AN ANALYSIS OF RELATIONSHIPS BETWEEN URBAN FORM (Density, Mix, and Jobs: Housing Balance) AND TRAVEL BEHAVIOR (Mode Choice, Trip Generation, Trip Length, and Travel Time)

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16. ABSTRACT

This project is part of a research agenda to discover ways to plan and implement urban forms that reduce dependence on the single occupancy vehicle (SOV). The purpose of this project was to empirically test the relationship between land use density, mix, jobs-housing balance, and travel behavior at the census tract level for two trip purposes: work and shopping. This project provides input into policies at the national, state, and local level targeted at the reduction of SOV travel and for urban form policies.

This research employed a correlational research design in which urban form (e.g. density) and travel behavior (e.g., mode choice) relationships were analyzed while controlling for non-urban form factors (e.g., demographics). Data for travel behavior variables (modal choice, trip generation, trip distance, and travel time) were obtained from the Puget Sound Transportation Panel. Data for the urban form variables employment density, population density, mix, and jobs-housing balance were obtained from the U. S. Census Bureau, the Washington State Employment Security Department, and the King County Assessor's Office. The databases developed for this study were composed of these data sources, matched together by one common variable: the census tract. The databases were structured around two separate units of analysis: the trip and the tract. Relationships between urban form and modal choice were analyzed at the tract level, while urban form relationships with trip generation, distance, and travel time were analyzed at the trip level.

Simple statistical analytical methods were used to identify relationships between urban form and travel behavior variables, including T-tests, linear correlation, partial correlation, multiple regression, and cross-tabulation. Findings from the application of these methods indicated that employment density, population density, and land-use mix were negatively correlated with SOV usage and postively correlated with transit usage and walking for both work and shopping trips. Employment density, population density, and land-use mix were negatively corrrelated with trip distance and positively correlated with trip generation for work trips. Travel time was positively correlated with employment density and negatively correlated with mixing of uses for work trips. The jobs-housing balance was negatively correlated with trip distance and travel time for work trips. Transit, walking, and SOV usage were found to have non-linear relationships with population and employment density for both work and shopping trips. An analysis of density thresholds was conducted to identify levels of population and employment density, where significant decreases in SOV travel and increases in transit and walking occurred.

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by

Lawrence D. Frank, Ph.D.
Office of Urban Mobility
Washington State Department
of Transportation

Washington State Transportation Center (TRAC)
University of Washington, JD-10
University District Building
1107 NE 45th Street, Suite 535
Seattle, Washington 98105-4631

Washington State Department of Transportation
Technical Monitor
Charles E. Howard, Jr.
Manager, Planning Office

Prepared for

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CHAPTER I

PROJECT PURPOSE AND RESEARCH APPROACH

INTRODUCTION

The purpose of this project was to empirically test the relationship between urban form and travel behavior at the census tract scale.

This project is part of a research agenda developed by the University of Washington for the Washington State Department of Transportation (WSDOT) (Pivo and Moudon, 1992). The purpose of the agenda is to discover ways to plan and implement urban forms that promote increased accessibility. At the crux of this agenda are the goals to decrease the need to travel, reduce dependence on the single occupant vehicle (SOV), and enhance the competitiveness of other travel modes.

During the development of the research agenda, policy makers and specialists stated that increasing the mobility of single occupant vehicles was no longer a feasible way to maintain people's access to opportunities in urban areas. These experts cited economic factors, new environmental legislation, public opposition, changing demographics, and political pressure to reduce fuel consumption as the primary reasons.

The research agenda has three elements:

1. physical relationships between urban forms and travel behavior,
2. public policies that can implement new urban forms, and
3. market factors that promote and inhibit the development of new urban forms.

This project was a study of the impacts of urban form on travel behavior and related to the first part of the agenda.

Urban form refers to spatial characteristics of the urban environment. It can be measured in terms of a variety of factors, such as density, land-use mix, presence or absence of pedestrian amenities, magnitude or scale, site design, or street network patterns.

Several urban form strategies have been recommended to reduce people's dependence on driving alone. These strategies include increasing residential and employment densities and mixing a variety of land uses (residential, employment, and commercial). While these strategies seem intuitively appropriate, relatively little work has been conducted to empirically test these relationships. That was the purpose of this project.

STRUCTURE OF ANALYSIS

The chapters in this report are structured around the following:

- a review of policies, literature, hypotheses and theories that attempt to explain aspects of the relationship between urban form and travel behavior,
- the process of developing a database to test selected hypothetical relationships, and
- documentation of the findings from an analysis of this database.

These three areas represent the spine of this project. More specifically, each of the eleven sections in the research approach presented in Table 1.1 has been developed into a chapter in this report.

Table 1.1. Research Approach

PHASE I: Background
purpose and research approach
relationship with policy objectives
review of empirical research efforts
theoretical basis for research
research methods used for hypothesis testing

PHASE II: Data
database development

PHASE III: Results
descriptive statistics
analysis of mode choice
density thresholds associated with mode choice
analysis of trip generation, trip distance, and travel time
implications on theory, practice, and future research

This project was conducted in three phases. In Phase I, information was gathered from other sources, allowing hypothetical relationships between urban form and travel behavior to be identified on the basis of theory, past research findings, and current policies. In Phase II, a database was created to provide a basis for empirically testing these hypothetical relationships. In Phase III, statistical techniques were used to conduct hypothesis testing. A summary of the implications of the findings on theory, practice, and future research is presented in Chapter 11.

RESEARCH DESIGN

Figure 1.1 is a conceptual model of the relationship between travel behavior and the factors that affect it. This conceptual model illustrates the significant impact that both urban form factors (i.e., density and land-use mix) and non-urban form factors (i.e., income, gender, age, and level of service) have on travel behavior. In this study, urban form factors were the focus, and non-urban form factors were used as control variables in recognition of their significance. For example, when the impacts of density on mode choice were tested, it was critical to account for the socio-economic characteristics of the trip maker. This enabled comparisons to be made between trip makers with similar socio-economic characteristics, which canceled the impact of these factors on travel choices and allowed the impacts of urban form factors to emerge.

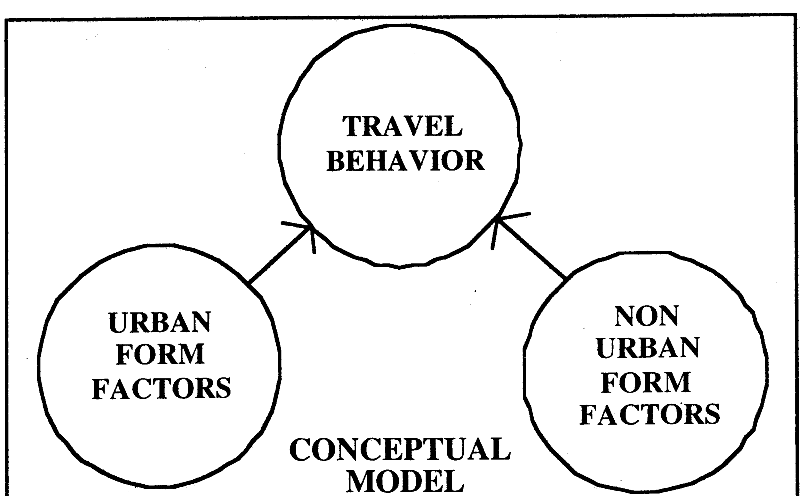

Figure 1.1. Conceptual Model

This project utilized a correlational research design in which the relationships between urban form as the dependent variable and travel behavior as the independent variable were analyzed (Babbie 1989). This research design was "cross sectional" and did not offer the ability to identify whether variation in the dependent phenomenon (e.g., modal choice) was a direct reaction to variation in the independent phenomenon (e.g., population density). Therefore, the study could not truly document causality. The primary constraint preventing identification of causality was temporal. In a cross-sectional research design a pre-test cannot be conducted; therefore, the temporal sequence of cause and effect cannot be longitudinally isolated in an experimental design.

There were two units of analysis in this research, the trip and the census tract. Where the trip was the unit of analysis, each trip end (origin and destination) was assigned values for land-use density, mix, and jobs-housing balance associated with the origin and destination census tracts. For example, a trip ending in a densely populated census tract would have been assigned a value based on the population density within that census tract. In addition, demographic factors associated with the "trip maker" were assigned to each trip. For each trip, additional information, such as income, gender, and age of the traveler, was identified. Per capita trip generation, trip distance, and travel time were the dependent travel behavior phenomena analyzed at the trip level.

The census tract was also used as a unit of analysis where travel behavior and demographic characteristics were aggregated to the census tract level. This aggregation allowed the researchers to analyze modal choice as a dependent phenomenon by calculating the proportion of trips per mode that originated and ended in each census tract.

Data used for this project were obtained from a variety of sources. This project utilized data on household travel behavior and demographics (control variables) from the Puget Sound Transportation Panel (PSTP). Data on land-use density were obtained from the 1990 Census and the Washington State Employment Security Department (ESD). Data on land-use mix were obtained from the King County Building and Land Use (BALD) Database. Data on travel behavior, land-use density, and land-use mix were all coded to the census tract, allowing use of the correlational research design described above. More specifically, census tracts with different levels of land-use density, mix, and jobs-housing balance could be compared to one another to test for differences in travel behavior.

Scale of the Analysis

As discussed in the Agenda For Research on Urban Form and Travel Behavior (Pivo and Moudon, 1992), various scales of urban form should be studied for their affect on travel behavior. Regional, district, and site level urban form are probably all important in different ways. This study focused on the district scale. More specifically, it used census tract data, which generally correspond to the district scale.

The relationships of density, land-use mix, and jobs-housing balance with mode choice, per capita trip generation, trip distance, and travel time may well vary according to the size of the area in which the analysis is conducted. For example, when the impacts of *density* on *mode choice* for *work trips* is assessed, the census tract is an appropriate scale because the character of many blocks around the trip origin and destination has a significant impact on several factors that affect mode choice, such as the cost and availability of parking. The block group may be too small to contain the influential factors. Any unit of area larger than the census tract may reduce the accuracy of the analysis by generating values of density and land-use mix that are inaccurate. On the basis of a preliminary review, the project staff concluded that the census tract or district scale was an appropriate intermediate scale for this analysis.

Variables In the Study and Why They Are Important

Travel behavior, urban form, and non-urban form must be measured using specific variables. The operationalization of these variables and their relation to current policies are discussed below.

Travel Behavior—Dependent Variables

Travel behavior means the way people access opportunities. In this study the relationship between urban form and travel behavior variables was studied. While modal choice was studied at the tract level, per capita trip generation, trip distance, and travel time were studied at the trip level.

1. Modal choice is the method utilized to make a trip. Common trip modes in this study included the single occupant vehicle (SOV), bus, carpool, vanpool, bicycle, and walking. The state's Transportation Policy Plan calls for a multi-modal system. This study was intended to help determine the impacts that urban form variables have on the demand for the modes cited above. The proportion of each census tract's total trips per mode was calculated. This allowed comparisons among census tracts to determine the degree to which each urban form variable described below was correlated with each mode. For this variable, the census tract was the unit of analysis.

2. Trip length is the distance traveled between trip origin and destination. Trip length can be utilized to obtain a measure of vehicle miles traveled (VMTs) by aggregating total trips per person or per household per unit of time.

3. Travel time is the amount of time required to get from the trip origin to the trip destination. The amount of time is a function of the level of service provided for a variety of modes, including driving, busing, carpooling, vanpooling, walking, and biking. The level of service is a measure of the amount and quality of service for a given modal option. Travel time is an important indicator of the amount of time used for commuting purposes. When used in conjunction with distance traveled (i.e., miles per hour), travel time is also an indicator of the overall efficiency of the transportation system. The factors allow the impacts of congestion to be measured as a function of average travel speeds.

4. Trip Generation is defined as the rate or number of trips an individual takes per unit of time. In this study that unit of time is a two day period. Trip generation rates are often used as basic indicator of travel demand created by a particular project.

Urban Form—Independent Variables

Urban form variables for two forms of density, gross population and employment, land-use mix, and jobs-housing balance were measured at the census tract scale. Each of these urban form variables are directly related to the objectives in the Washington State Growth Management Act and Vision 2020.

1. Density is defined in terms of the number of residents, households, or employees per unit of area. Separate variables measuring population and employment density were developed in this project. In this research, population and employment densities were measured by acre at the census tract scale (i.e., average density per acre for tract n). When the impacts of population and employment density on any type of behavior are considered, it is important to recognize that actual, or physical, density and perceived density may differ (Alexander 1988, Stanilov 1993). While people respond to their perceptions of density, it is difficult to account for its qualitative aspects.

Considerable research on the impacts of physical density on mode choice has been conducted (Pushkarev and Zupan 1982, Spillar 1989, Cervero 1988, Meyer, Kain, and Wohl 1980). This project examined the impact that density has on trip length, travel time, vehicle occupancy, and mode choice. Findings could impact both existing and proposed legislation. For example, if density were found to be negatively related to trip length for shopping trips, then policies seeking shorter trips might account for this by rezoning shopping districts or residential areas to allow for higher densities. State Environmental Protection Act (SEPA) regulations might include a provision that reduced traffic mitigation requirements if development would reduce travel demand through higher density. Infill areas could be exempted from concurrency requirements under the Washington State Growth Management Act where density is desired.

Density is alternatively defined in terms of population and employment densities. There are several types of density measures. This analysis focused on gross population and employment density. Gross population density is a measure of the entire population or number of employees within a designated geographic area, divided by the size of the designated area (Pushkarev and Zupan 1976). Examples of units of area for which gross population or employment density is most often measured include census tracts, traffic analysis zones (TAZs), census block groups, and census blocks (Spillar, 1989). Gross population density is frequently used to measure the relationship between density and transit patronage. This is because the data are relatively easy to obtain and the calculations are simple. A pitfall of this measure is that it fails to account for extreme variations that occur within areas chosen as the unit of analysis. For example, at the census tract level extremely high residential densities may occur in one portion of a tract, while another portion of the tract may be completely undeveloped.

Another type of density measure is known as the *density of developed land*, which is defined as the total residential or employment population of a district, divided by the area within that district used for some urban purpose (Pushkarev and Zupan 1976). This density measure differs from net density, which measures the number of residents, households, or employees in the area devoted to a specific use (Stanilov 1993). This measure is supported by a calculation identical to the one used to arrive at gross population density; however, undeveloped areas are subtracted from the devisor in the calculation. For example, a census tract's total residential population may be divided by the total land area of the census tract, minus the portion of the census tract that is undeveloped. Undeveloped land may include public open space and streets.

