within two miles of home was significant. In contrast, less than 20 percent of the King County inhabitants' stops were within this distance.

Table 29. Average Daily Travel Mileage by Household Type and Annual Household Income

	< $35,000		> $35,000	
With Child(ren)	**miles**	*(n)*	**miles**	*(n)*
Queen Anne + Wallingford	13.13	*96*	15.26	*663*
North Seattle	25.88	*44*	26.93	*96*
Inner	30.17	*79*	34.20	*189*
Outer	36.73	*133*	41.45	*242*
One Adult				
Queen Anne + Wallingford	16.53	*183*	17.56	*100*
North Seattle	20.53	*61*	18.15	*12*
Inner	30.85	*38*	36.45	*16*
Outer	37.23	*39*	28.00	*10*
Two Adults				
Queen Anne + Wallingford	11.75	*264*	15.48	*669*
North Seattle	20.58	*117*	24.49	*140*
Inner	27.34	*66*	31.88	*166*
Outer	37.85	*117*	36.64	*279*
Senior				
Queen Anne + Wallingford	12.04	*153*	16.17	*98*
North Seattle	17.27	*60*	11.69	*10*
Inner	23.79	*56*	21.55	*21*
Outer	38.04	*50*	28.63	*19*

(n) = number of daily person trips

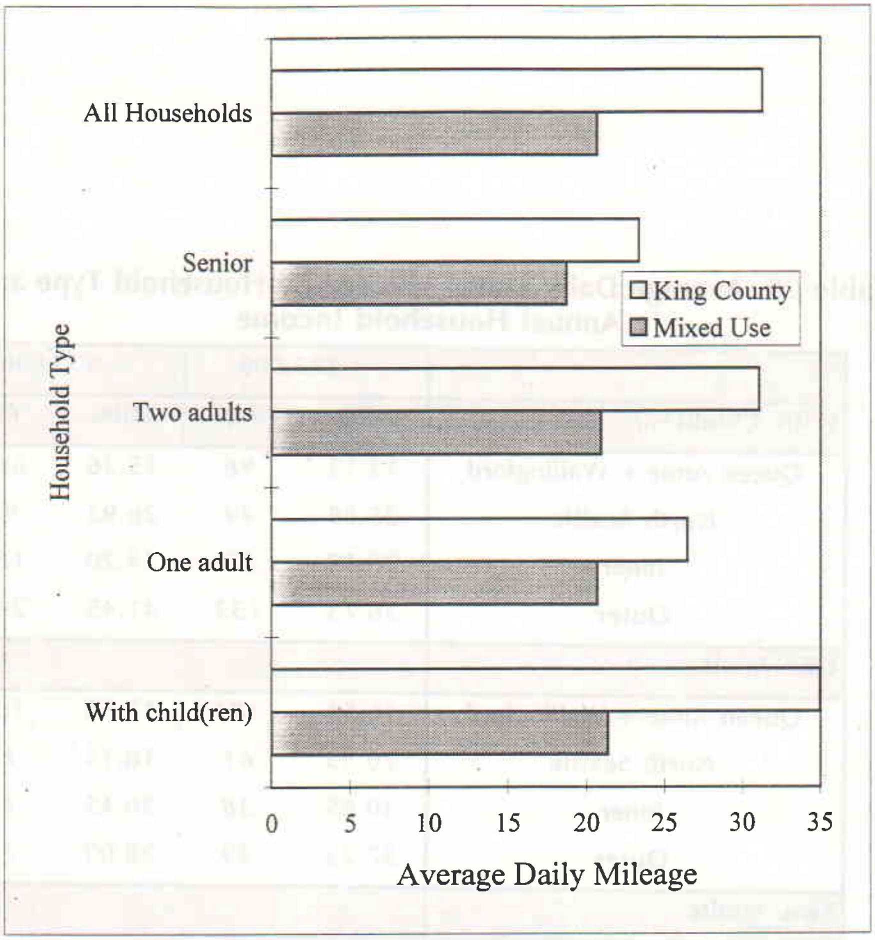

Figure 20. Average Daily Person Mileage by Household Type

Table 30. Comparison Studies

Study	Study Area	Neighborhood Types
Friedman, Gordon and Peers (1992)	San Francisco	older, mixed land use communities with gridded street *vs.* newer segregated land use suburban tract with limited hierarchical streets
Ewing, Haliyur and Page (1994)	Palm Beach County, Florida	six area ranging from a urban mixed land-use neighborhood to sprawling residential suburbs
Cervero and Gorham (1995)	San Francisco and Los Angeles	transit-oriented gridded neighborhood developments built before 1945 *vs.* auto-oriented, random street pattern neighborhoods built after 1945
Holtzclaw (1991)	San Francisco	four areas ranging from a sprawling suburban residential bedroom community to an urban area with diverse land use
McNally and Ryan (1993)	Hypothetical	area with a gridded neotraditional street patterns *vs.* suburban area with an arterial-collector pattern

Work Trip Analysis Summary

What was evident from this part of the analysis is that a large number of all daily trips involved a stop at work. During the average weekday, in both data sets, 40 to 50 percent of all trip chains involved a work stop. During the evening commute this percentage rose from 50 to 60 percent of all trips.

Work trip chains however, were shorter than non-work chains. The mixed-use respondents' average daily work and non-work chains were always shorter than those from the King County data. The length of an average work trip was found to relate fairly consistently to the length of trip for shopping and personal trips. These results suggested that work location, as well as home location, may also be an important determinate of travel.

Intra-Neighborhood Trips

Within the three mixed-use neighborhoods, the distance from an individual's household to streets with a concentration of goods and services influenced the extent to which they walked for shopping purposes. To a lesser extent, this distance also influenced the level of walking for personal trips. Individuals appeared to very sensitive to distance. In the Queen Anne neighborhood, the most notable example, individuals from households within a block of a commercial street (0.1 miles) made 60 percent of their local shopping trips on foot. In contrast, those from households four or more blocks away made only 20 percent of their shopping trips on foot.

Travel Mileage

When controlling for income and household type, individuals from the mixed-use neighborhoods of Queen Anne and Wallingford clearly had lower average daily travel mileage than any individuals from the PSRC's King County areas. The residents from these areas also drove less and walked more than people from the other areas. Survey respondents from the City of Seattle and the north Seattle area had lower daily mileage than the Kirkland mixed-use neighborhood. However, the Kirkland residents' average daily mileage was lower than the rest of King County.

Comparisons with Other Studies

This section compares a number of the studies reviewed in Chapter 2 with the findings in this report. (For clarity, this report and its findings will be referred as the *mixed-use neighborhood study*). The studies that are compared to the mixed use neighborhood study are presented in Table 30.