2. Land-use mix is the composition of uses within a given geographic area. According to Cervero, "Mixed use developments are those with a variety of offices, shops, restaurants, banks, and other activities intermingled amongst one another" (Cervero 1988). Limited research has been conducted to test the impact of land-use mix on travel behavior. Research has indicated that considerable reduction in mid-day travel and overall automobile dependence can be achieved through the integration of services into office parks (Cervero 1988, Pivo 1993). If further research establishes that greater land-use mix at both the household and employment trip ends can reduce travel demand, the policy implications may be vast because much of the existing zoning in urban and suburban areas is based on the principle of land-use separation. As an example, impact fees could be altered to promote land-use mix by providing developers with economic incentives. Specifically, a development that would have been solely for office use might have an off-site impact fee of $2,000,000 for installing a traffic signal, increasing sewer capacity, and increasing the size of the neighborhood park. If the developer chose to allocate some of the development for the provision of retail services that would meet the needs of employees located in that development and reduce their off-site travel, the exaction could be reduced.

As mentioned above, little research has been conducted to empirically test the impact that land-use mix has on travel behavior. This emission is partially due to the limited availability of data to support such research efforts. This project is unique in that sense. Parcel level data were made available by the King County Assessor's office. These data provided information about the amount and type of use on each parcel. The integration of these data with travel data allowed empirical tests to be conducted to assess the impacts that land-use mix has on a variety of travel behavior characteristics.

3. Jobs—housing balance is a measure of the ratio of jobs to households within a designated geographic area. In this study the unit of area was the census tract;

therefore, the ratio of jobs to households was calculated on the basis of the number of jobs and households within each census tract. The premise of this variable is that tracts that have close to an equal number of jobs and households will be associated with shorter travel times and distances for the journey to work (Pivo 1987).

Non-Urban Form Variables

The literature revealed that several types of non-urban form variables are highly correlated with travel behavior, and these were controlled for in this study. In addition, the collective examination of both non-urban form and urban form relationships with travel behavior allowed the significance of their relative contributions to be assessed.

1. Level of transit service has a significant impact on whether transit is competitive with the automobile and, therefore, is directly related to modal choice. One international study of the U.S. and several European nations found transit supply (measured in terms of annual vehicle kilometers per capita) was more highly correlated with transit ridership than were population density or auto-ownership rates (DeMenzes and Falcocchio 1983). Other variables included in this study were metropolitan area density and automobile ownership. Factors that affect the competitiveness of transit include frequency of service, travel time, transfer requirements, distance to the nearest bus stop at trip origin and destination, comfort, security, and cost. Transit level of service extremes range from the absence of transit service in suburban locations to 5-minute headways in urban areas. Controlling for the level of transit service was necessary to isolate the impacts of density, land-use mix, or jobs-housing balance on travel behavior. Level of transit service was measured in this study in terms of the distance to the nearest bus stop from trip origins. Data supporting this variable were obtained from the Puget Sound Transportation Panel (PSTP).

2. Demographic factors that have been found to impact travel behavior include income, gender, age, household type (life cycle stage), and vehicle availability.

Controlling for each of these factors helps to isolate the relationship between urban form and travel behavior by comparing cases with similar, non-urban form attributes. For example, in testing the relationship between gross employment density and trip distance, it is logical to control for age because transit users are often members of particular age groups. Therefore, comparisons are needed between cases with similar, non-urban form characteristics (e.g., age groups) to isolate travel behavior and urban form relationships.

Demographic factors are also important because they are often correlated with urban form. Higher incomes are associated with both lower density and high travel demand. Therefore, it is important to remove the effect of income before looking at the effect of low density to ensure that the travel behavior effects revealed are caused only by low density. If higher incomes are not controlled for, changing density may produce smaller than expected results because incomes may continue to encourage high SOV demand.

3. Prices and subsidies. Costs have a dramatic impact on travel behavior. Costs are manipulated through subsidies and incentives that have a direct impact on travel choices. Incentives to choose the SOV are abundant. Hanson reported, "Automobile use in the United States has been subsidized directly through highway funding policies, and indirectly through externalities and petroleum subsidies" (Hanson 1992). These subsidies have played a major role in the development of a pattern of urban and regional development characterized by sprawl. Subsidies favoring the automobile are imbedded in federal tax codes, as the provision of free parking at the work place is subject to significant federal tax deductions. According to Pickrell, "For many employees, the availability of free parking at work represents a stronger incentive to drive than if their employers offered to provide them with free use of an automobile and free gasoline for the trip" (Pickrell 1990). Evidence of the impact of these policies on mode choice have been well documented. When the Los Angeles area's ride sharing agency phased in market rates for employee parking, the percentage of employees who drove alone to work declined from 42 percent to 8 percent. At the same time, carpooling rose from 17 percent to 58 percent of all work trips for the agency's employees (Miller 1982).

There is a distinction between actual and perceived costs and their impacts on travel behavior. The perceived level of congestion is an example of a measure based upon an individual's interpretation of the level of service of the transportation system. The Puget Sound Transportation Panel (PSTP) has collected data from a telephone questionnaire to support this variable; these data were included in this project's database. Although pecuniary costs are highly significant in the analysis of travel behavior, relatively few PSTP data measured these factors. However, non-pecuniary costs, as measured by travel time, were documented in the database.

SUMMARY

This project was concerned with the impacts of urban form on travel behavior. It also used non-urban form factors as "control variables" in the research design in recognition that travel behavior is affected by both urban form and non urban form factors. The project's travel behavior variables were mode choice, per capita trip generation, travel time, and trip distance. Urban form variables were employment density, population density, land-use mix, and jobs-housing balance. Control variables included level of transit service, age, income, gender, household type, household size, and vehicle availability.

CHAPTER II

RELATIONSHIPS BETWEEN THIS RESEARCH AND CURRENT POLICY OBJECTIVES

Over the past five years several new pieces of legislation have been implemented at the federal, state, and local levels to reduce travel demand and encourage non-single occupant vehicle (SOV) travel. This research could potentially contribute to a better understanding of how urban form might help achieve these policy goals.

POLICIES DIRECTLY RELATED TO URBAN FORM

Vision 2020—Growth and Transportation Strategy for the Central Puget Sound

Vision 2020 was adopted on October 25, 1990, by the Puget Sound Council of Governments. The purpose of this framework plan is to provide a growth and transportation strategy for the central Puget Sound region (PSCOG 1990). This strategy recognizes the importance of developing a planning process that transcends the boundaries and responsibilities of individual jurisdictions.

Vision 2020 encompasses several policy objectives that focus on the interrelationships between land use and transportation. Only the policy objectives that deal directly with the impacts of urban form on travel behavior are discussed here. These policies include the following:

- the call for a more geographically compact and transit-oriented development pattern and
- a more energy efficient and less polluting development pattern.

According to the PSCOG, "Vision 2020 supports a new order of more compact, people-oriented living and working spaces, thereby reversing trends that have created increased numbers of low density, auto dependent communities" (PSCOG 1990). Vision 2020 proposes the following methods to achieve these policy objectives:

- limit the expansion of the urban area by establishing urban growth boundaries;
- focus a significant amount of new employment and housing into approximately 15 mixed-use centers; and
- serve these mixed-use centers with a more efficient, transit oriented, multi-modal transportation system.

Clearly, the objectives and strategies adopted by Vision 2020 recognize the inter-relatedness of land-use patterns and the ability to achieve more efficient travel characteristics.

The findings from this research project should help evaluate the viability of Vision 2020 in designated centers. Vision 2020 is based on the assumption that more dense mixed-use centers will yield a less auto-dependent travel pattern. This research tested the effects that increasing density and land-use mix would have on the reduction of SOV travel. The fact that this project utilized data gathered from households and census tracts in the central Puget Sound further relates the findings to Vision 2020.

The Washington State Growth Management Act (GMA)

The Growth Management Act has several purposes. This discussion is limited to the aspects of this new legislation that are related to this research. According to the Washington Legislative Transportation Committee, "Transportation problems in Washington State have increased dramatically over the past several years due in large part to the rapid growth of the Central Puget Sound Region and lack of growth in other parts of the state" (State of Washington Legislative Transportation Committee 1990). The Growth Management Act seeks to address these problems by restructuring the planning processes that govern both land use and transportation. Local comprehensive plans are now required for all counties (and cities within those counties) that have populations of over 50,000 or growth rates of more than 20 percent over the previous 10 years (HB1825, 1991). These plans must contain transportation and land-use elements. Plans must also include the reassessment of *land-use assumptions* to maintain service levels. To further the coordination of transportation and land-use planning efforts, the adoption of regional transportation planning organizations (RTPOs) has been encouraged.

By testing the impact of land-use patterns on travel behavior, this project could help identify local land-use policies that would reduce travel demand.

The Growth Management Act requires that countywide policies be adopted to encourage transit oriented development. In the central Puget Sound, these policies must be consistent with the goals in the Growth Management Act and Vision 2020 (the regional plan). King County and Snohomish County (two of the three counties in which this study was based) have adopted countywide policies that are directly related to this research. These policies include objectives for minimum employment and residential densities within urbanized areas. The King County countywide policies are published in a document titled King County - Countywide Policies (King County Council; 1993). The Snohomish County Countywide policies are published in a document titled Snohomish County Urban Centers Policies and Criteria (Snohomish County Tomorrow Steering Committee, 1993). The levels of employment and population density identified in this research that are required to foster transit usage will be useful for determining the utility of the density targets of the countywide policies.

NON-URBAN FORM POLICIES

The Washington State Transportation Policy Plan (STPP)

The Washington State Transportation Policy Plan (STPP) provides a statewide framework for all transportation related planning issues within Washington State. The mission statement of the STPP is as follows (Sub-Committee on Desired Future Conditions, 1989): "The transportation mission in Washington State is to provide safe, efficient, dependable, and environmentally responsive transportation facilities and services, and in doing so, to:

- protect the natural environment and improve the built environment;
- promote a positive quality of life for Washington citizens; and
- enhance the economic vitality of all areas of the state."

The policy plan is structured around four goal areas, with associated goal-policy directives. These goal areas are working together, protecting our investments, personal mobility, and economic opportunity. The goal statements that are most closely related to the purpose of this project are presented in Table 2.1. A brief statement is provided to clarify the relationship between each goal statement and the purpose of this project.

Table 2.1. The Washington State Transportation Policy Plan

GOAL STATEMENT	RELATIONSHIP WITH THIS PROJECT
Provide safe, reliable, and convenient access to employment, educational, recreational, cultural, and social opportunities for all citizens in urban and rural environments.	This project will aid decision-makers in adopting policies that allow transit dependent populations to enjoy greater accessibility to opportunities
Link land-use planning with transportation planning	By documenting the impacts of specific land-use characteristics on travel behavior, researchers may be able to provide a scientifically based argument that justifies the need to develop plans more fully. Furthermore, specific findings from the research may provide direction regarding the areas where the greatest gains can be made to alter existing travel behavior patterns through intervening in the land use planning process.
Conserve scarce resources	Studying the relationship between land use patterns (densities and/or land use mixing) provides the opportunity to identify the types of land-use patterns that have the least travel demand. For example, if this research shows that census tracts with the greatest mixing of uses has the least VMTs per capita, then it may be inferred that land use mix has a positive impact on the reduction of travel demand.
Reduce pollutants and other waste by-products from the transportation system	Pollutants from the transportation system can be divided into air and water. In terms of air pollution this goal relates to the objectives set forth in the Clean Air Act Ammendments of 1990. Water pollution associated with highway runoff has been found to be directly correlated with the number of vehicles that pass a given point (Mar, 1987). The reduction in vehicle trips would thereforehelp to aid efforts targeted at improving water quality. Identifying the land use factors that are most critical in reducing vehicle trips would help develop policies that effectively achieve this goal.
Sponsor innovative research and development in cooperation with academia and the private sector	This research effort provides a unique and innovative approach to correlating travel behavior and land-use data.

Commute Trip Reduction

The Commute Trip Reduction (CTR) law requires a significant reduction in single occupant vehicle (SOV) travel and promotes the subsidization of bus passes, guaranteed rides home, and the provision of bicycle facilities, among other programs. The CTR identifies different standards for businesses of various sizes (number of employees). The promotion of other modes to reduce VMTs takes many forms. For example, Section 2 of RCW 82.08.0287 mandates that vans that are used regularly as ride sharing vehicles be exempt from certain taxes (Revised Code of Washington, 1992). This law may impact employers' locational decisions and expansion decisions. The most significant portion of the CTR law that impacts land use is the requirement that jurisdictions review local parking ordinances. With a required reduction in SOV travel, developers now have a strong argument to reduce the amount of parking required by local zoning ordinances. The implications of reducing parking is that buildings could be located more closely, increasing density.

The Clean Air Act Amendments of 1990 (CAAA)

Section 108 (e) of Title I of the Clean Air Act Amendments of 1990 (CAAA) requires that the Environmental Protection Agency (EPA) guide jurisdictions in developing and implementing transportation and other measures necessary to attain the national air quality standards of the CAAA (EPA, 1991). In response to this mandate, guidelines have been developed on integrating air quality and transportation planning. The primary purpose of the guidelines is to achieve transportation planning that reduces air pollution.

The legislation places significant restrictions on vehicle emissions, in recognition of the fact that the majority of all urban pollutants comes from SOV travel. The Clean Air Act recognizes that reducing vehicle emissions per mile traveled is insufficient to significantly reduce air pollution because vehicle miles traveled (VMTs) in major metropolitan areas have increased dramatically over the past few decades. The central Puget Sound is no exception to this problem. From 1970 to 1988 VMTs in the central Puget Sound rose from 22.5 million to 49.4 million—an increase of greater than 123 percent (PSCOG 1988).

Therefore, the primary tool the CAAA recommends to achieve clean air in urban areas is to change travel behavior, in particular to reduce total VMTs (EPA, 1991). Total VMTs may be reduced by manipulating the urban form and non-urban form variables described in this project. The ability to change travel behavior and VMTs through densification and filling urban areas with a wider variety of land uses is one policy option that may help regions meet air quality standards.

Intermodal Surface Transportation Efficiency Act (ISTEA)

The Intermodal Surface Transportation Efficiency Act (ISTEA) was passed on November 26, 1991. ISTEA is the six-year renewal of the former Federal Surface Transportation Act and is the most progressive piece of federal transportation legislation to date. It is progressive in the sense that ISTEA not only provides substantial resources for alternative modes to the automobile, it also rewards projects that mesh a variety of modes. In addition, implementing Code of Federal Regulations (CFR) specifies that local growth management and land-use plans be given consideration in the preparation of state and regional transportation plans.