While each study used a different definition for its study areas, each was comparing urban areas with mixed land use and neotraditional design characteristics to suburban areas with less diverse land use. Each study also used different quantitative indicators of transportation activity; but there was some commonality, and some comparison of results is therefore possible. However, any comparison of results should interpreted with some care. Differences exists between the each study. For

Table 31. Mode Split by Locations

Mode	Mixed Land Use or Neotraditional Area			Non-mixed Land Use or Suburban Area		
	Queen Anne	Friedman	Ewing (West Palm)	Inner King County	Friedman	Ewing (Wellington)
Drive-alone	42%	49%	51%	57%	68%	49%
Auto. Passenger	30%	15%	46%	37%	18%	48%
Transit	7%	17%	2%	3%	3%	0%
Pedestrian	20%	17%	<1.5%	3%	8%	<3%
Bike	1%	1%	<1.5%	0%	2%	<3%

example, to make the PSRC and the mixed use survey data compatible, the mixed-use neighborhood study removed all trips less than five minutes duration; this was 8 percent of all trips of which 45 percent were pedestrian. The ability of the other studies to capture short trips is unknown.

Since one of the potential benefits of a mixed-use, neotraditional neighborhood is reduced automobile traffic, a number of the studies explored mode choice. Table 31 compares the mode choice percentages from the mixed-use neighborhood study with two other studies. One of the studies was Friedman, Gordon and Peers's examinations of neighborhoods in the San Francisco area (1992). The other study used in Table 31 was Ewing, Haliyur and Page's comparison of six communities in Florida (1994). To facilitate comparison with the mixed-use neighborhood study, two of the communities with the greatest differences in characteristics were selected for Table 31. One was West Palm Beach, which was described as a "traditional" urban community with gridded streets and a mixed land use. The other community, Wellington, was described as newer residential suburban area full of cul-de-sacs and other characteristics representing "everything neotraditionalist love to hate."

From the mixed-use neighborhood study, table 31 included data from the Queen Anne mixed-use neighborhood and the largely suburban King County inner zone.

The differences between the mixed land use area (neotraditional in design) and the non-mixed area (suburban) drive-alone percentage was notable for the mixed-use neighborhood study and the Friedman study. Friedman found that a urban land-use development's drive-alone rate was 20 percent lower than suburban development's (68 percent vs. 49 percent). Similarly, the Queen Anne mixed-use respondents' drive-alone rate was about 16 percent less than the suburban-oriented inner King County (42 percent vs. 57 percent).

In Table 30, the Ewing study showed the community of West Palm Beach, with many neotraditional characteristics, as having a mode choice almost identical to that of the suburban neighborhood of Wellington. Ewing's report, however, placed little emphasis on mode choice and stressed the importance of "hours of travel." He noted, for example, that the average time per trip for those households in West Palm Beach was 40 percent less than those in Wellington. In his the report differences in travel time were linked to the different levels

Table 32. Daily Trips per Household

	Neotraditional or Mixed-use		Suburban Area or Non-Mixed	
	Queen Anne, Wallingford, Kirkland	Friedman	King County (PSRC)	Friedman
Drive Alone	4.03	4.41	4.81	7.07
Transit	0.49	1.51	0.36	0.29
Pedestrian	1.33	1.51	0.4	0.83
All modes	8.44	9.00	8.98	11.03

Table 33. Work Trips Mode Split

Mode	Neotraditional, Transit or Mixed Neighborhood			Automobile, Suburban or Non-mixed Neighborhood		
	Queen Anne, Wallingford, Kirkland	Cervero	Friedman	King County	Cervero	Friedman
Drive-Alone	62.1%	66.8%	53%	72.4%	76.6%	83%
Transit	8.6%	9.7%	30%	7.4%	9.4%	4%
Pedestrian	12.7%	10.4%	4%	5.6%	3.7%	3%

of accessibility. Ewing concluded that having facilities and services internal to a neighborhood resulted in shorter automobile trips and fewer hours of travel. This matches the conclusion from the mixed-use neighborhood study in the sense that the mixed-use neighborhood respondents tended to have shorter automobile trips than those living in other parts of King County. Similar to the finding in the mixed-use neighborhood study, Ewing determined that daily trips per person remained fairly consistent for all communities.

Examination of trip generation rates is possible by comparing results from the mixed-use neighborhood study and the Friedman study. Table 31 compares daily trip rates per household.

In the mixed-use neighborhood study, the number of daily trips per household was similar for both the King County and the mixed land use areas. The Friedman study, in contrast, determined that the daily trip generation rate showed greater variability. For example, when looking at all modes, there were two more trips per day in suburban areas than in more mixed land use areas. The Friedman report concluded that these differences in daily trip rates were due to the urban design characteristics. The report also suggested that individuals living in areas with neotraditional design features had a somewhat lesser need to make trips. In contrast, the mixed-use neighborhood study found that all households, regardless of location, had a similar level of daily trip generation.

Table 32 includes work trip mode percentages from the mixed-use neighborhood study, from Friedman and from Cervero and Gorham's recent study that examined work trips from a number of neighborhood pairs in California (1995). One half of a pair was an older neighborhood developed around transit lines that also had gridded streets. The other half was a nearby newer, lower density, automobile-oriented neighborhood with a random street pattern. Table 32 includes work trip mode choice percentages averaged from seven neighborhood pairs in San Francisco.

While recognizing that the influence of the neotraditional neighborhoods may be greatest for non-work travel, in all three studies, those living in more mixed neighborhoods used the automobile less for work trips than those in suburban areas. The reason for this varied. In the mixed-use neighborhood study and the Cervero study, reduction in drive-alone percentages was due to greater levels of pedestrian work travel. The Friedman study showed a lower drive-alone percentage due to higher levels of transit ridership; Friedman noted that the neotraditional like neighborhoods in his study had good transit service available. In contrast, the quality of transit service in the Cervero study and the mixed-use neighborhood study was unknown; neither effort developed an indicator of transit service intensity. The effect of this was that changes in transit ridership could not be used as a discriminating characteristics in either analysis.

Another travel measure found in several reports was vehicles miles of travel (VMT). Holtzclaw studied several communities including, a standard suburban development consisting mostly of residential housing and urban mixed-use development. He found that annual VMT in a neotraditional like neighborhood was 50 percent of the suburban area. This was similar to the difference found in the mixed-use neighborhood study for all three neighborhoods using daily (instead of annual) VMT. McNally and Ryan, in a hypothetical analysis of street network, also concluded that daily VMT would higher in suburban areas (1992).