The primary goal of ISTEA is to improve the transportation system through increased efficiency. This project may provide insight into how various land-use patterns affect mode choice and travel demand, thus providing empirical evidence on how land-use policies can assist in meeting ISTEA objectives. Its analysis of travel behavior as a function of urban form may provide decision makers with information on whether urban form policies can help offset travel demand.

URBAN FORM STRATEGIES TESTED IN THIS PROJECT

As described above, the GMA and Vision 2020 include land-use strategies intended to reduce travel demand. Increasing population density, employment density, land-use mix, and the balance between numbers of jobs and households are four strategies on which this project focused. Other urban form strategies were identified in the literature but were not tested in this project because they were less quantifiable and/or required analysis on a smaller scale. One example is pedestrian and transit friendly land-use and site planning. To test the relationship between this strategy and travel behavior, data would have to be collected at the site or block level. This is one area in which future research could identify new site planning templates that would help reduce travel demand.

This section reviews the studied strategies (see Table 2.2) and describes how this project empirically tested their effectiveness.

Table 2.2. Urban From Strategies to Reduce Travel Demand

Population & Employment Densification/Consolidation
Land-Use Mix
Jobs-Housing Balance

The strategies presented in Table 2.2 are targeted at urban development that maximizes the efficiency of the city as a system while minimizing negative impacts on the environment. These strategies attempt to achieve the goal of "sustainable development," ensuring that utilization of resources and the environment today does not damage prospects of their use by future generations (WCED 1987). This goal suggests that "the city should be contained from its sprawl and rebuilt from within" (Newman 1991).

Densification/Consolidation/Containment

Intensifying and containing development has been a focal point of growth management policies in several states over the past two decades. Florida, Oregon, Vermont, Washington, Hawaii, and others have decided that more efficient urban systems and associated development patterns require densification. Increased transportation efficiency may be achieved by reducing distances between trip origins and destinations. Planners are trying to increase development densities through a variety of planning tools, including reducing parking space requirements, establishing urban growth boundaries, and requiring concurrency between infrastructure and development. Intensifying development is one of the key ingredients necessary for the development of suburban centers or urban villages. While suburban centers or urban villages focus on the density within a center, development densification may be essential along the transportation corridors that connect these centers. This research applies to the overall density of development at the census tract scale, regardless of center or village boundaries. Future research that focuses on density strictly within center or village boundaries will provide additional (and perhaps more directly applicable) information that planners could use to reduce travel directed at the center or village.

This project directly tested the relationship between travel behavior and density at specific locations within the central Puget Sound. If findings are consistent with other, similar research efforts, then a less auto-dominant land-use pattern could be partially achieved through densification. For densification to be achieved, local zoning ordinances would have to be amended. Several tools have been proposed to focus new development within developed portions of urban areas. These tools include

- establishment of urban growth boundaries,
- density bonuses,
- minimum density zoning, and
- second unit ordinances.

Land-Use Mix

Increased land-use mix is currently being adopted as a policy goal in several regions across the United States. These regions include Portland, Oregon; Sacramento, California; Montgomery County, Maryland; and the central Puget Sound. Increased land-use mix is recognized as a means of reducing travel demand while improving the interest and character of the urban environment. Land-use mix is being applied in these and other regions at a variety of development levels, ranging from a project basis to community development and comprehensive plans. At the project level, developers may be required or given incentives to include more than one use in a development. At the local or regional level, the plans being adopted place a high priority on the inclusion of a variety of uses within walking distances to work and employment.

The impacts that land-use mix has on travel behavior have not been thoroughly researched. Findings from the limited research done to date indicate that land-use mix at the employment trip end impacts travel demand by reducing mid-day trips (Cervero 1988, Pivo 1993). This project included an evaluation of the relationship between land-use mix and mode choice, per capita trip generation, trip distance, and travel time at trip origins and destinations for work trips and shopping trips. The implementation of a policy that promoted land-use mix would have to overcome the trend to favor plans that separate uses. Policies intended to overcome this institutional impediment, such as Growth Management and Vision 2020, may be supported by the information from this project.

Jobs-Housing Balance

The definition of a land-use pattern that offers an even balance of jobs to housing is still unclear in the literature. Policies to implement a land-use pattern that minimized commute trip lengths would have to include housing that matched the income levels of nearby employment and incentives for employees to live near their jobs (Downs 1991).

Downs speculates that significant negative social implications are associated with such policies (i.e., the mass promotion of socio-economic segregation).

The following reasons have been identified for the popularity of jobs-housing policy (Guiliano 1991).

- It addresses public pressure to manage or limit growth.
- It is vague enough to avoid political obstacles associated with more specific policies such as those that are directly targeted at altering household travel behavior.
- It reflects more general concerns about developing and maintaining communities with an adequate variety of employment and housing that is affordable to a wide range of income levels.
- The promise from optimistic projections may be irresistible. The Southern California Association of Government's (SCAG) growth management plan promotes jobs-housing balance by redirecting 9 percent of the new jobs and 5 percent of new housing expected between 1984 and 2010 to job poor and housing poor areas, respectively. "As a result of this policy the SCAG land use and travel forecast models estimate these shifts will result in a 35 percent reduction in VMT and commensurate reduction in vehicle emissions" (Guiliano, 1990).

Barriers to jobs-housing balance include

- exclusionary zoning practices (Cervero 1989), and
- local governments with limited access to traditional revenue sources, which are more attracted to commercial development because it generates more revenue than residential development.

This project allowed household travel behavior (trip length and travel time) to and from census tracts with a more balanced ratio of jobs to housing to be compared with that of census tracts that were less balanced. This comparison may provide information about the effect that matching numbers of jobs to households has on travel demand at the census tract level.

SUMMARY

This project may provide information that is applicable to urban form policies (e.g., the Growth Management Act or Vision 2020) whose mechanisms include land-use density, mix, and jobs-housing balance. Findings from the research review indicated that considerable work has been conducted to assess the impacts of density on travel behavior, while little is known about the effects of land-use mix. This research may indirectly provide insight into several other relationships between land-use strategies and travel demand, such as the correlation between jobs-housing balance and travel demand. Table 2.3 provides a summary of the relationships between the six policies described above and this research.

Table 2.3. Policies and Their Relationship To This Project

POLICY NAME	RELATED VARIABLES	NATURE OF RELATIONSHIP
Intermodal Surface Transportation Efficiency Act (ISTEA)	travel behavior	encourages alternative modes of transportation and the reduction of vehicle miles traveled
The Clean Air Act Amendments of 1990 (CAAA)	mode choice, trip length, and vehicle occupancy	requires a reduction in vehicle miles traveled
The Growth Management Act (GMA)	density and mode choice	promotes the reduction of sprawl, encouraging densification and concurrent development between land use and transportation; promotes a multimodal transportation system
Commute Trip Reduction Law (CTR)	density and all travel behavior variables	requires the review of parking requirements in local zoning ordinances and promotes less SOV travel
State Transportation Policy Plan (STPP)	travel behavior	encourages mobility options for all, including populations without access to automobiles
Vision 2020	density and land-use mix	promotes the clustering of development into mixed-use centers and the utilization of mass transit

CHAPTER III

PAST EMPIRICAL RESEARCH EFFORTS TO ASSESS THE IMPACTS OF URBAN FORM ON TRAVEL BEHAVIOR

> ***"Few forces have been more influential in modifying the earth than transportation, yet transportation itself is a result of other forces" (Ullman 1956).***

The forces that Edward Ullman referred to 35 years ago relate to the concept of site or settlement patterns. Analytical efforts that have focused on the relationship between settlement patterns or land use and transportation are the focus of this section.

It is seldom refuted that a relationship between land use and transportation exists. The relationship between the origins and destinations of our daily trip making activities is a direct result of the land-use patterns in which we live. The purpose of this section is to document efforts to empirically test how land use impacts the ways in which people behave or make their travel choices.

While transportation and urban form are in large part functions of one another, there is little certainty about their mutual influence relative to the many forces that bear upon each, particularly upon urban form (Altshuler 1978). For the purposes of this report, urban form is defined as the distribution of activities within the urban system. Population density, employment density, land-use mix, and jobs-housing balance are the four primary urban form variables with which travel behavior has been found to be most highly correlated.

A literature review revealed four primary groups of research. They are presented in Table 3.1.

THE IMPACTS OF URBAN FORM AND TRANSIT INFRASTRUCTURE ON THE ENVIRONMENT

Land-Use Impacts on Energy Consumption

The disparity between energy and land-use planning concerns can be attributed to the different governmental levels at which they are addressed. Energy policy is addressed at the federal and state levels, while land-use decisions are made by over 40,000 local

Table 3.1. Focus of Past Research

RESEARCH CATEGORIES	DESCRIPTION
the impacts of urban form and transit infrastructure on the environment	research that attempts to isolate a causal relationship between energy consumption and land use patterns
intra-regional land use patterns	research to assess why sprawl is occurring, the impacts of sprawl on the journey to work, and the usefulness of the jobs housing balance approach
impacts of mixed use planning on travel behavior	efforts to analyze the impacts of mixing uses at work locations on trip reduction and modal choice
the effects of density on transit ridership and travel demand	research to identify the likelihood that differing levels of density will result in a higher modal share for transit

jurisdictions throughout the United States (Burchell and Listokin 1982). This institutional disparity has been partially responsible for jurisdictions' ability to make local level land-use decisions without regard for energy considerations (Harwood 1989).

Over the past few decades several studies have assessed the impacts of land use on energy consumption. The significance of this work is that it has documented the need for more accountability between local land-use decisions and energy policy. Research conducted to assess the impacts of land-use patterns on energy consumption has concluded that the land-use planning factors are, indeed, responsible for the rate at which individuals consume gasoline. (Newman and Kenworthy, 1989) Findings from a comparative analysis of 32 urban areas around the world revealed that gasoline consumption per capita decreases dramatically as density increases. Per capita annual fuel consumption in Houston was nearly 600 gallons with an average density of less than 10 persons per acre. In comparison, per capita fuel consumption in Hong Kong was approximately 25 gallons with an average density of 120 persons per acre.

This study also concluded that gasoline consumption per capita in ten large United States cities varied by up to 40 percent, primarily because of land-use and transportation planning factors, rather than because of price or income variation. (Newman and Kenworthy 1989). Development density was found to be strongly correlated with the rate of fuel consumption for both central city and outlying areas.

Criticisms of the study conducted by Newman and Kenworthy have included the following (Gomez-Ibanez, 1991):

- it did not analyze all causal factors simultaneously,
- it failed to consider energy usage from modes other than the automobile,
- it failed to consider new residential construction that would most likely have shown a high correlation between high income/low density, and low income/high density, and
- it lacked consideration of the costs of policies to reduce automobile dependence.

In response to the criticism of Gomez-Ibanez, Newman and Kenworthy stated, "The overall perspective of the review by Gomez Ibanez is that income and prices determine urban form and transport and that physical planners can do little to intervene in the process" (Newman and Kenworthy, 1992). Thus Gomez-Ibanez was suggesting that the underlying determinants of urban form are economically based and that density may be a proxy for these. Furthermore, simply generating higher density is not likely to be effective at altering demand because density itself may not be causally related to travel behavior. Rather, underlying factors such as level of service for transit or the costs of auto travel associated with higher densities affect travel demand.

Research findings that average commuting times did not increase between 1980 and 1985 in 20 of the largest metropolitan areas in the United States has resulted in the generalization that sprawl is not responsible for inefficient travel patterns (Gordon, Richardson, and Jun 1991). Gordon et al. equated congestion and associated travel times with the total costs of travel while ignoring a myriad of other costs associated with sprawl and low density development, such as increased fuel consumption (Newman and Kenworthy 1989). Gordon et al. further objected to growth management strategies to balance the distribution of jobs and housing because they contended that the market maintains a balance and constrains commuting time (Bourne 1992). In addition, they disapproved of proposals to provide more affordable housing and improved transit service to central areas, arguing that current employment markets in these locations were stagnant (Gordon, Richardson, and Jun 1991).

Critiques of the study by Gordon, Richardson, and Jun include the following (Bourne 1992):

- the omission of a full range of social, economic, and political relationships necessary to determine a causal relationship between commute times and decentralization;
- lack of discussion of the relationship between employment stagnation in central areas and limited public investment in these locations in the recent past (e.g., Is the use of employment stagnation in central areas as an argument to limit public investment a self-fulfilling prophecy?);
- the assumption that the present tendency toward decentralization is the result of an "unfettered" market, which takes no account of extensive subsidization of automobile usage in the form of public funds for highway programs, artificially low gasoline costs, and the externalization of environmental costs associated with automobile travel; and
- lack of explicit evidence to support the assumption that sprawl increases economic efficiency.

Other studies to assess the impacts of density on energy consumption have also suggested that energy can be saved through urban densification (Owens 1978, Rickaby 1987). In a comparative analysis of the energy consumption rates of six settlement patterns the following observations were made (Rickaby 1987):

- concentrating growth into existing urban areas had the greatest impact on the reduction of fuel consumption;
- concentrating growth into dispersed-nucleated villages in a metropolitan region also had a positive effect on energy consumption; and
- the closer that these dense satellite developments were to the urban center, the greater were the savings in energy consumption.

The level of investment in public transportation infrastructure has also been found to be highly inversely correlated with the rate of fuel consumption in major metropolitan areas around the globe. According to Newman and Kenworthy, "Cities with significant portions of electric rail (like Tokyo, Paris, and Munich) have very low fuel use and greenhouse gas." Newman and Kenworthy described the investment in transit infrastructure as a "leveraging principal" by which transit usage creates a different type of city. This different type of city is denser, with shorter distances between trip producers (households) and trip generators (employment, shopping, etc.). Therefore, the presence of electric rail may not actually be the casual factor but a proxy for urban form.

Land-Use Impacts on Air Pollution

Considerable research on the impact of land use on environmental pollution was conducted in the 1970s. Findings from this work suggested that the most important determinants of environmental pollution are city size and the scale of manufacturing concentrations. Further comparative research found that lower pollution levels were associated with densely concentrated urban areas than with less dense configurations. Berry stated, "The core oriented city, with steep density gradient and a radially structured transportation system, has greater land use intensity, proportionately more open space, and lower levels of air pollution than the dispersed city" (Berry 1974). When this conclusion is applied to U.S. metropolitan regions, it suggests that the poorest air quality will be found in the very largest, most dispersed urban regions that have substantial manufacturing employment.

INTRA-REGIONAL LAND USE PATTERNS

Regional Size and Residential Location As Determining Characteristics of Urban Travel

Several studies conducted during the late 1960s and early 1970s used population size as a proxy for the separation of homes and travel destinations. These studies revealed a strong correlation between population size and average trip length, indicating that residents of larger metropolitan areas often need to commute farther than residents of smaller communities (Voorhes, 1968; Bellomo, et al., 1970). In an analysis of automobile trips, research findings determined that as trip origins (residences) move away from the central business district (CBD), average trip lengths increase for these residences (Zahavi, 1976).

The Impacts of Suburbanization on the Journey-to-Work

The impacts of dispersed development on travel behavior are currently under dispute. Some research has suggested that the dispersion of office activity and other uses throughout an urbanized area may indeed reduce overall travel times (Schneider 1985, Pisarski 1987, Gordon and Richardson 1991).

Other studies have supported findings that sprawl has caused an increase in vehicle miles traveled and associated trip length. Traditional conceptions of suburbs are no longer valid. Some suburban communities have a large employment base relative to a limited housing supply. Substantial arguments have been wagered over whether sprawl is accountable for the suburban mobility crisis. While the dispersion of employment may create more opportunity for jobs and housing to balance, considerable problems have been attributed to the suburb to suburb commute in association with the emergence of scattered employment centers throughout the suburbs (Pisarski 1987, Levine 1991, Daniels, 1980).

The implications of scattered trip ends on travel behavior have been found to be quite significant. According to Levine, "Transit's mode share declines sharply with employment suburbanization" (Levine 1991). Suburban mobility has become one of the primary concerns for transportation planners. In absolute terms, the suburb to suburb commute has been found to generate substantially more vehicle miles traveled (VMTs) than commutes from central city to central city or even from central city to suburbs. Table 3.2 illustrates the trip lengths associated with suburban and central city commutes. Although the percentage of change in central city to central city commutes was significant between 1975 and 1980, the absolute distances for suburban commutes was by far the greatest.

Table 3.2. Trip Lengths Associated With Suburban and Central City Commutes

MARKET FLOW (1980)	**TRIP LENGTH IN MILES (1980)**	**TRIP LENGTH CHANGE (% change 1975-80)**
central city to central city	6.3	18.8
central city to suburbs	10.6	3.9
suburbs to central city	12.2	2.1
suburbs to suburbs	8.2	17.1

(Source: Commuting In America; Pisarski 1987)

Jobs-Housing Balance: A Panacea?

Jobs-housing balance refers to the distribution of employment in relation to the distribution of households in an urban area (Guiliano 1990). According to the Association of Bay Area Governments (ABAG) in California, a jobs-housing balance is achieved if people live in housing that is affordable at the wages they earn and travel minimum distances to their jobs and the services they use (ABAG 1985). The balance between jobs and household locations has been the subject of considerable discussion over the past five years. At the policy level, criticisms have been raised that locational decisions are difficult to assess and model simply on the basis of the relationship between work and home. Evidence suggests that the relationship between where people choose to live and work is very complex. Some of these complexities are presented below (Guiliano 1990, Shefer 1991).

- Incremental trip costs are relatively small compared to housing costs.
- The number of multiple-worker households is growing.

- Gender differences within households affect journey to work patterns.
- The relationship relies on regulation such as the provision low income housing or commercial/industrial square footage.

Most of the empirical research that exists suggests that policies designed to increase jobs-housing balance may be ineffective and that even if they were successful, any reduction in travel demand would be minimal. In certain locations that are "balanced," people may still not choose to live near their jobs. According to White, "The problem of workers making excessively long commuting trips is unlikely to be solved by redirecting the location of new housing and jobs" (White 1989). These problems may need to be dealt with more directly. Jobs-housing policies assume that the causal relationship between jobs-housing balance and travel behavior is significant enough to achieve congestion and pollution goals. However, research suggests that jobs-housing policies are too indirect and simply can not have enough of an impact to substantially reduce congestion and air pollution.

Nevertheless, research in Toronto concluded that the rising residential population in the city center offset the increased number of commuting trips to the city center that were anticipated because of rapidly increasing office development. This study concluded that "for each 100 additional dwelling units in the Central Area there has been a reduction of approximately 120 inbound trips during the morning three hour rush period"(Nowlan and Stewart, 1991). This finding suggests that housing policy can help offset transportation impacts due to additional development.

THE IMPACTS OF MIXED-USE DEVELOPMENT ON TRAVEL BEHAVIOR

Land-use mix helps increase people's level of accessibility to a variety of activities. As generally defined, accessibility consists of two elements (Handy 1991):

- "travel impedance, as represented by travel time; and
- attractiveness, as represented by the spatial distribution of activities, often differentiated by type."

Empirical research regarding the impacts of mixed use on travel behavior is limited. Research conducted to assess the impacts of land-use mix at employment and residential trip ends has concluded that a causal relationship does exist. Some of the findings of this research are presented below. Other work that has focused on the implications of accessibility can be indirectly used to develop a theory regarding the nature of the causal relationship between land-use mix and various aspects of travel behavior for a variety of trip purposes.

One empirical research effort that was conducted to assess the impacts of land-use mix found motorized travel could be reduced by introducing services such as banks, restaurants, and others into office complexes. According to the Institute of Transportation Engineer's (ITE) Trip Generation Manual, a 100,000 square foot office development will generate 18.7 more daily trips than a development of similar size that contains a mixture of uses. (Cervero 1988).

Mixed-use development patterns have the potential to create a net reduction in travel demand. While mixed use has not been as extensively researched as density, this aspect of urban form is receiving some critical attention. Several employee surveys were conducted at business centers in the Los Angeles area to determine the potential for ride sharing. One of the top two reasons given for commuting alone by the 17,000 surveyed employees of the Warner Center Office Complex was the need to run mid-day errands (32 percent of the respondents) (Cervero 1988). Workers in mixed-use developments find that they are able to perform mid-day errands or to eat lunch without their cars when certain services are located within their work environments.

Vehicle miles traveled has been found to be a function of land-use mix at residential locations as well. One study of six neighborhoods in the Bay Area discovered that land-use mix was partially responsible for a reduction in vehicle miles traveled (Handy 1991, Holtzclaw 1990).

THE EFFECTS OF DENSITY ON TRANSIT RIDERSHIP

Population and employment density are the aspects of urban form that have been found to be most highly correlated with travel behavior (Pushkarev and Zupan 1982, Newman 1989, Cervero 1987, Spillar 1989). Pushkarev and Zupan found that as density increased, both per capita and total transit ridership increased. Additional work to test the findings from this research has led to considerable debate about the density necessary to support various forms of transit service (Pickrell 1985, Spillar 1989). The primary criticism is that Pushkarev and Zupan's thresholds to support rail transit were too low. This problem may have been due to the fact that the New York metropolitan area was used as a case study in Pushkarev and Zupan's analysis. Characteristics of New York City include densities that are extraordinarily high at the employment trip end, which skews mode choice for commuters living in suburban locations.

Declining densities have been associated with decreases in transit use, as dispersed origins and destinations cannot be effectively served with conventional transit service (Kain 1988). This relationship is based on fundamental transit accessibility theory. The primary mode for access to transit is walking. The maximum distance that a potential transit rider will walk has been found to be approximately 1/4 mile, depending upon the qualitative nature of the walk, the presence or absence of barriers, and other factors (Gray and Lester 1979). Because transit serves pedestrians, it follows that a significant proportion of potential riders have to be within a comfortable walking distance of transit service for it to be considered accessible. For this to occur, a certain level of density must be achieved at both the home and the employment trip ends.

Past research has questioned whether density is itself a causal factor of travel behavior or a proxy for other characteristics that are present at different levels of development intensity. For example, non-SOV travel has been found to be much lower in outlying areas that have densities equal to central areas. For example, Klahanie Ridge (located east of Bellevue, Washington) has an average of 6.8 dwelling units per acre (Moudon and Weisman 1990). This density is comparable to that of the Wallingford neighborhood in Seattle. However, transit usage in Klahanie Ridge is limited by a lack of transit service. Wallingford, on the other hand, has a high level of transit service and ridership. In this case, a primary causal factor affecting mode split is modal level of service. This indicates that density itself may not be the primary factor affecting travel behavior and that other factors may be more responsible.

To document this relationship, data on transit ridership as a percentage of total work trips (1990) for several employment centers in the Central Puget Sound are provided, together with the related employment density, in Table 3.3.

Table 3.3. Transit Ridership

EMPLOYMENT CENTER	% 1990 WORK TRIPS ON TRANSIT	EMPLOYMENT DENSITY PER ACRE
Seattle CBD	43%	543 employees
Bellevue CBD	6%	215 employees
Denny Regrade	28%	522 employees
University District	23%	61 employees *students not included

(Source: Puget Sound Council of Governments, 1990)

Table 3.3 shows that transit ridership is highly correlated with employment density, as in 1990 43 percent of all trips to the Seattle CBD were served by transit, while ridership fell off significantly at lower densities. While the University District had a lower employment density than Bellevue, it had a far higher proportion of trips served by transit. This could be misleading because the employment density figure (61 employees per acre) for the University District does not reflect students traveling to and from the University district via transit. If students were added to the employment density figures for the University District, the proportion of transit ridership per level of employment density would be closer to that of the other employment centers shown in Table 3.3.

Bellevue had a significantly lower proportion of transit ridership per employment density level than the other employment centers (even when accounting for students in the University District's employment density figures). This result supports findings in the literature and in this project that the relationship between transit ridership and density is non-linear. This means that as employment density increases, the proportion of trips served by transit increases exponentially.

Another interpretation of these findings is that factors other than density affect mode choice. These factors may include income, level of transit service, availability of parking, and predisposition to use transit. These data depict the need to account for a variety of factors that affect modal choice. Factors for which density may be a proxy are presented in Table 3.4.

Table 3.4. Underlying Factors Associated With Density

attitude towards riding transit
level of transit service
auto ownership
income
cost of parking
relative cost of auto and transit
cultural background
perceived convenience of transit over long distances

The effects of density on travel behavior are also impacted by other factors. Research has been conducted to test the combined impacts of density and travel distance on mode choice. One researcher found that the relationship between density and transit use was less significant than a combination of density and trip length. This concept is "Density moments" = density multiplied by distance (Mamasani, 1988).

SUMMARY

Findings from this analysis confirm that urban form affects travel behavior in several ways. Empirical evidence has revealed these relationships and is presented in very general terms below in the form of hypothetical relationships between urban form and travel behavior.

Hypothetical Relationships Between Travel Behavior and Urban Form

- As density decreases, vehicle miles traveled (VMTs) increase while transit ridership decreases.
- As density increases, household vehicle trip production decreases and non-motorized trip production increases.
- Density may not be a causal factor but rather a proxy for a host of other factors that do impact travel behavior.
- Average trip length increases as density decreases.
- As employment density increases travel time increases.
- As land-use mix increases travel demand decreases.

Other Significant Findings

- A critical examination of jobs-housing policies will be necessary to provide the relief from congestion and air pollution that is needed.
- Travel times for work trips in the United States did not increase between 1980 and 1985.
- Decreased costs associated with SOV travel have facilitated sprawl, which has in turn increased congestion and air pollution.

These findings provided guidance and a set of checks and balances for this project. While the impacts of density on travel behavior has been heavily researched, the impacts of land-use mix has not. This does not mean that all the impacts of density on travel behavior have been discovered. Rather, the impacts of land-use mix on travel behavior represent an opportunity to contribute to an area where much more research is necessary.

Two other significant findings resulted from the review of the literature, each illuminating opportunities for this project. The first is that the relationship between urban form and shopping trips is relatively unresearched. The second is that urban form has been studied in relationship to trip origins or destinations but not to both trip ends collectively.

CHAPTER IV

THE DEVELOPMENT OF HYPOTHETICAL RELATIONSHIPS BETWEEN URBAN FORM AND TRAVEL BEHAVIOR

Travel behavior or travel demand analysis has been the subject of significant research over the last half century. This chapter describes the fundamental premises upon which two distinctly different approaches to studying travel behavior have been developed and cultivates some assumptions about how they relate to urban form. These two approaches are micro-economic/compensatory, and attitudinal value-based/non-compensatory.

Whereas micro-economic theory seeks to provide a rational explanation of peoples' actions in terms of personal costs, attitude or value-based approaches recognize that rational economic explanation is not always possible. For example, residents in suburban developments with densities, level of transit service, and demographic characteristics similar to those of urban developments take a higher percentage of their trips by SOV. This may indicate that an attitudinal disparity exists between suburban and urban residents over the use of transit. Micro-economic theory is not able to account for these factors, while the non-compensatory approach takes into account factors such as attitudes that affect travel behavior.

These theories may be thought of as complementary because they do not negate the validity of one another; rather, they focus on different aspects of human behavior. Non-compensatory approaches have been developed because of the shortcomings associated with personal utility optimization models upon which micro-economic choice theory is based. In this chapter, the strengths and weaknesses of each approach are assessed. The chapter also offers an explanation of how both compensatory and non-compensatory approaches can explain current, and perhaps desired, travel behavior patterns in terms of urban form.

MICRO-ECONOMIC COMPENSATORY APPROACHES

Microeconomic theory has dominated the analysis of travel behavior for nearly 40 years. The theory of equilibrium between supply and demand has been re-articulated for the purposes of modeling travel behavior. Underpinning this theoretical approach is the utility maximization postulate, which assumes that consumers will act to maximize their personal gain while minimizing their costs (Beckmann, McGuire, and Whinsten, 1955).

Micro-economic theory has been applied at both the aggregate and disaggregate levels in the study and analysis of travel behavior. According to Kanafani, "In micro-economic theory, demand is approached at two levels: an individual level, referred to as consumer demand, and an aggregate level referred to as market demand" (Kanafani, 1983). Market demand is obtained by aggregating, or summing, all individual consumer demands. The application of these two approaches to estimating consumer demand has significant ramifications in the application of demand theory to transportation, where microscopic analysis (the prediction of individual behavior) is common. Both compensatory and non-compensatory approaches to modeling individual behavior are examples of disaggregate forms of research (Train, 1986). Modeling consumer demand at the aggregate level often utilizes the development of approximate and consistent demand equations.

Transportation supply variables describe different aspects of the costs and levels of service by which needs (demand) might be met. Supply functions are influenced by technology, by the operating policies within a transportation system, and by the levels and nature of the traffic using the system.

Single occupant vehicles dominate travel in the United States; they have gained significant advantage over other modes during the past 30 years. (Newman, 1991; Pisarski, 1987). According to micro-economic theory, personal utility is currently maximized for most individuals through automobile use. The cost of driving is less than the costs of other alternatives. This cost is inclusive and represents non-pecuniary costs such as time, convenience, comfort, and government subsidies, although these are not often represented in modeling applications. According to micro-economic theory, the supply of auto-oriented travel is high, reducing its relative cost. In addition, once a consumer owns an automobile, his or her marginal cost of using it is very low relative to other alternatives.