The conclusions from all studies matched those of the mixed-use neighborhood study in the sense that all found that areas with more mixed land use could be linked to lower aggregate levels of transportation activity. What varied among the studies was which travel characteristics changed. The mixed-use neighborhood study, the Cervero study, and the Friedman study, found that mixed-use neighborhoods with neotraditional characteristics showed lower levels of drive-alone automobile use. Each also found a corresponding increase in pedestrian levels, but only the Friedman study found notable changes in transit use between areas (perhaps due to good transit accessibility in San Francisco). Friedman and Cervero found that trip generation rates increased in less mixed land use areas, whereas the mixed-use neighborhood study determined that the trip generation rate remained constant across all locations. Ewing, in contrast to other studies, found that the mode choice varied somewhat due to increased levels of carpooling, but also found that vehicle hours of travel was the more significant measure.

the mixed-use neighborhood study and the Cervero study, reduction in drive-alone percentages was due to greater levels of pedestrian/work travel. The Friedman study showed a lower drive-alone percentage due to higher levels of transit ridership. Friedman noted that the neotraditional-like neighborhoods in the study had good transit service available. In contrast, the quality of transit service in the Cervero study and the mixed-use neighborhood study was unknown, neither effort developed an indicator of transit service intensity. The effect of this was that changes in transit ridership could not be used as a discriminating characteristic in either analysis.

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as a secondary. Ewing concluded that having facilities and services within a neighborhood resulted in shorter automobile trips and fewer hours of travel. This matches the conclusion from the mixed-use neighborhood study in the sense that the mixed-use neighborhood respondents tended to have shorter automobile trips than those living in other parts of King County. Similar to the finding in the mixed-use neighborhood study, Ewing determined that daily trips per person remained fairly consistent in all communities.

Comparisons of trip generation rates is possible by comparing results from the mixed-use neighborhood study and the Friedman report. Table 11 compares daily trip rates per household.

In the mixed-use neighborhood study, the number of daily trips per household was very similar in both King County and the mixed land use areas. The Friedman study, in contrast, determined that the daily trip generation rate showed greater variability. For example, when looking at all modes, there were two more trips per day in suburban areas than in more mixed land use areas. The Friedman report concluded that these differences in daily trip rates were due to the urban design characteristics. The report also suggested that individuals in the areas with neotraditional design features had a somewhat lesser need to make trips. In contrast, the mixed-use neighborhood study found that all residents, regardless of location, had a similar level of daily trip generation.

Table 12 includes work trip mode percentages from the mixed use neighborhood study, Friedman and from Cervero and Gorham's recent study, that examined work trips from a number of neighborhood pairs in California (1995). One half of a pair was an older neighborhood developed around transit lines that had gridded streets. The other half was a similar newer, lower density, automobile-oriented neighborhood with a random street pattern. Table 12 includes work trip mode choice percentages averaged from seven neighborhood pairs in San Francisco.

While recognizing that the influence on travel behavior of neighborhoods may be complex and not well understood, in all three studies, those living in more mixed neighborhoods used the automobile less for work trips than those in suburban areas. The reason for this varied. In

Chapter 6. Summary and Future Research

Report Summary

There are three major conclusions from this study. They are as follow:

1. The analysis supports the concept that mixed land use neighborhoods are associated with lower average daily miles of travel. This finding was based on the comparison of mixed-use neighborhood data with similar data from King County (for compatibility, only weekday trips of more than five minutes duration were compared). Throughout the analysis, individuals from the two mixed land use neighborhoods in Seattle (Queen Anne and Wallingford) traveled fewer miles per day than did the King County survey respondents. Except for some examples with low survey sample sizes, this situation occurred even after controlling for the effects of household size and income and occurred for both work and non-work travel.

As a means of reducing extraneous effects, this study compared the data from the two Seattle mixed-use neighborhoods with the survey data from the larger (north Seattle) area that includes these two neighborhoods. This procedure reduced concerns that the two mixed-use neighborhoods might have lower trip lengths than other King County areas simply because they were located close to a major employment area (Seattle's downtown). The mixed-use neighborhood respondents consistently had a lower average rate of daily travel than did the PSRC's survey respondents from north Seattle.

Other findings indicated that people living in mixed land use areas generally had different travel characteristics than did people in other portions of King County. The mixed-use neighborhood inhabitants had a greater number of complex, multi-stop chains than did those from other areas of King County, but the mixed-use chains were also shorter. This suggests that many trip destinations for the mixed-use area were closer by and more readily accessible.

One statistic demonstrated fairly concisely that many of the trip stops taken by the mixed-use inhabitants were close to home. About 17 percent of the mixed-use resident's trip stops were within a mile of home, but only 4.5 percent of King County residents' trip stops were. This large difference suggests the potential effect of having shopping opportunities and other destinations close to home. In part because of good accessibility, the Seattle mixed-use residents drove less and walked more than people in other areas in the county. These findings support the concept that people living in mixed land use areas have shorter trips and use a motor vehicle less.

The results from the analysis of the Kirkland neighborhood were interesting because this area represented a transition between a residentially oriented suburban neighborhood and a more traditional mixed land use neighborhood. Kirkland had the lowest density of the three study neighborhoods and the greatest dispersion of goods and services. The streets in the mixed-use neighborhoods in Seattle were in a grid pattern, whereas Kirkland's street pattern includes both a grid and a fair number of streets in the classic suburban cul-de-sac pattern. As a result of this transitional character, the Kirkland survey respondents' average daily mileage was typically more than the other mixed-use neighborhoods, and more than

PSRC's respondents living in the City of Seattle. Kirkland's travel statistics tended to be similar to those of people from the inner, and more suburban, zones in King County.

The daily travel mileage differences between the two data sets and various analysis zones were independent of the levels of trip generation. This research found that households of similar category tended to have the same number of trip stops and multi-purpose trips (chains) per day, no matter what their location. This indicates that travel demand and trip generation would be the same for both mixed and non-mixed land use neighborhoods. What differs between areas is the inhabitants' choice of mode and the length of their trips.

2. A household's accessibility to local providers of goods and services will influence the choice of modes. This study explored the shopping and personal trips of the mixed land use neighborhood respondents relative to their distance from local commercial streets. Examination of mode choice within the study neighborhoods demonstrated that individuals would frequently walk for shopping purposes when a household was within a few blocks of a commercial street. This rate of walking, however dropped off rapidly with increasing distance from the commercial street. To a lesser extent, this pattern of decreased walking as distance from commercial areas increases also held true for personal trips. These findings suggest that nearby shopping opportunities can generate a significant number of walk trips. The evidence also suggests that these and other walk trips may result in lower vehicle-miles traveled. Residents from the Queen Anne and Wallingford neighborhood drove 10 to 20 percent less than people from other parts of King County.