For this trend to be reversed over the next ten years the social costs of driving alone must no longer be externalized on the environment and other people. These externalities take the form of air pollution and the consumption of huge quantities of land that could be put to uses other than roads. The cost of driving alone must reflect a whole set of costs that are currently subsidized by the government in the form of highway construction, inexpensive gasoline, and the provision of employee parking (Pickrell, 1990, Lowe, 1990). Government regulations such as limiting parking supply and congestion pricing would serve to increase the costs of driving alone and reduce its utility relative to other modes.

The development of more appealing alternatives to the automobile must also accompany the reduction of auto-oriented subsidization. The construction of bike and pedestrian facilities, in addition to increased levels of service for transit, are necessary to make these modes competitive (Antoniou, 1971). Factors that affect the ability to enhance the utility of alternative modes include urban form and costs.

Strengths

One of the primary attractions of the utility-based models is that they are easy to use. The micro-economic utility-based models are readily quantified and have attractive mathematical properties. These models allow analysts to assess policy implications by trading-off costs for opportunities. For example, a utility function can be derived for travel time cost based upon the value a consumer assigns to their time. An analyst may determine that a 20 cent increase in transit fares is equivalent to a decrease in travel time of 10 minutes. This scenario illustrates how policy changes can be evaluated and forecasts can be made on the basis of different alternatives (Ulberg, 1989).

The ability that micro-economic, utility-based models have to quantify and assess various transportation supply options is critical to the development of transportation policy. It is also important that, although demand and supply functions are independent, micro-economic approaches have supply side applications. Supply-demand equilibrium, as defined in micro-economic theory, allows consumer demand behavior to be predicted on the basis of alternative supply side options (Kanafani, 1983). Micro-economic, utility-based models are also flexible and are more easily calibrated than other modeling approaches.

Weaknesses

Problems associated with the use of the micro-economic demand theory include the stochastic nature of consumer choice; the assumption that consumers have perfect information; the implications of consumer attitudes and values, which are difficult to quantify; and the correlation between non-pecuniary costs such as time, convenience, and comfort with a single unit that measures personal utility. Each of these issues is discussed below.

A primary problem with the application micro-economic demand theory to any consumer choice is the premise of rational behavior. In the scientific literature the concept of rational behavior is used to describe the decision process itself. "In general, it means a consistent and calculated decision process in which the individual follows his or her own objectives, whatever they may be" (Ben-Akiva, 1985). This concept is contrary to the human quality of impulsiveness, which allows individuals to respond to choices on the basis of their variable psychological state at the time they make a decision.

Problems associated with the human capacity to store and utilize information pertinent to a particular choice further limit the perfection of the economic paradigm. The concept of perfect rationality assumes an omniscient individual who can obtain and store vast quantities of information, perform complex computations, and make consistent decisions on the basis of these computations. Bounded rationality recognizes the constraints on the decision process that arise from human beings' limited information gathering and processing capabilities (Simon, 1957, in Ben-Akiva, 1986).

This approach to modeling travel behavior is termed "compensatory" because it is based on the assumption that a utility function can be developed to illustrate the trade-offs involved in a consumer's decision. For example, according to this model, a household will choose an auto that is smaller than it would like if the price of a larger vehicle is sufficiently high. Thus, one characteristic (price) compensates for the low value of another (Train, 1986). The theoretical premise is that at some point of compensation, all things will be traded. However, this premise is not realistic because of the influence of personal values. Individuals make certain choices on the basis of their belief systems, which may contradict externally perceived utility.

Micro-economic utility based models utilize cost and time while ignoring other quantifiable variables such as comfort and convenience. Researchers have demonstrated a significant improvement in predictability when the variable "convenience" is added (Ulberg, 1989). In addition, research has suggested that the use of perceived values for cost and time, as opposed to actual values, works better in explaining mode choice. (Dobson and Tischner, in Ulberg 1977, 1978)

Compensatory Relationships With Urban Form

Micro-economic theory explains how the relative costs of different urban forms affect travel decisions. Below are examples of how micro-economic theory would explain the effects of employment density, population density, land-use mix, and jobs-housing balance on various aspects of travel behavior.

Costs Associated With Population and Employment Density

High levels of employment density are associated with high parking costs, greater congestion, and high levels of transit service. According to micro-economic theory, the increased costs associated with automobile travel and the decreased costs of transit service, especially where HOV lanes were implemented, would affect travel choices. The costs of automobile travel could be measured as parking costs and the travel times associated with congestion. The costs of using transit could be measured as non-pecuniary factors such as the reduced travel time created by increased headways and express service to high density employment centers. As a result of these factors, consumers would be less likely to choose the automobile and more likely to choose transit for travel to these locations.

On the other hand, less dense settings in suburban locations are associated with low parking costs and a low level of transit service. According to micro-economic theory, modal choice favoring SOV travel to and from locations with these characteristics could be explained by the relative costs of various modes associated with this particular urban form.

Population density is associated with factors that are similar to those associated with employment density, that is, increased land prices and parking costs. However, whereas employment density impacts the trip destination end (employment is an attractor), population density impacts the trip origin (populations, or households, are trip producers). Areas with high levels of population density almost always have better transit service than areas with low population density. Increased land values associated with high population density are also related to higher costs of parking. Residents of higher population density areas may choose not to own a car because of high parking costs at their homes. These two factors together produce a subset of the high density population that is dependent on public transportation. According to micro-economic theory, the combined effect of the costs associated with high population densities at trip origins and high employment densities at trip destinations would result in the highest possible modal share for non-SOV modes.

Costs Associated With Land-Use Mix

Urban forms with high levels of land-use mix reduce the distance people must travel to access a particular type of service. Shorter distances are associated with lower travel time costs. One relationship that may be expected is that more trips are taken where the access to opportunities is greater. Simply put, where land-use mix is greater, the cost of accessing an opportunity is likely to be lower in terms of travel time or distance. This may translate into higher per-capita trip generation for residents or employees of areas where more uses are mixed (and densities are also higher). Micro-economic theory would interpret this relationship as the manifestation of latent demand. This latent demand suggests that people who live and work in areas with homogeneous land-use patterns would make more trips if travel time and distance costs were lower. According to micro-economic theory, the reduction in trip distance associated with increased land-use mix is due to the fact that individuals will choose to travel shorter distances to access opportunities, given the option. The shorter distance costs less in terms of travel time and increases person utility relative to traveling farther.

Several anomalies contradict this relationship. One example is the effect of regional shopping malls on trip length. Regional shopping malls are known to draw on extremely large market areas, thus generating long trips and travel times. This effect is due to the wide variety of goods and services that are available in regional shopping centers. In this instance, the individual may determine that the ability to accomplish several tasks in one location offers greater utility than making several shorter trips. This relationship is analyzed in detail in Regional Versus Local Accessibility: Variations in Suburban Form and the Effects on Non-Work Travel (Handy 1992).

Costs Associated With Jobs-Housing Balance

The concept of planning with a higher level of balance between jobs and households is the direct product of applying personal costs to travel behavior. Micro-economic theory would postulate that, all else being equal, people choose to live as close as possible to their place of employment to reduce time and distance travel costs. In this project, jobs-housing balance provided a measure of the travel costs for the journey to work by testing how evenly jobs and households were distributed within a census tract. Census tracts whose number of jobs and households are matched more closely are more likely to contain jobs for residents and housing for workers within the tract than tracts whose jobs to households ratios are imbalanced. Therefore, one can hypothesize that residents within highly balanced tracts will have lower travel time and distance costs than residents of umbalanced tracts. According to micro-economic theory, the effect of jobs-housing balance on the reduction of trip distance and travel time is due to the fact that people will choose to substitute shorter trips for longer trips to lower their travel costs.

NON-COMPENSATORY APPROACHES

Other approaches to modeling travel behavior have been developed to make up for the deficiencies associated with micro-economic utility based methods. These approaches attempt to account for the qualitative aspects of consumer choice. They are based on the theory that consumer choice is significantly affected by attitudes and values, which are qualitative and are inadequately explained within the personal utility optimization framework. Much of the market research pertaining to mode choice has been based on psychological decision theory. This theory utilizes attitude as a construct to describe and explain how people perceive and process the attributes of alternatives and make a choice. Cognitive decision making models have been developed in response to this theoretical construct (Ulberg, 1989). Psychometric analysis has also been employed to derive attitudes from quantitative measurement tools such as surveys and questionnaires.

Most micro-economic compensatory approaches to modeling travel behavior, particularly the multi-nomial logit method, typically assume that irrelevant alternatives are independent. Research has found that this notion is incompatible with observed patterns of preferences, which exhibit systematic dependencies among alternatives. Another approach to modeling travel behavior, the choice theory, "elimination by aspects," was developed by Amos Tversky to resolve this problem. In this theory, each alternative is viewed as a set of aspects. At each stage of the choice process an aspect is selected (with a probability proportional to its weight at that time) and all alternatives without a specified level of this aspect are eliminated. This process continues until all alternatives have been eliminated except one (Tversky, 1972). Any set of aspects can be regarded as a particular state of mind leading to a unique choice. The probabilities of each aspect merely reflect that "at different moments of time different states of mind (leading to different choices) may prevail."

Strengths

Non-compensatory approaches to studying travel behavior recognize the importance of the qualitative nature of decision making. In the case of mode choice, qualitative aspects include comfort, convenience, reliability, safety, and privacy. All of these factors are significant variables whose exclusion results in a less powerful model. These approaches attempt to provide insight into the significance of attitudes and values involved in consumer choice. They suggest methods in which the "seemingly" random nature of consumer choice can be quantitatively explained. An individual's perception of alternative choices is accounted for by several non-compensatory options. In addition, the impact of amenities and thoughtful design considerations for alternative modes is emphasized.

Weaknesses

Non-compensatory models are difficult to estimate, calibrate, and validate; therefore, they are most often regarded as inefficient in comparison to compensatory models. Non-compensatory models do not function well as policy testing devices and, therefore, are less effective as decision making aids. Quantification of qualitative factors is highly subjective. Therefore, whoever conducts this exercise will most likely be influenced by her or his own values.

Urban Form Relationships With Non-Compensatory Factors

Cultural factors such as attitudes and values vary with different levels of density and land-use mix. People who live in high density locations that contain a wide variety of uses may base their travel decisions on factors or weights that are different than those of individuals who live in low density locations. For example, some people who could afford to live elsewhere choose to live in high density locations because they value the diversity and cultural opportunities available in these locations. Other people may choose not to drive because it is against their conscience to pollute unnecessarily. These types of individuals may be willing to trade off the travel time gain of the SOV over transit because being among various types of people or being environmentally conscious is important to them. The point is that density is a surrogate for a host of factors other than costs.

Non-compensatory, or behavioral, theory would explain the hypothesis that increasing levels of density and mix reduce travel demand through the non-cost factors associated with density and land-use mix. These factors include the different attitudes, values, and perceptions of residents and workers of areas of different densities and mixes.

CHAPTER V

AN ASSESSMENT OF APPROACHES TO TEST HYPOTHETICAL RELATIONSHIPS BETWEEN URBAN FORM AND TRAVEL BEHAVIOR

Methods commonly used to assess the relationships between urban form and travel behavior are presented in this chapter. A clear understanding of possible research designs and their limitations is essential for the selection of appropriate research methods.

Several methods were considered for this ability to answer the following four questions:

- Does urban form affect travel behavior ?
- Does urban form affect travel behavior when non-urban form variables are controlled ?
- What is the magnitude of the relationships and their associated policy implications ?
- Is the relationship between urban form and mode choice linear or non-linear ?

Over the past 30 years the interaction between land use and transportation has been modeled throughout the world to provide planners and elected officials a basis on which to make resource allocation decisions. These efforts have developed various research methods. A review of these methods provided a basis for the selection of the research methods used in this project. The selection was based on the ability of the methods to answer the four questions posed above and the overall purpose of the research, which was to isolate the relationship between vectors of urban form and travel behavior. As a result of the review, five statistical methods were selected.

LAND USE—TRANSPORTATION MODELING PRACTICES

Researchers began to conduct extensive computer aided modeling of land use and travel behavior in several metropolitan regions around the United States in the early 1960s. This activity was partially the result of two sociopolitical developments (Putnam, 1991):

- the demand for scientific means for preparing highway impact statements, and

- the emergence of specific federal governmental concern with urban problems.

Another important factor was the development of digital computer technology. According to Putnam, the result was that in the late 1950s and early 1960s more was learned about the empirically observable determinants of spatial patterns than had been learned in the previous 50 years (Putnam, 1991).

Currently Adopted Modeling Practices

There is a lack of emphasis on urban form factors in currently accepted methods for modeling transportation-land use interaction. While there is acknowledgment of the relationship between decentralization, density, and travel behavior, little if any work has been done to incorporate other urban form factors (e.g., land-use mix, jobs-housing balance). This research provides some credence to the significance of urban form factors and the need to pay more attention to them in land use transportation modeling excercises.

The most widely accepted method of identifying travel demand for transportation planning purposes in the United States today is known as the four-step modeling process. This process is based upon land-use forecasts that are input at the beginning of a linear process (Meyer, 1986). These four steps and their associated analytical methods are described below.

Trip Generation

"Trip generation models are used to predict the trip ends generated by a household, usually on a daily or weekly basis" (Meyer, 1986). Models used to predict trip generation (from a household) and those used to predict trip attraction (the destination of a home or non-home based trip) differ both in methods and in weighted variables. Trip generation models fall into two categories (Federal Highway Administration, 1975 see Meyer pp. 289).

Linear regression models—Ordinary least squares regression is most often used to estimate trip generation because of the high correlation between trip generation and these variables: household income, automobile ownership, residential density, and distance of the household to the central business district (CBD). The advantages of these models are that they (Meyer, 1986)

- are very easy and inexpensive to construct,
- are highly available for current software and computing technology, and
- are conceptually easy to understand.

Linear regression models also possess a number of disadvantages. Among these, they are subject to

- multi-colinearity (the correlation among explanatory variables), which makes model estimation difficult;
- the assumption that explanatory variables may have linear "additive" impacts on trip generation, which may be wrong;
- model parameters that may not be stable over time; and
- aggregate socio-economic factors on a zonal basis, which may result in gross generalizations that are highly inaccurate regarding certain sub-populations.
- actual relationships being modeled may not be linear

Cross-classification models—These modeling approaches group households with similar socio-economic characteristics rather than by geographic location. This grouping allows comparisons among homogeneous groups. This approach may be very useful for research in which land use characteristics are the explanatory variables. Cross-classification intrinsically provides control over the factors by which groups are selected.

Trip Distribution

Trip distribution models link the zonal trip ends identified in the *trip generation* step. Ultimately, the flows from one zone's trip producers (households) are linked with the attracters from another zone (employment, shopping, entertainment). The models used to calculate trip distribution are described below.

Growth factor techniques—These were used in earlier studies but are now seen as outdated. Growth factor models started with trip movements between zones in a base year and then scaled them in accordance with the growth of attractors in each zone (Fratar; 1954 my note: see Meyer; Wilson, 1974).

Intervening opportunity models—These are difficult to calibrate and have had limited use (Stouffer, 1940).

Disaggregate destination choice models—The unit of analysis for this approach is the individual rather than the district. Disaggregate destination choice models possess a relatively rich representation of the causal factors that affect a traveler's decision making. They also possess a higher degree of transferability because they are not tied to a specific geographic location.

Gravity models—The gravity model focuses on the spatial interaction of geographic locations. The gravity model is the most common trip distribution model and represents a family of models. According to Vaughn, "These models basically state that the amount of traffic between two zones is proportional to the product of the population or attraction of the zones multiplied by a deterrence factor between the zones (based upon travel time, costs, or distance between zones)," (Vaughan, 1987).

Modal Split

The purpose of modal split models is to predict the percentages of trips that will be taken by various modes. When the percentages are calculated before the trip distribution step in the UTPS, the method is known as *trip-end modeling*. When they are calculated after the trip assignment step, the method is known as *trip interchange modeling*.

Trip end models—This approach to modeling modal split assumes that transit riders share certain socio-economic characteristics and are "captive" riders. The term captive ridership, when applied to transit, conveys the notion that these riders have no other available means of transportation.

Trip interchange models—Because trip interchange models are utilized after the trip distribution step in the modeling process, they have the advantage of applying service characteristic information (associated travel time, costs per mode, land use) as well as socio-economic factors. Multinomial Logit Modeling (a form of disaggregate modeling) has been found to be particularly useful in determining modal split. This method will be discussed in greater detail in the next section.

Trip Assignment

In this final stage of the UTPS, trips are assigned to actual routes within the transportation system. The underlying assumption of the assignment technique is that the traveler will choose the route that minimizes travel time and cost. Imperfect information and perceptions affect the traveler's decision making process, hampering the techniques' ability to predict route choice. Traffic assignment techniques include the following.

Minimum path (all-or-nothing) assignment—This method assumes a perfect or ideal world in which no capacity constraints (i.e., congestion) exist. This approach is highly simplified and bases all trip assignments on the premise of least cost. The results are relatively easy to understand; however, this assignment technique does not provide a realistic depiction of the actual transportation network, which suffers from factors associated with congestion.

Equilibrium assignment—This trip assignment technique accounts for the effects of limited capacity and associated congestion by utilizing an algorithm to reallocate trips from links where congestion occurs to other, less congested links

(USDOT, 1978). Therefore, equilibrium assignment interprets costs as a function of network flows.

Stochastic assignment—In addition to recognizing cost as a function of user flow levels, stochastic assignment accounts for the randomness within the decision making process. This technique recognizes that several alternative routes may exist between an origin and destination, and travelers may perceive these as having identical travel times and equally attractive. Stochastic assignment treats cost factors associated with particular routes as random (Meyer, 1984).

Criticisms of the UTPS Modeling Process

Urban form is only accounted for in the first stage (trip generation) of the linear UTPS modeling process. While linear regression models used in the trip generation stage of the UTPS modeling process can include density and regional location factors, they most often do not account for land-use mix or jobs-housing balance. The findings from this research and other efforts suggest that these models could account for a greater understanding of travel behavior if measures of land-use mix and jobs-housing balance were included.

According to Guiliano, "The UTPS is completely sequential; there is no feedback from one step to another. As a result there is no interaction between transportation supply and demand" (Guiliano, 1984). Travel demand is calculated without any consideration for system supply (transportation network), except in the final network assignment. This process ignores reality. Planners know that the basis of travel demand is the distribution of population and employment and other activities within a given area. The choice of given destinations is a function of travel time and costs. Modeling is based on the premise that individuals will choose to minimize their costs, thus behaving rationally. Therefore, given two destinations with similar characteristics, the one that is the most accessible will attract the most activity. Because the interaction of supply and demand changes over time, it cannot be explained by the UTPS method (Guiliano, 1984).

If the adopted land-use-transportation modeling process is not interactive, then how can our planning account for the relationship between land use and transportation? To make transportation planning and land use more interactive, a feedback loop would be needed so that land use could be manipulated on the basis of model output. In return, the proposed transportation network could be manipulated until some desired state was reached. This empirical model would allow an integrated set of transportation infrastructure and land-use policies to be developed.

Integrated Approaches to Modeling Transportation and Land-Use Interaction

Transportation planners seldom use integrated models. Webster has commented, "While many of the fully integrated land use/transport models so far developed have been used to analyze policies in particular cities, it is comparatively rare for transport planners to use them in preference of the universal '4-step' transport model" (Webster, et al., 1988). In light of the fact that transportation and land use are obviously interdependent, it is unfortunate that transportation planners choose to model land-use patterns as a given, ignoring the fact that changes in the transport system induce changes in land use. The reluctance to use fully integrated models is attributed to their relative complexity and perhaps also a lack of faith in them. The historical development of fully integrated models is also significantly responsible for their lack of acceptance. When the first integrated models were introduced they promised too much and were extraordinarily difficult to calibrate. Over time, these models have improved and become easier to use. Two of the earliest models are the Lowry Model and the EMPIRIC Model (Meyer and Ibanez, 1981). The Integrated Transportation Land Use Package (ITLUP), developed by Stephen Putnam, is also described below because of its widespread use and its impact on the development of regional simulation models.

The Lowry Model

The Lowry Model, named after its founder Ira S. Lowry, is based on the theory of urban spatial interaction (Webber, 1988). This theory postulates that the location of activities within an urban area is a function of the relationship it shares to other activities and the locations of these other activities. The Lowry Model predicts the location of residences and population-serving employment within a metropolitan area. The number of residences within each zone is assumed to be a function of the distance between the zone and major employment nodes, as well as the amount of developable land in a zone. This is an application of the gravity model.

The Lowry Model distinguishes between basic and population-serving industries. The location of basic employment is fixed, while the location of population-serving employment is assumed to be a function of the population within the zone and adjacent zones. Therefore, the Lowry Model's potential to forecast transportation's impact on development patterns is compromised by the fact that any shift in "basic" employment is overlooked (Meyer and Ibanez, 1981). Derivatives of the Lowry Model include the Projective Land Use Model (PLUM) and the Interactive Projective Land Use Model (IPLUM) (Putnam, 1983).

Empiric

EMPIRIC uses extremely simple versions of conventional residential and workplace theory location models to account for future distribution of population and employment. This simulation technique is based on a set of simultaneous linear equations. Usually the model uses approximately 10 equations and 50 to 60 variables (Moore, 1975). EMPIRIC divides employment into several categories: manufacturing, retail, service, financial/insurance, real estate, and other. The future level of employment is assumed to be primarily a function of the zone's future population levels, an index of its future accessibility by automobile and transit, and its current quantity of vacant land.

Future population is assumed to be a function of past population level and future auto and transit accessibility between the zone in question and major employment centers.

Integrated Transportation and Land Use Package (ITLUP)

In 1971 a USDOT grant titled "Inter-relationships of Transportation Development and Land Development" was awarded to Stephen Putnam (USDOT, 1971). The result of this grant was the development of the Integrated Transportation and Land Use Package (ITLUP). According to Webster, "This model takes the exogenous regional forecasts of total employment, population, activity rates and household size at each time point, and predicts the spatial location of households in each zone of the study area, and the interzonal patterns of work and shopping trips on two modes, public and private transport" (Webster, 1988). The modeling package is divided into two sub-modeling routines known as DRAM and EMPAL. EMPAL is responsible for the location of employment-related land uses. EMPAL locates four categories of employment by considering the access costs of different populations from each zone in the study area and the existing location of employment of the same type. Residential location is calculated by DRAM, which is a Lowry type model. It usually distributes households into four income groups by using a derived attractiveness function. This attractiveness function is the product of the following variables: vacant developable land, the presence of necessary services, the social mix of the resident population, and accessibility to employment of different types. ITLUP has been applied most extensively to the San Francisco Bay area, with up to 291 zones for certain applications (Webster, 1988).

The results of these simulation efforts support the location theory postulation that transportation investment and land use have a causal relationship. These efforts have revealed that, in addition to the causal factors presented in location theory (transportation costs), other variables, including "cost and suitability of land, and buildings, labor market conditions, available services, social factors, and, for households, life-cycle and life-cycle considerations, are also critical factors in location choice" (Deakin, 1991).

Over the past three decades several other interactive land use transportation modeling packages have been developed. They are listed in Table 5.1 with their date of development and originating country.

Table 5.1. Transportation Modeling Package

MODEL NAME	COUNTRY OF ORIGIN	DATE
TOPAZ	Australia	1970
DORTMUND	Germany	1977
CALUTAS	Japan	1978
OSAKA	Japan	1981
AMERSFOORT	Netherlands	1976
SALOC	Sweden	1973
LILT	UK	1974
MEP	UK	1968

(Source: ISGLUTI Study, 1988)

CALUTAS, DORTMUND, ITLUP, LILT, and MEP incorporate detailed characteristics of several modes. The significance of this is that these models allow users to desegregate travel demand forecasts by mode, purpose, and/or population characteristics. AMERSFOORT and TOPAZ allow interzonal trip patterns to be forecast, but neither utilizes an explicit transportation network (Webster, et al., 1988).

Criticisms of Integrated Land Use Transportation Modeling Packages

Criticisms of these modeling approaches are widespread. These models were developed approximately 20 years ago, when different problems affected urban areas. The use of models developed in response to planning issues that were critical 20 years ago in today's urbanized locations has met with limited success at best. Prastacos said, "These models represent the planning concerns of their time, concerns that were different in scale and scope from today's problems. They describe an urban environment with a population composition, economic structure, and geographic distribution significantly different from the one that exists today" (Prastacos, 1985).

Other criticisms stem from the lack of focus attributed to the individual decision maker. Simply put, aggregate approaches do not provide sufficient information to accurately predict choices made by differing population groups.

Qualitative Choice Models

A newer set of models has been developed in response to the criticisms of aggregate methods. The shift to disaggregate modeling approaches is attributable to the following reasons (Train, 1986):

- Microeconomics theory is inherently more applicable at the individual level and can be drawn upon in specifying and interpreting disaggregate models to a degree not possible with aggregate models.
- Survey data on households and individual firms are becoming more available, enabling planners to estimate disaggregate models where it would have been previously impossible.
- More precise testing of underlying parameters has been made possible by the availability of disaggregate level data.

Qualitative choice models focus on the individual decision maker. "All qualitative choice models calculate the probability that a decision maker will choose a particular alternative from a set of alternatives, given data observed by the researcher" (Train, 1986). Examples of qualitative choice models include the LOGIT and PROBIT models. According to Deakin, "These models typically include, in addition to land use and transportation accessibility variables, detailed household, socio-economic, and lifestyle descriptors (including the number of workers present, household income, age of household members, presence of children, etc." (Deakin, 1991).

Findings suggest that the currently adopted four-step modeling process is insensitive to land use and characteristics of travel demand. Interactive approaches to modeling transportation and land use have met with some success; however, they are unable to accurately predict individual choice or to fully utilize the properties of microeconomics as applied to consumer choice. Qualitative choice models offer the most potential to reach the goal of predicting household travel behavior because of their focus on the individual decision maker.

STATISTICAL TECHNIQUES USED FOR HYPOTHESIS TESTING IN THIS PROJECT

On the basis of the review of transportation and land modeling practices, this project chose an approach most akin to qualitative choice models to allow disaggregate modeling to be conducted at the household level. In predicting household level travel behavior, the project could make full use of the demographic data supplied by the Puget Sound Transportation Panel (PSTP). In addition, qualitative choice models are based on personal utility functions, which allow microeconomic theory to be applied to the individual decision maker.

The following statistical methods were applied at the disaggregate or household level and at the census tract level. Where they were applied at the census tract level, mean values for demographic characteristics were calculated from household level data to minimize loss through aggregation and to retain the applicability of microeconomic theory.

T-Test

The purpose of using the t-test was to compare the mean travel time and trip distance for travelers moving to and from census tracts whose ratio between jobs and households was balanced and tracts whose ratio between jobs and households was imbalanced.

T-tests were used in this analysis to determine whether work trips that ended in census tracts whose jobs to households ratio was close had a shorter trip distance or travel time than trips ended in tracts with a wider ratio. A t-test is used to compare the mean or average values between two unique subsets of cases. For example, all census tracts in the study that had a jobs to household ratio of between 0.8 and 1.2 were grouped into a category that was considered "balanced." All other census tracts were in another group considered imbalanced. The t-test was then applied to identify the mean trip distances and travel times for each of these groups. The t-test provided a statistical method to determine whether the difference between the mean trip distance and travel time values were significantly different from zero in the study population. Therefore, the t-test is an extremely simple means to test a hypothesis by comparing mean values for unique groups within a sample. Two types of errors are associated with t-tests. The first error (type 1) occurs when findings suggest two means are not equal when in fact they are; the second (type 2) occurs when two means are found to be equal when in fact they are not.

Correlation

Correlation was used in this analysis to interpret whether a relationship existed between urban form and travel behavior without controlling for other factors. Correlation was also used to test whether the relationship between an urban form or non-urban form variable and a travel behavior variable was positive or negative.

The Pearson correlation coefficient, commonly abbreviated as "r," measures the degree to which a *linear* relationship exists between two variables (Norusis 1990). A perfect, positive linear relationship between two variables has a value of 1.00, while a perfect, negative linear relationship has a value of -1.00. No relationship at all is recorded as 0.00. While past research has indicated that most relationships between travel behavior and urban form are non-linear, the Pearson correlation provided a basis for determining the degree to which urban form and travel behavior variables were related to one another. Correlation coefficients were presented (both urban form and non-urban form) by dependent variable. The generalizability of this relationship to the study population was explained through the population correlation coefficient (p). The lower the value of (p) is, the more statistically significant is the relationship indicated by the

Pearson correlation coefficient (r). A (p) value of less than .05 is commonly accepted as the point at which the linear relationship between two variables is significant.

Partial Correlation

Partial correlation is used to test the relationship between phenomena while controlling for intervening factors.