This study also looked at walk trips to transit stops for the Queen Anne and Wallingford neighborhoods. The analysis found that both transit users and non-users had nearly equal, and good, geographical access to transit stops. In addition, the residents from these two mixed-use neighborhoods did not have levels of transit ridership notably different from other areas in Seattle. These findings suggests that factors other than simple accessibility to transit stops influenced transit use by the mixed-use respondents.

3. Work trips, especially as part of chained trips, are an important element in daily travel patterns. In both the King County and mixed-use data, a significant number of all chains involved a work stop. During weekdays, over 40 percent of all daily weekday trip chains involved a work stop. In the PM peak period, over 50 percent of all trips had one work stop. The length of the work trip also showed a consistent relationship with the length of shopping and personal trips. If an individual had a long work trip, they also tended to have long shopping or personal trips, no matter what area they lived in. These results suggest that work trips and, by extension, work locations, are an important determinant of daily travel.

This influence of work location on daily travel patterns has important implications for the study of mixed land use areas. Existing neotraditional literature and research concentrate on household locations. However, it is possible that trips to and from work, trips made from work (such as lunch time errands), and non-work stops made during a commute, could negate some of the transportation advantages of households located in mixed-use areas. Future research on mixed land use areas should consider the effects of the work site and the work trip.

Future Activities

This empirical travel data set relating to travel in mixed-use neighborhoods offers many opportunities for future research. The data are unusually rich in detail since they include accurate data on the location of households and trip ends. Just a few of the many possible research topics that would increase understanding of the transportation and land use linkage include the following:

Additional Mixed-Use Survey Information. As a preface to the mixed-use survey, potential respondents were asked about attitudes toward traffic congestion, transit use, their occupation, the level of walk trips to work, and other questions. In this research, much of the information obtained was not correlated to an individual's actual travel patterns as determined by the travel diary. Relating a respondent's attitudes and stated transportation preferences to actual travel behavior would be useful. This process would measure the accuracy of individual's self-estimated transportation use and provide information on the relationship between attitudes and transportation behavior.

Another element of the Innovation Unit's mixed-use neighborhood project that was not used in this study was a neighborhood shoppers survey. This effort included interviews of passing pedestrians in the mixed-use neighborhoods about their trip purpose, modes, and destinations. Future use of this information would provide a clearer understanding of the nature of the three mixed-use study neighborhoods and would validate some of the findings in this report.

Daily Interdependency. A number of studies of travel and trip chain behavior have suggested that interdependency between days is an important factor in determining travel patterns (e.g., Thill and Thomas 1987). Since the mixed-use travel diary covers a two-day period, an analysis of interdependency between days is possible. Since the diary includes all members of a household who are at least 15 years old, relating travel patterns among members of a household may also be possible. This process may address issues such as gender-based travel roles within a household and levels of household-formed carpooling.

Walk and Bicycle Trips. The mixed-use data set is unique in that it contains accurate trip distances for short trips. This accuracy permits a detailed analysis of the nature of pedestrian and bicycle travel. Since each of these trips potentially could replace an automobile trip, why and where people walk and bicycle is relevant. One related issue is the socio-demographic characteristics of those who use these modes. Another broader question is the role of the pedestrian and bicyclist in a multi-purpose trip. For example, if people can walk to shop during a lunch break from work, are they more likely to use transit? Since the trip data from this study are contained in a GIS package, it is also possible to integrate other spatial data sets that contain information on factors that might influence walk and bike trips. Such information might include terrain data or sidewalk locations.

Work Locations. This report suggests that work trips play an important role in determining travel characteristics. Possibly due to data constraints, the existing studies concerning neotraditional neighborhoods concentrate on household location. As a means of exploring ramifications of this gap, a further analysis of the mixed-use data could look more closely at the location of work sites for each household. If trip stops could be linked, using accessibility measures, to work locations, instead of the home location, the relative importance of the work site could be quantified. If work sites were found to have a large influence on daily travel patterns, this would have some important implications for the neotraditional concept.

Non-workers. A number of the mixed-use survey respondents did not have a work trip in their day. This was either because they were retired or unemployed, worked at home, or had a day off. Since the mixed-use data set included some weekends, there were a number of surveys with non-work days. Comparing the travel patterns of those with work trips to those without would provide important information on both groups. Information from this analysis would be of interest to researchers studying telecommuting and home offices.

Intra-Neighborhood Work Trips. Approximately ten percent of the mixed-use neighborhood survey respondents had work locations in their neighborhoods. Since the commute to work is major contributor to urban congestion, the workers who had these short commutes may be of particular interest. Analysis of these short trips in the mixed-use data would provide information such as the mode used for short trips and the type of employment.

Transit Stop Access. This study explored walk trips to bus stops. However, the analysis was limited to straight-line accessing to the nearest stop, regardless of the service provided at that stop. A better understanding of transit ridership and transit useability could be obtained if all trips in the mixed-use data set were matched with the nearest route serving that trip. This would provide an indicator of the ability of transit to serve the inhabitant in the mixed-use neighborhoods. Another improvement of this analysis would replace straight-line distance with walk path information. This would provide a more accurate indication of the distance individuals would be willing to travel to use transit.

Mixed Land Use Areas in the PSRC Data Set. This study frequently compared the mixed-use data to the PSRC's Panel Survey data for

King County. Since the King County data covered a large area, it is probable that some of the respondent's households were in areas that had land use that was as diverse as that of areas selected for the mixed-use neighborhoods. Use of parcel information, model zone data, employment information, and other sources of data to obtain land use information may permit identification of other mixed-use areas in King County. More concise research results then could be obtained by determining which of the King County survey households were in areas that also qualified as mixed land use.

Trip Chaining. The majority of trips in the mixed-use data sets involved trip chaining. The mixed-use data contain detailed information on trip purpose, trip stop locations, and socio-economic data on the trip maker. This information provides a foundation for research that would contribute to the general understanding of chaining behavior. The findings in this study also suggest that mixed-use respondents have different chaining patterns than do the King County residents. Further exploration of this issue could contribute to the exploration of the difference between neotraditional and suburban neighborhoods.

Comparison with Other Sources of Travel Data. This study was limited to a comparison of the mixed-use data with the first wave of PSRC's panel survey data. The use of number of other data sources would expand the scope of the analysis and would result in a better understanding of the transportation characteristics of mixed-use neighborhoods. Other sources that might be of interest include the Census Bureau's Urban Transportation Planning Package (UTPP) and the PUMS data and results from the Nationwide Personal Transportation Survey.