Partial correlation is similar to correlation described above. The only difference is that partial correlation rules identify the effects of additional variables on the relationship between two variables. "The partial correlation coefficient, a technique closely related to multiple regression, provides us with a single measure of linear association between two variables, while adjusting for the linear effects of one or more additional variables" (Norusis, 1990). When applied correctly, partial correlation could help uncover deceptively strong relationships between urban form and travel behavior variables. Partial correlation can also be used to identify which intervening variables are most significant.

Multiple Regression

Multiple regression is used to test the relative contribution of independent variables that explain the variation in a dependent phenomenon, explain the nature (positive or negative) and slope of the relationship, and provide a means to control for intervening factors.

Regression analysis is a form of hypothesis testing used to determine the degree to which one variable impacts another (Babbie 1989). Regression analysis techniques are used to test for a linear relationship between dependent and independent variables. Unlike correlation, regression involves the identification of a dependent variable, e.g., *mode choice,* and one or more independent variables, e.g., *employment density.* Most regression analysis involves the development of a model (usually in the form of an equation representing a line) that allows a hypothetical relationship to be tested. The development of the model (the regression line) represents the ability to predict the nature and degree to which a change in the dependent variable can be explained by one or more independent variables. For example, past research has found that transit ridership (dependent variable) increases as population and employment density increase (independent variables). With regression, it would be possible to predict the amount of transit ridership that would result from various levels of population and employment densities. Regression analysis was utilized in this research to test the hypothesis that increasing levels of employment density, population density, and land-use mix result in reduced dependence on single occupant vehicle (SOV) travel.

Overall Measures of Regression Models

Adjusted R-Square. The adjusted r-square indicates the level of variability in the dependent variable that is explained collectively by the independent variables.

Test(s) for significance. The null hypothesis (that no linear relationship exists between the dependent and independent variables) is rejected or accepted on the basis of the interpretation of the F-statistic (Sig.F) and F-value. The F-statistic indicates the overall "goodness of fit" of the model. The closer to zero the F-statistic is, the greater is the likelihood that the model is statistically significant and that a linear relationship between dependent and independent variables does exist. The F-value is the ratio of the mean square for regression to the mean square for the residuals. The stronger the linear relationship is between the dependent variable and the independent variables, the higher is the F-value. The range in F-values for the models in this analysis was between 7.2 and 135.42.

Degrees of Freedom. The degrees of freedom indicate the number of cases (census tracts) within the sample that the model represents. The greater the percentage of possible cases that is represented by the model, the better.

Measures of Variables Within Regression Models

Beta Weights. The strength of each independent variable's (urban form and non-urban form) relationship with the dependent variable is indicated by the value of the beta. The higher the *absolute* value of the beta, the greater is the explanatory power of the variable within the particular model. A negative relationship is denoted with a negative beta.

Slope. The B-value is the coefficient of the independent variable used in the regression model. The B-value indicates the *slope* of the regression line modeled between each independent variable and the dependent variable. This relationship is used to determine the *magnitude of the relationship* between an urban form variable (e.g., population density) and the dependent variable (e.g., percentage of SOVs). For example, when percentage of SOVs at trip destinations is modeled, the independent urban form variable *average employment density at trip origins and destinations* has a B value of -0.28. This indicates that every additional employee (one unit) of the independent variable, (employees per acre) will result (all else being equal) in a -0.28 percent decline in SOV usage.

Test For Significance (Sig T). This statistic indicates whether the B coefficient and beta weight for each independent variable within a model are significantly different from zero. The nearer the T-value is to zero, the greater is the likelihood that the independent variable has a linear relationship with the dependent variable.

Cross-Tabulation

The purpose of using cross tabulation was to test for non-linearity between urban form variables and mode choice.

Cross tabulation was used in this study as means of documenting the distribution of trips taken by mode at varying levels of population density and employment density. Cross-tabulation is not applied to land-use mix because mixed use was not foound to have a non-linear relationship with mode choice. Between seven and nine intervals were created for density variables to determine the distribution of trips at varying levels of density. Plots were based on the relationship between recoded density variables (from continuous to interval) and measures of mode choice for SOV, carpool, transit, and walking.

CHAPTER VI

THE DEVELOPMENT OF A URBAN FORM—TRAVEL BEHAVIOR DATABASE

The databases used in this study were designed to do three things:

- to test hypotheses explaining the relationship between urban form and travel behavior while controlling for intervening variables that also affect travel behavior;
- to test urban form relationships with travel behavior at both trip ends collectively as opposed to one trip end independently; and
- to test urban form and travel behavior relationships for work trips and shopping trips independently.

A summary of the data needed for this study is presented in Table 6.1. These data enabled the team to explore associations between urban form and travel behavior for specific trip purposes while controlling for non-urban form factors that also affect travel behavior.

Table 6.1. Data Needed for Study

Urban Form Data	Population density Employment density Land use mix Jobs-housing balance
Travel Behavior Data	Trip generation by purpose Trip mode by purpose Trip distance by purpose Travel time by purpose
Control Variable Data	Transit level of service Household characteristics

The research team collected these data from a variety of sources, which are listed in Table 6.2.

Table 6.2. Data Sources

SOURCE	DATA
Puget Sound Transportation Panel (PSTP)	Travel behavior Transit level of service Demographic factors
U.S. Census Bureau	Population
Washington State Employment Security Department (DES)	Employment
Puget Sound Regional Council (PSRC)	Area of census tracts in acres (for calculating density)
King County BALD File	Land-use mix

The Puget Sound Transportation Panel (PSTP) provided data on travel behavior and control variables. Urban form data were obtained from the other four sources. These data described the characteristics of census tracts where trips originated and ended. Thus, this study focused on the effects of urban form at the census tract scale. District or census tract population and employment were divided by the area of the census tracts (in acres) to obtain the gross population and employment density for each tract. Data used to compute land-use mix for each tract were obtained from King County.

THE TRIP LEVEL DATABASE

The relationship between urban form and travel time, trip distance, and trip generation were studied using a database that contained information about nearly 30,000 individual trips taken in 1989 by about 1,500 households. For each trip in the survey, data were collected about the trip, the urban form in the census tract where the trip began and ended, the transit level of service at the trip origin and destination, and the characteristics of the trip makers' households. Data on travel behavior, demographics, employment, and population were available for King, Pierce, and Snohomish counties. Data on land-use mix was only available for King County.

MATCHING DATA SOURCES BY CENSUS TRACT CODE

Data from the five sources were incorporated into one database using census tract numbers that were common to all five sources.

Each of the five data sources, however, had its own method of coding census tracts, which complicated the process of sorting and matching the database. Complications arose from random usage of 1980 or 1990 census tracts designations. This was particularly critical because tracts that had been subdivided in 1990 were tracts where significant growth had occurred over the decade. For example, data from the Employment Security Department (ESD) on Seattle's University District had been coded with the 1980 designation (59.00), whereas all of the other sources had used the 1990 designation, dividing the University District into two tracts (59.01 and 59.02). To further complicate the matching process, coding schemes used to code tracts differed by data source.

Table 6.3. Census Tract Coding Scheme by Data Source

DATA SOURCE	NUMERIC CODING METHOD	1980 AND/OR 1990 DESIGNATIONS
Puget Sound Transportation Panel	five digits with no decimals (10002)	both 1980 or 1990 designations
1990 Census File Stf-1	five digits plus a decimal place (100.02)	1990 designation
Department of Economic Security	five digits with no decimals (10002)	1980 designation
King County BALD file	four digits with no decimal deleting the fourth digit (1002)	both 1980 or 1990 designations
Puget Sound Regional Council	five digits plus a decimal place (100.02)	both 1980 or 1990 designations

For example, census tract 100.04 may have been coded 10004, 100.04, or 1004, depending on the data source. Table 6.3 presents the methods each source used to code census tracts.

Table 6.3 reveals the great inconsistencies among the ways in which the five data sources designated tracts. Logically, the 1990 Census file (Stf-1) should have had all of the new census tract designations. However, census tracts from the King County BALD File, The Puget Sound Regional Council, and the Puget Sound Transportation Panel (PSTP) had been randomly recoded to match new designations. Without any justification for reallocating jobs from Employment Security data or parcels from the King County BALD File into one of two or more new tracts, the only alternative was to aggregate back to 1980 designations. Therefore, all of the tracts were reviewed (574) to identify those that were missing cases from any of the data sources listed above. Each tract that was missing cases from any of the data sources was manually recoded. This process was considered critical to the creation of a database that accounted for areas in the region where new growth and activity had been significant enough to justify the sub-division of census tracts.

Further complicating the process of matching the database by census tract was the requirement to numerically recode all of the tracts from data sources that did not utilize the five digit format with a decimal place. By aggregating tracts back to their 1980 designations and numerically recoding to create a consistent format, the research team was able to match data from the five sources into one database with very few missing cases.

DESCRIPTIONS OF EACH DATA SOURCE AND PREPARATION METHODS

Information from the five data sources presented in Table 6.2 was obtained as raw data and required various manipulations to become useful for this project. This section describes the data sources and the process used to develop variables from them.

<u>Puget Sound Transportation Panel (PSTP)</u>

The PSTP is a longitudinal cohort study that collected data in 1989, 1990, 1992, and 1993. "The Puget Sound Transportation Panel (PSTP) is the first application of a general urban transportation panel survey in the United States. Following the Dutch National Mobility Panel, it responds to the needs for direct data on the effects of demographic characteristics and transportation conditions on household travel behavior in an urban area" (Murakami and Watterson, 1990). Between 1989 and 1992, the survey retained approximately 70 percent of the 1680 original households located in King (709), Snohomish (413), Pierce (368), and Kitsap (190) counties. This project is based on the 1989 wave of PSTP for King, Snohomish, and Pierce counties.

The PSTP data were structured in four tiers, represented in Figure 6.1.

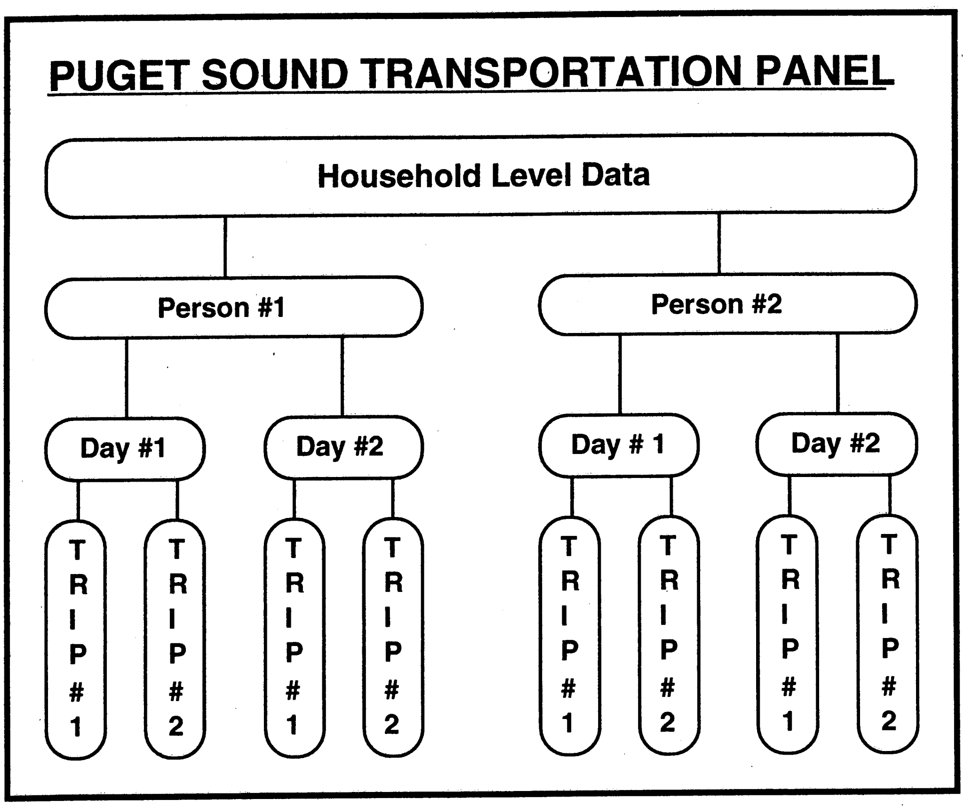

Figure 6.1. Puget Sound Transportation Panel

Each of the approximately 28,955 valid trips included in the PSTP's 1989 survey was coded to a day, person, and household. Household and person level data were obtained through telephone interviews. These data mostly pertained to demographic information and people's perceived travel characteristics. Travel diaries were filled out over a two-day period by household participants who were over 15 years old. These diaries contained detailed travel behavior information, including trip length, travel time, trip purpose, and mode choice. Each trip end was coded to a census tract, which was part of the trip level data. Data at the household and person level were matched by household ID. Data from the trip file were matched to this file by household ID, person ID, and day number (1 or 2). This process enabled the PSTP to attach household level, person level, and day information to each trip.

Weighting

The sampling technique the PSTP used for the data collection is known as "choice based." According to Pendyala et al., "Choice based sampling has become widespread in transportation planning studies largely in response to rising costs of surveys and the need to study infrequent travel choices" (Pendyala, Goulias, Kitamura, 1991). Transit and carpooling were the "infrequent" travel choices that were surveyed—and over-sampled—in the PSTP. Therefore, the survey contained more transit and carpool households than would normally have been found in the population. Conversely, SOV households and associated trips were under-sampled, resulting in an under-representation of SOV trips.

A weighting system was used to produce a sample that would be representative of the study population. This was accomplished by using weights developed by Pendyala, Goulias, and Kitamura. All of the households in the survey were coded according to whether they were SOV, transit, or carpool oriented. This determination was based on the criterion that households were SOV unless at least one person in the household made at least four one-way trips by transit or carpool each week. As a result of this criterion, 1149 households were designated SOV, 354 transit, and 180 carpool. SOV and carpool households were multiplied by 1.108, and transit households were multiplied by .4073. The result was that transit households were reduced and carpool and SOV households were increased to levels that were more representative of the study population.

Trip Chains

Another complication associated with the PSTP data involved trip chaining. Because trips are frequently made in a sequence, the mode choice of one is often a function of the mode used for the previous trip. For example, one trip may be from work to the store by SOV and a second from the store to home by SOV, creating a "trip chain." The choice to travel from the store to home by SOV is determined by the original choice to travel from work to the store by SOV. Therefore, it would be logical to account for whether a trip was part of a trip chain when attempting to isolate the impact of urban form on mode choice. However, because each trip in the database was coded independently, it was impossible to identify where a trip chain began and ended. Therefore, trips were analyzed in this study without reference to whether they were part of a trip chain.