Short Trips. The data set used in this survey is unique because trip starts and ends are accurately located. This situation, combined with the ability to calculate shortest paths on the TIGER network, permits an accurate analysis of the short trips. Probably because of a lack of good data, these trips have typically been ignored in many urban travel analysis processes. Examination of the short trip in the mixed-use neighborhood may provide insight into little-examined areas, such as walk trip to transit stops, the role of short trip as connector in trip chains, and extremely short automobile trips (such as a trip to the corner store for milk). Short trips in motor vehicles are of particular interest for air pollution analysis because of emissions due to cold starts.

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Appendix A:
Variables in the Mixed-Use Data Files

Variable Name	Value	Description
LINENBR		survey form line number
HHID		survey form household ID
PERID		survey form person ID
CENSUSFR		trip from census tract
TAZFR		trip from traffic analysis zone (TAZ)
CENSUSTO		trip to census tract
TAZTO		trip to traffic analysis zone (TAZ)
TRAVTIME		travel time in minutes (TAZ to TAZ)
TRAVDIST		travel distance (TAZ to TAZ)
PURPOSE		trip purpose
	0	missing
	1	work
	2	work-related business
	3	shopping
	4	professional service
	5	family/personal business
	6	school
	7	college
	8	church
	9	visit friends
	10	pleasure trip
	11	other social/recreation
	12	home
	13	eating/drinking
	14	work related appointment
	15	personal service appointment
STARTHR		start time - hour
STARTMN		start time - minute
ARRVHR		arrive time - hour
ARRVMN		arrive time - minute
MODE		travel mode
	0	missing
	1	car, truck, van
	2	vanpool
	3	carpool
	4	bus
	5	para-transit
	6	taxi
	7	walk

	8	bike
	9	motorcycle
	10	school bus
	11	ferry/car
	12	ferry/foot
	13	monorail
	14	boat
	15	train
	16	airplane
DRIVER		respondent trip status
	D	driver
	R	rider
	U	neither
DAY		survey day (first or second day)
DUR		trip duration in minutes
SERVE		walk trip to or from transit stop index
BOUND		trip stop in or out of study boundary
STAY		trip stop duration (-99 = end of trip)
RIDESHR		over count trip index
SHRTPATH		shortest path distance in miles
SUPERFR		trip from PSRC super zone
SUPERTO		trip to PSRC super zone
DIST1		census tract to census tract distance in miles
DIST2		revised census tract to census tract distance in miles
RINGFR		from analysis zone
	0	missing
	1	Seattle CBD
	2	north Seattle
	3	south Seattle
	4	inner zone
	5	outer zone
	9	outside King County
RINGTO		to analysis zone
	0	missing
	1	Seattle CBD
	2	north Seattle
	3	south Seattle
	4	inner zone
	5	outer zone
	9	outside King County
CTSHORT		census tract to census tract shortest distance

		in miles
AGE15PS		persons in household 15 or older
NUMVEH		number of vehicles in household
NUMBIKE		number of bicycles in household
HHSIZE		number of people in household
TOTADULT		number of adults in household-
TOT6_17		number people age 6 to 17 in household
TOT1_5		number people age 1 to 5 in household
TOT_LOG		total number of survey respondents in household
INCOME		annual household income
	1	less than $35,000
	2	more than $35,000
	3	don't know
	4	refused
SEX		
	1	male
	2	female
AGE		
	99	refused
AGE_GP		age group
	1	15-17
	2	18-24
	3	25-34
	4	35-44
	5	45-54
	6	55-64
	7	65-98
	8	refused
EMPLOYMT		respondent's employment status
	1	employed
	2	student
	3	neither
BUSPASS		own bus pass
	1	yes
	2	no
LICENSE		own drivers license
	1	yes
	2	no
PSRC		weekday or weekend data adjustment
	0	survey day on weekend
	1	survey day on weekday

MIXEDKEY		Kirkland land use index (not used)
	0	less mixed use
	1	more mixed use
	2	more mixed use
HHTYPE		household category
	1	any child(ren) < 6 years
	2	child(ren) 6 - 17 years
	3	1 adult < 35 years
	4	1 adult 35 - 64 years
	5	1 adult 65+ years
	6	2+ adults < 35 years
	7	2+ adults 35 - 64 years
	8	2+ adults 65+ years
TRUEDIST		aggregated short path distance in miles
CITY_ID		mixed use neighborhood ID
	1	Queen Anne
	2	Wallingford
	3	Kirkland
HH_BLOCK		household census block ID
HH_TAZ		household TAZ ID
COMMERCI		straight line distance in miles to nearest commercial street
TRANSIT		straight line distance in miles to nearest transit stop
TAZ_FROM		trip from TAZ index
	0	outside mixed use neighborhood
	1	inside mixed use neighborhood
TAZ_TO		trip to TAZ index
	0	outside mixed use neighborhood
	1	inside mixed use neighborhood
VMT_CNT		over counted VMT index
	0	rider (share)
	1	driver
	2	rider (no share)
	3	neither
	4	rider (share ride within 5 minute)
	5	rider (share ride within 10 minute)
DAYOFWK		day of week
	1	Monday
	2	Tuesday
	3	Wednesday
	4	Thursday

	5	Friday
	6	Saturday
	7	Sunday
N_MODE		adjustment index for trip mode for analysis
	1	automobile
	2	bus/transit
	3	walk
	4	bike
	5	others
N_PURPOS		adjustment index for trip purpose for analysis
	1	work
	2	shop
	3	school
	4	personal
	5	appointment
	6	home
	7	others
N_HHTYPE		adjustment index for household type for analysis
	1	with child
	2	one adult
	3	two adults
	4	senior
	5	others

Appendix B. Geocoding Process

This appendix discusses the technical details of the geocoding of the mixed-use neighborhood survey data. Geocoding assigned latitude and longitude to the address, street intersection, and landmarks provided by survey respondents.

Address Geocoding

Initially, the addresses were automatically geocoded on a street segment using the address matching procedures contained in commercial GIS software. This resulted in successful assignment of a latitude and longitude to approximately 80 percent of the unique addresses in the data set. The remaining addresses could not be geocoded automatically for several reasons:

- Duplicate streets within a county. There is more than one address within the King County TIGER file corresponding to 210 Main Street. This problem would not have occurred if the scale of the study area had been confined to one city, or if the software had had the capability to match both address and city locations.
- Incomplete or missing street address ranges in the TIGER file. A number of the addresses were correct, but could not be found within the TIGER file. This problem was attributable to one of two factors: (1) incomplete address range coding in the TIGER file; or, (2) extension of a street and the corresponding address ranges after the latest update of the TIGER file.
- The street was not found in TIGER. This situation was typically caused by the construction of new streets after the TIGER file had been coded or, less frequently, by coding errors in the TIGER file.
- Misspelled or mis-coded street names. For example, McGraw St. was acceptable, but Mc Graw St. was not.
- Problems with street directionals. The address matching procedure in the GIS software required directionals. 1st Avenue could not be geocoded, but 1st Avenue South could. There were also interpretation problems involving the directionals. The GIS software, for example, interpreted South America Street as S. America Street.
- Multiple street names. Aurora Avenue is also known as Highway 99 and as Pacific Highway. Although TIGER has an alternative street name file, it was not used by the GIS software.
- Addresses were out of the study area.
- Coding and typing errors.

A few addresses could be automatically geocoded after some simple error corrections. Working through the respondent database and fixing obvious spelling errors resulted in a few more geocoding hits.

The remaining, uncoded addresses required manual coding. A researcher used paper maps, the GIS software, and some detective work to manually assign each address to the nearest intersection. Since the intersection of street segments within TIGER was a point or node in the GIS software, it was easy to assign each address to an intersection. Each point corresponded to an intersection with a latitude and longitude that could in turn be assigned to the address.

Intersection Geocoding

Approximately one quarter of the locations listed by the survey respondents were intersections. A search for commercial software that would automatically match large numbers of intersections was unsuccessful. Because the number of intersections was relatively large, an in-house program was developed to automatically geocode intersections.

The resulting intersection matching program used both the Census' TIGER segment and node files and our survey respondent data set as input. The first step in developing the program was to assign a unique node ID to the longitude and latitude coordinates pairs that defined each street segment in the TIGER line file. Next, a street segment file, derived from the TIGER file, was created. The two node IDs for each segment (one for each end) and the street segment ID were then linked. This resulted in a database association between each TIGER street segment and a pair of intersection coordinates. Because each street is typically composed of many intersection-to-intersection segments, the next step was to generate a node-street name file containing all unique street names, followed by all related node IDs for that street.

The node-street name file was accessed by another program, which attempted to determine whether two streets intersected. If they did intersect, then they would have a common node ID (as found in the node ID list).

The intersection geocoding process automatically compared each intersection listed by a respondent in the survey data set to the node-street name file. If the respondent data set of input streets matched those in the node-street name file, then the nodes associated with these streets were placed in an array. Each intersection in the data set was compared. As streets were found, another node-array was built. Then a comparison was made with one node-array against the other. All matched nodes (as found by in each node-arrays) were downloaded. Those nodes corresponded to the intersections of the two streets listed by the survey respondent. If more than one pair of matched nodes were found the match was considered unsuccessful.

The intersection-matching program was effective in assigning latitude and longitude to over half of the intersections. The program's failure to geocode the other half of the intersections was attributed to several factors, listed below:

- Ambiguous input. This was the most common reason for a non-match. If a survey respondent listed an intersection as 8th St. and 148th Ave, this intersection could be at several locations (for example, SE 8th St. and SE 148th Ave.), or at NE 8th St. and NE 148th Ave). A handful of respondents provided even less information. One, for example, noted that he or she started a trip at the intersection of 6th and 20th. In King County, (which has 99,000 street segments) this corresponds to eight possible locations. As with addresses, the ability to concurrently match cities would probably have increased the number of successful matches.

- Uncertain street locations. A number of survey respondents listed the approximate block area rather than two intersecting streets. For example, they may have listed 3rd Ave and 4th Ave to indicate they were between 3rd and 4th Avenues. Unfortunately, such listings are not enough information to locate these origins/destinations automatically or manually.

- Intersections at offset streets. Occasionally, two intersecting streets were slightly offset, resulting in two separate nodes that functionally represented one intersection. (For drivers, this is the situation wherein you do not proceed straight through an intersection, but take a jog to the right or left to continue traveling in the same general direction.) This was especially common at the junction of two different gridded street networks. Since the in-house intersection matching program eliminated all duplicate matches, this situation resulted in a number of non-matches. A post-processor program was developed to take advantage of the fact that two matched, but rejected, intersections only a few hundred feet apart were probably offset. The post-process compared all intersection matches that were in pairs. If any pair was less than a one-tenth of a mile part (based on their latitude and longitude) one of the pair was randomly accepted as the geocoded intersection.

• Coding and typing errors.

As with the addresses, the intersections that could not be geocoded required manual coding.

Geocoding Landmarks

Landmarks could not be automatically coded and had to be a located manually. Creation of a landmark master list simplified the manual coding process. Many major landmarks were locations, such as universities, shopping malls, and airports; and as such, they appeared multiple times under multiple names in the survey database. For example, one shopping center was listed as Northgate Mall, Northgate Shopping Center, Northgate Shopping Mall, etc. Despite the multiple names, it was possible for the coder to refer to the master list under Northgate and to assign a latitude and longitude accordingly.

Table 1 presents the results of the geocoding process for addresses, intersection and landmarks.

Table 1. Geocoding Results

	Queen Anne	Wallingford	Kirkland	Total
All Locations				
Total	6,747	6,113	5,768	18,628
Unique locations	2,437	2,274	2,058	6,769
Addresses				
Total	3,803	4,243	4,585	12,631
Unique	1,521	1,239	1,433	4,193
Auto-Matched	1,235	1,007	825	3,067
Not Matched	286	232	608	1126
Auto-Matched	81.2%	81.3%	57.6%	72.8%
Intersections				
Total	1,431	1,584	867	3,882
Unique	827	928	555	2,310
Auto-Matched	548	522	243	1,313
Not Matched	279	406	298	983
Auto-Matched	66.3%	56.3%	43.8%	57.3%
Places				
Total	223	286	316	825
Unique	89	107	101	297
Not matched	89	107	101	297
Auto-Matched	0.0%	0.0%	0.0%	0.0%
All Data				
Not matched (Auto or manually)	210 (3.1%)	178 (2.9%)	179 (3.1%)	567 (3.0%)
Matched	96.9%	97.9%	96.9%	97.0%

Appendix C:

Variables in the PSRC Panel Survey Data Files

Variable Name	Value	Description
HHID		survey form household ID
PERS		survey form person ID
DIARY		survey day (first or second day)
DAYOFWK		day of week
	1	Sunday
	2	Monday
	3	Tuesday
	4	Wednesday
	5	Thursday
	6	Friday
	7	Saturday
MDD		Month / Day
TOTTRIP		total number of trips by person per day
TRIPNUM		trip number
PURPOSE		trip purpose
	1	work
	2	shopping
	3	school
	4	visiting
	5	free-time
	6	personal
	7	appointment
	8	home
	9	college
TYPE		trip type
	1	home-based work
	2	home based other
	3	non-home-based
MODE		trip mode
	0	missing
	1	car
	2	carpool
	3	vanpool
	4	bus
	5	para-transit
	6	taxi
	7	walk
	8	bike
	9	motorcycle

	10	school bus
	11	ferry/car
	12	ferry/foot
	13	monorail
	14	boat
	15	train
	16	airplane
BEGTIME		travel begin time
ENDTIME		travel end time
D_R		respondent trip status
	1	driver
	2	rider
	3	N/A
NUM		number of people in this trip
REL1		1st person related to respondent
REL2		2nd person related to respondent
REL3		3rd person related to respondent
ORIGCT		origin census tract ID
DISTCT		destination census tract ID
STOP_FR		trip stop in chain that is from
	0	other
	1	home
	2	work
	3	way to work
	4	way to home
STOP_TO		trip stop in chain that is to
	0	other
	1	home
	2	work
	3	way to work
	4	way to home
STAY_DUR		stay duration
DISTANCE		census tract to census tract travel distance in miles
RING_FR		trip from analysis zone
	1	Seattle CBD
	2	North Seattle
	3	South Seattle
	4	Inner
	5	Outer
	9	outside King County
RING_TO		trip to analysis zone

	1	Seattle CBD
	2	North Seattle
	3	South Seattle
	4	Inner
	5	Outer
	9	outside King County
RINGHOME		household location in analysis zone
	1	Seattle CBD
	2	North Seattle
	3	South Seattle
	4	Inner
	5	Outer
	9	outside King County
COUNTY		county index
	1	King County
	2	Snohomish County
	3	Pierce County
	4	Kitsap County
	x	unmatched
SAMPLE		sample category
	1	SOV
	2	transit
	3	carpool
	4	unmatched
RECRUIT		
	R	random direct dailing
	B	blank
	T	transit over sampling
	U	unmatched
DIST2		revised census tract to census tract distance in miles
CTSHORT		census tract to census tract shortest path distance in miles
HHSIZE		number of people in household
TOTADULT		number of adults in household-
TOT6_17		number people age 6 to 17 in household
TOT1_5		number people age 1 to 5 in household
TOT_LOG		total number of survey respondents in household
NUMVEH		number of vehicles in household
BUS_DIST		
HHTYPE		household category

	1	any child(ren) < 6
	2	all child(ren) 6 - 17
	3	1 adult < 35 years
	4	1 adult 35 - 64 years
	5	1 adult 65+ years
	6	2+ adults < 35 years
	7	2+ adults 35 - 64 years
	8	2+ adults 65+ years
NEW35K		household annual income
	0	less than $35K
	1	more than $35K
NEW30K		household annual income
	0	less than $30K
	1	more than $30K
CENSUS_T		household census tract
INCOME		household annual income
SEX		
	1	male
	2	female
AGE		
AGE_GP		age group
	1	15 - 17
	2	18 - 24
	3	25 - 34
	4	35 - 44
	5	45 - 54
	6	55 -64
	7	65 - 98
	8	refused
EMPLOY		respondent's employment status
	1	yes
	2	no
	3	DK/refused
OCC		occupation
WK_CITY		city code for work place
WK_FREQ		number of days per week respondent works
WK_MOD1		travel mode to/from work
WK_MOD2		travel mode to/from work
WK_MOD3		travel mode to/from work
WK_MOD4		travel mode to/from work
WK_NUM		drive to work alone or with others
WK_BUS		regularly take bus in past 6 month (Y/N)

WK_POOL		regularly pooled in past 6 month (Y/N)
CAR_REQD		car required at work (Y/N)
CAR_CHLD		car required to pick up children (Y/N)
CAR_FREQ		frequency children are picked up
STUDENT		currently attend school
	1	yes
	2	no
	3	DK/refused
SCHOOL		school code
SCH_CITY		city code where school is located
SCH_MOD1		travel mode to/from school
SCH_MOD2		travel mode to/from school
SCH_MOD3		travel mode to/from school
SCH_MOD4		travel mode to/from school
SCH_NUM		drive to school alone or with others
BUS_FREQ		frequency using bus per week
BUSPASS		own transit pass (Y/N)
LICENSE		own valid driver's license (Y/N)
CHAIN		trip chain ID
LINK		link ID of trip chain
N_MODE		revised index for trip mode for analysis
	1	automobile
	2	bus/transit
	3	walk
	4	bike
	5	others
N_PURPOS		revised index for trip purpose for analysis
	1	work
	2	shop
	3	school
	4	personal
	5	appointment
	6	home
	7	others
N_HHTYPE		revised index for household type for analysis
	1	with child(ren)
	2	one adult
	3	two adults
	4	senior
	5	others
VMTVALID		over counted VMT index

	0	rider (share)
	1	driver
	2	rider (no share)
	3	neither
	4	rider (share within 5 minutes)
	5	rider (share within 10 minutes)

Appendix D. Accuracy of Short Distance Calculations

As a check of short distances in the mixed-use and PSRC data sets, the transportation model network-generated trip distances were compared to distances obtained using a GIS's shortest path function operating on the King County TIGER network. The analysis was applied to a selected set number of the mixed-use neighborhood trips. The research found that the model trip assignment based distances overestimated travel distances for intra-neighborhood trips.

Shortest Test Methodology

The methodology used for this analysis involved isolating a number of shorter intra-neighborhood trips from the mixed-use neighborhood travel diary data set. Each trip's travel distance was calculated by three methods: (1) a simple straight-line distance, (2) distance output from the trip assignment step of the PSRC model, and (3) the shortest street network travel path as calculated by the GIS package TransCAD on a TIGER network. These three distances were then compared.

Study Area and Trip Selection

The Kirkland and Queen Anne neighborhoods were selected for the exploration of short trips. The Queen Anne neighborhood contained streets in a more traditional grid system, whereas the Kirkland neighborhood had larger irregular blocks and a number of developer inspired loops, dead ends, and cul-de-sacs.

The GIS software was used to isolate a set of origin and destination points contained within each study neighborhood. The resulting Queen Anne study area included 1485 intra-neighborhood trips. The Kirkland study area was larger, but contained 1,011 trips.

Types of Distances

Three methods were used to calculate trip distances. The first was the straight-line distance between each trip origin and destination. This distance was easily calculated within the GIS software and was used as measurement of the absolute minimum distance for any trip. This distance served as a check on the other distance calculations — no trip distance could be less than the straight-line distance.

The PSRC distance was based on travel distance as output from the PSRC transportation model. Concern about the inaccuracies of modeling short travel distances that prompted this examination of short trips could primarily be attributed to the nature of the PSRC model network and zones. Because of the zone structure, any trip that traveled entirely within a zone (functionally from a centroid to the same centroid) was not placed on the model network. Instead, an intra-zonal travel distance was assumed. For the PSRC, this intra-zonal distance was calculated by determining the distance between a zone centroid and the closest neighboring centroid and multiplying that distance by 0.7. The resulting intra-zonal distance was assigned to any trip that did not leave a zone.

Centroid access distance for each zone was built into the model network.

The shortest path was based on travel distance calculated on a TIGER-derived street network using a GIS software procedure. This represents the most efficient travel path and did not account for link speed or congestion. However, for short trips, the shortest path should match an individual's travel patterns. Short trip makers should not divert to higher capacity facilities such as freeways; so their travel pattern should be effectively that of the minimum distance following the street network.

Distance Calculation

The next step required the actual calculation of the distances for the trips in the selected data sets. Since each of the trips was stored in a GIS, it was relatively simple to have the software calculate straight-line distance between the origin and destination locations.

The calculation of the PSRC distance was completed by using a using a model derived TAZ (traffic analysis zone) travel distance matrix supplied by the PSRC. This 530 by 530 TAZ to TAZ matrix contained trip assignment distance between each TAZ in the Puget Sound region. Trips along the diagonal of this matrix (intra-zonal) were calculated based on distance between zonal centriods (as discussed above). In order to use this matrix, the origin and destination points of each the neighborhood trips were assigned to a TAZ. The GIS's point-in-areas function was used for this process. Once each trip had been tagged with a start and finish TAZ, an in-house program was applied. This program referred to the proper row and column of the TAZ to TAZ matrix and selected the intersecting cell with a travel distance.

The most difficult distance to calculate was the shortest path, mainly due the large size of the shortest path files and the limitations of the GIS software. Since shortest path distances could only be calculated on a TIGER line layer, the process initially required tagging each trip origin and destination with the ID number of the nearest TIGER intersection. The GIS software was then used to develop a many-to-many shortest path table. These resulting distance matrices were large (15-25 megabytes) because they contained shortest path travel distance for all TIGER intersections in the study areas. While the trips and distances of interest for this research represented only a small portion of the trips in the matrix, restrictions of the GIS package required this gross approach. An in-house program was developed to extract the shortest path distance between each TIGER intersection that was tagged by a trip origin and destination. These distances were then assigned to each of the selected trips used for this study.

Since the shortest path procedure was based on intersection-to-intersection distances, there was some possibility of inaccuracy. This was because most origin and destination points would not be exactly at an intersection. However, the errors should be small because of the large number of TIGER intersection points, both for actual street intersections and shape points, in the two study areas. Any origin/destination point would not be far from an intersection.

Results

Each of the three distance calculations for the study neighborhoods was loaded in to a statistics package and compared. The results are shown in tables 1 and 2. As expected, the average distance as calculated by the straight-line distance was shorter than the other two methods. These straight-line values were the unrealistic minimal travel distance (as the crow flies) for each trip. For Queen Anne, the average straight-line travel distance was 0.25 miles while for Kirkland the distance was 0.48. The greater distance for Kirkland indicated the larger extent of the study area. The maximum values in the tables indicated that the selected data did an adequate job of capturing only the shorter trips. No trip made by a respondent in Queen Anne neighborhood ended more than a linear mile from the start of their trip. For Kirkland, again reflecting the large study area, this distance was slightly more than two miles.

For both neighborhoods, the shortest TIGER path distances were less than the PSRC distances. However, this difference was considerably greater for the Kirkland than for Queen Anne. The PSRC distance was greater than the shortest path distance by an average of 0.19 mile for Queen Anne whereas this difference was 1.7 miles for Kirkland.

One factor that may have contributed to the larger Kirkland difference was zone size. Kirkland's census tracts and, thus, the PSRC modeling zone are larger than those in the Queen Anne neighborhood. This results in larger intra-zonal travel distance and the greater possibility for inaccuracy in Kirkland.

Table 1. Queen Anne Travel Distance Analysis

	Straight Line Distance	PSRC Model Distance	Shortest Path Distance	Difference (PSRC - Shortest)
Mean	0.25	0.97	0.78	0.19
Minimum	0.00	0.70	0.22	-0.79
Maximum	0.91	2.60	1.89	2.29
Sum	352.19	1344.60	1081.44	
Standard Deviation	0.17	0.28	0.24	0.33

n = 1385

Table 2. Kirkland Travel Distance Analysis

	Straight Line Distance	PSRC Model Distance	Shortest Path Distance	Difference (PSRC - Shortest)
Mean	0.48	2.29	0.59	1.70
Minimum	0.00	1.00	0.00	-0.27
Maximum	2.09	5.00	2.53	4.34
Sum	487.71	2310.60	594.14	
Standard Deviation	0.36	1.40	0.44	1.27

n = 1101

About the Innovations Unit

The Innovations Unit is an advisory group to the Washington State Transportation Commission that conducts technology and policy research on emerging transportation developments and opportunities in Washington State. The goals of the Innovations Unit are to

- provide long-range program development support to the Transportation Commission,
- generate unfiltered visions of a wide range of future short-term and long-term transportation technology and policy options, and
- establish a research methodology that fosters development of innovative transportation concepts.

The Innovations Unit has three objectives representing successively more detailed and focused studies:

Objective 1. Monitor emerging technologies and strategies. Compile and synthesize up-to-date information about emerging and innovative transportation technologies, strategies, and policies.

Objective 2. Research selected topics of Commission interest. Conduct detailed background research of specific technology and policy issues, under the direction of the Commission's Policy Development Subcommittee. Produce a series of white papers outlining technology and policy implications germane to the Washington State transportation system.

Objective 3. Support in-depth technology and policy research. Conduct and/or coordinate detailed research of key enabling technologies, strategies, and policies.

The research activities of the Innovations Unit emphasize early, preparatory studies of emerging potential transportation solutions, and include interaction with elected officials, public agencies, university researchers, the private sector, and members of the public. Its activities are intended to complement and support in-depth applied research and implementation by the Washington State Department of Transportation (WSDOT) through its Research Office, and reinforce ongoing State Transportation Policy Plan activities.