U.S. Census Bureau

The primary purpose of using information from the Census Bureau was to obtain data on the numbers of people and households within each census tract. Data from the U.S. Census of Population and Housing were made available by the Puget Sound Regional Council (PSRC). Data used for this study were from summary tape file 1 (1990 STF1-A), which contained data for the four-county PSRC region. The census files included King (STF1KNG1.prn), Snohomish (STF1SNO1.prn), and Pierce counties (STF1PRC1.prn). These data required no major manipulations outside of matching the census tract field to the other data sources.

Washington State Employment Security Department (ESD)

The primary purpose of using information from the Washington State Employment Security Department (ESD) was to obtain data on the numbers of jobs and employers within each census tract. Data from the ESD were made available by the Puget Sound Regional Council (PSRC). Employment data were used for this study from King, Snohomish, and Pierce counties. The basic source for the employment data was the ESD's ES-202 files. These files contain data on firms, organizations, and individuals whose employees are covered by the Washington Employment Security Act (PSCOG, 1991). The data from these firms are collected through payrolls submitted quarterly to the ESD, which the ESD then produces as quarterly county employment and wage reports.

Weighting

The ESD data only contain information on employees covered by the Washington State Employment Security Act; therefore, they are not a comprehensive survey of the total number of jobs or employers in each census tract. The ESD estimates that it covers more than 85 percent of all wage and salary jobs in the state of Washington (PSCOG, 1991). The locations of the additional jobs (an estimated 15 percent) are unknown.

To obtain an accurate estimate of employment figures by census tract in King, Snohomish, and Kitsap counties, each census tract's employment statistics (number of jobs and employers) were factored from 85 percent to equal 100 percent. A multiplier of 1.176 (85 x 1.176= 99.96) was used to equally distribute the additional 15 percent of jobs and employers over the census tracts in the study. The uniform distribution of additional jobs not alter the *relative value* of each census tract's total employment.

King County Building and Land Development File (BALD)

The King County Building and Land Development File (BALD) was provided by the King County Assessor's Office. The BALD file is an enormous database that contains information pertaining to approximately 500,000 parcels in King County. The purpose of using the BALD file was to develop a measure of land-use mix at the census tract scale. Such a measurement was possible because each parcel was coded to a census tract in 1991. Each parcel in the BALD file has a field for land-use code, lot size, and the area or square footage of use. Therefore, the amount or intensity of use (in square feet) devoted to particular land uses within each census tract could be quantified (using the area or square footage). Ultimately, the goal was to develop a measure of land-use mixing that would indicate how evenly total use (in square feet) was distributed within a census tract among a predetermined set of land uses.

On the basis of a literature review and interviews with subject matter experts, the research team determined that relatively little empirical research has been conducted to test the relationship between land-use mix and travel behavior. One study focused on the employment center (Cervero, 1988). Findings from this study suggested that the presence of office, retail, and housing within an employment center can substantially reduce travel demand.

An in-person interview was conducted with Dr. Cervero at the University of California at Berkeley to identify the best method to measure land-use mix at the census tract scale. Dr. Cervero used an entropy measure in his research, which is described below. Another method to determine zonal land-use distribution is the Zonal Lorenz curve, which is based on a "Gini" coefficient that determines the unevenness of distribution (Green 1980).

The entropy index method was selected because it provides a descriptive statistic of the degree of heterogeneity between a variety of uses, whereas the Gini coefficient is more useful in determining an equitable distribution. Because little theoretical information on the ideal or most equitable distribution of land uses exists, it was more logical to utilize the entropy index method.

The BALD File has a land-use classification system with several hundred possible designations. A set of seven land-use classifications were developed on the basis of information from the literature and subject matter experts. In particular, Dr. Cervero suggested that institutional and entertainment classifications would have been useful in his work. Underpinning the selection of these seven land use categories was the hypothesis that people who live and work in census tracts with a wider variety of land uses will incur less demand on the transportation system.

The seven land-use categories selected for the in entropy index are as follow:

- single family residential,
- multi-family residential,
- retail and services (commercial),
- office (commercial),
- entertainment,
- institutional, and
- industrial/manufacturing.

The entropy index was based on the following equation:

level of land-use mix (entropy value) = -{[single family * $\log_{10}$(single family)] + [multi family * $\log_{10}$(multi family)] + [retail and services * $\log_{10}$(retail and services)] + [office * $\log_{10}$(office)] + [entertainment * $\log_{10}$(entertainment)] + [institutional * $\log_{10}$(institutional)] + [industrial/manufacturing * $\log_{10}$(industrial/manufacturing)]

This equation resulted in the development of a normalized value of between 0 and 0.845 (the log of K or the number of categories, which was to be seven) assigned to each census tract. A census tract that had all seven categories of land use whose square footage of development was evenly distributed among these categories would have a value of .845. This is unlikely to occur; however, one tract did come close with a value of 0.794.

Puget Sound Regional Council (PSRC)

The primary purpose of obtaining data on the land area of each census tract was to calculate gross population and gross employment density. Raw data provided the area of each census tract in square miles for every census tract in King, Pierce, and Snohomish counties. The area in square miles was first converted to acres. Then the area of each census tract (in acres) was used as a divisor to develop measures of gross employment and population density for each census tract.

The Tract Level Database

Mode choice is a nominal variable and, as such, was not suitable for the multiple regression analysis used in the study. To convert mode choice into continuous variables that would be more suitable for dependent variables in multiple regression modeling, the percentage of all trips originating or ending in each census tract by mode was calculated. These new modal proportions were used together with urban form and control variables to build a database in which the census tract was the basic unit of analysis.

To generate control variables, mean household characteristics were computed for each census tract. For example, the mean or average income for survey households within each tract was calculated. Where demographic variables were categorical (e.g., household type), the proportion of the households in each census tract from each category was calculated.

The aggregation process resulted in the development of considerably smaller files. Four files were developed through this process that allowed the relationships between urban form and mode choice to be analyzed separately for two trip purposes (work trips and shopping trips) at both origins and destinations.

CHAPTER VII

DESCRIPTIVE STATISTICS FOR SELECTED TRAVEL BEHAVIOR, URBAN FORM, AND NON-URBAN FORM VARIABLES

The purpose of this chapter is to present descriptive statistics for variables generated from the data sources described previously. Only variables that were found to be significantly related to travel behavior are presented in this chapter.

TRIP LEVEL VARIABLES

Descriptive statistics are presented in Table 7.1 for the work and shopping trip subsets of the trip level database.

Table 7.1. Trip Level Variables From the Puget Sound Transportation Panel

Variable Name	Trip Purpose	Mean	mode	Std Dev	Minimum	Maximum	Valid cases
agegp	age group of household survey participant * (1=15-17, 2=18-24, 3=25-34, 4=35-44, 5=45-54, 6=55-64, 7=65-98, 8=refused)						
	SHOP		4	1.61	1	8	3692
numveh	number of household vehicles * (1 = one vehicle through 8 = eight vehicles)						
	SHOP		2	1.15	0	8	3692
busdisto	distance to nearest bus stop from trip origin * (1=<2 blocks, 2=3-5 blocks, 3=>5 blocks, 4=<1/4 mile, 5=1/4-1/2 mile, 6=1/2-1 mile, 7=>1 mile, 8=other, 9=don't know)						
	WORK		1	2.69	1	9	4818
	SHOP		1	2.66	1	9	3692
numtrips	number of trips per two day period made by household survey participant						
	WORK	5.26		2.67	1	18	4818
	SHOP	6.74		2.89	2	18	3692
tripdist	distance of trip in miles						
	WORK	8.91		8.92	0.3	68.17	4739
	SHOP	4.467		4.93	0.3	40.9	3669
travtime	time required to take trip in minutes						
	WORK	21.49		15.58	1	120	4711
	SHOP	14.34		11.24	1	120	3689

* indicates variable is categorical (either ordinal or nominal)

Age group and number of household vehicles were related to shopping travel behavior, while transit level of service at trip origins was related to both work and shopping travel behavior. People between 35 and 44 years of age made the most shopping trips, and most shopping trips were made by households with two vehicles. Work and shopping trips in the survey most frequently originated within 1/4 mile of a transit stop.

The mean number of work trips and shopping trips survey participants took were 5.26 and 6.74, respectively (for a two-day period). Travel impacts from shopping trips were somewhat mitigated by the fact that their distance (4.47 miles) was shorter than that of work trips (8.91 miles). The mean travel distance for work trips was approximately twice the mean distance for shopping trips. The mean travel time for work trips was 21.49 minutes, while for shopping trips it was 14.34 minutes, a difference of approximately 50 percent.

TRACT LEVEL VARIABLES

Mode Choice Variables

The mode choice variables presented in Table 7.2 describe the proportion of work and shopping trips to or from each census tract by SOV, carpool, transit, and walking. Approximately 2 percent of the work and shopping trips in the database were taken by other modes (e.g., paratransit, bicycle, taxi).

The modal mix of work trips originating from the typical census tract was clearly dominated by the SOV (74.76 percent), followed by carpools (14.33 percent) and then a small proportion of transit (5.16 percent) and walking (3.69 percent). An even smaller proportion of work trips ending in the average tract were made by bus (1.68 percent) and foot (3.37 percent).

Carpool trips composed a much greater proportion of shopping trips than work trips. This proportionate gain in carpool shopping trips was primarily the result of a lower proportion of SOV shopping trips.

Table 7.2. Census Tract Level Mode Choice Variables

Variable Name	Trip Purpose	Mean	Std Dev	Minimum	Maximum	Valid cases
sovpctO	percent of trips originating in census tract made by SOV					
	WORK	74.76	26.66	0	100	509
	SHOP	58.61	30.39	0	100	497
sovpctD	percent of trips ending in census tract made by SOV					
	WORK	80.09	25.94	0	100	446
	SHOP	58.94	33.07	0	100	393
crplpctO	percent of trips originating in census tract made by carpool					
	WORK	14.33	21.51	0	100	509
	SHOP	34.98	29.85	0	100	497
crplpctD	percent of trips ending in census tract made by carpool					
	WORK	13.06	21.93	0	100	446
	SHOP	33.63	31.72	0	100	393
buspctO	percent of trips originating in census tract made by transit					
	WORK	5.16	13.34	0	100	509
	SHOP	1.23	6.35	0	100	497
buspctD	percent of trips ending in census tract made by carpool					
	WORK	1.68	5.48	0	51.81	446
	SHOP	1.45	8.45	0	100	393
walkpctO	percent of trips originating in census tract made by walking					
	WORK	3.69	12.52	0	100	509
	SHOP	3.16	10.03	0	100	497
walkpctD	percent of trips originating in census tract made by walking					
	WORK	3.37	12.44	0	16.67	446
	SHOP	4.165	14.53	0	100	393

Demographic Variables

Table 7.3 shows that the household types most highly related to mode choice for shopping trips were households of a single adult under 35 and households of a single adult between 35 and 64. They composed, on average, about 3 and 5 percent of the households making shopping trips to the typical tract, respectively.

Hhtype 5 (single adults over 65) was the group most highly related to work trip mode choice. They composed an average of about one half percent of the households that made work trips to the typical census tract.

Table 7.3. Census Tract Level Demographic Variables Based on Trip Destination Data

Variable Name	Trip Purpose	Mean	Std Dev	Minimum	Maximum	Valid cases
hhtype3	proportion of survey households per census tract with one adult less than 35 years old					
	SHOP	3.13	12.99	0	100	393
hhtype4	proportion of survey households per census tract withone adult between 35 and 64 years old					
	SHOP	5.97	16.4	0	100	393
hhtype5	proportion of survey households per census tract with one adult over 65 years of age or older					
	WORK	0.456	5.113	0	100	446
license1	proportion of survey participants per census tract that have a driver's license					
	WORK	98.07	8.31	0	100	446
	SHOP	90.98	18.58	0	100	393
employ1	proportion of trips ends per census tract made by survey participants that are employed outside the home					
	WORK	93.49	19.11	0	100	446
	SHOP	57.86	31.3	0	100	393
buspass1	proportion of trip ends per census tracts made by survey participants with a buspass (based on trip destination data)					
	SHOP	4.3	19.05	0	100	116
vehavail	proportion of trip ends per census tract made by survey participants that have access to less than one to themself					
	WORK	9.41	21.64	0	100	446
	SHOP	11.07	20.98	0	100	392
numveh	mean number of vehicles available for survey participants ending trips in each census tract					
	SHOP	2.23	0.725	0	6	393
age	mean age of survey participants ending trips in each census tract					
	SHOP	47.28	12.44	16	82	393

On average, more than 90 percent of the work and shopping trips were made by individuals with a driver's license. Only 4.3 percent of the shopping trips to the average tract were made by individuals who had a buspass, and only 10 percent of the work and shopping trips were made by individuals who had less than one vehicle available to themselves. As would be expected, a significantly larger proportion of work trips (93.49) than shopping trips (57.86) ending in the average tract were made by individuals who worked outside the home.

URBAN FORM VARIABLES

Urban form variables were significant at both the tract and trip levels of analysis. Descriptive statistics for these variables are presented below. The Appendix E contains maps showing their geographic distribution.

Population Density

Table 7.5 shows that at the trip level, work travel behavior was most significantly related to population density at trip origins (See Table 7.4). Shopping trips were most significantly related to the average of the population density at both trip ends. The mean population density at the origin of work trips was about 5.5 residents per acre. The mean for the average of the density at both ends of shopping trips was about 5.75 persons per acre. The highest density tract from which work trips originated was about 58 persons per acre.

Employment Density

Table 7.5 shows that at the trip level, the average work trip originated in tracts with significantly lower employment density (about 14 employees per acre) than where it ended (about 37 employees per acre). This is intuitively correct, as the trip destination for work trips is typically in areas with employment concentrations. The average of the employment density at the origin and destination of the typical shopping trip was somewhat lower (12.6) than for the typical work trip. This was expected, as shopping trips are not as strongly correlated with employment concentrations. The highest gross employment density where any trip began or ended was about 400 workers per acre in the downtown Seattle office core.

The typical tract had an average employment density that was lower than the location from which the typical trip began or ended. This is because at the tract level all tracts are given equal weight when computing their average characteristics, while at the trip level the tracts with more trips have more impact on the urban form characteristics of the average trip. In the case of density, more trips emanate from higher density locations, which inflates the density associated with the average trip.

Table 7.4. Trip and Census Tract Level Population Density Variables

TRIP LEVEL						
Variable Name	**Trip Purpose**	**Mean**	**StdDev**	**Minimum**	**Maximum**	**Valid Cases**
popdenO	gross population density per acre at trip origins					
	WORK	5.461	4.715	0.006	58.26	4258
popdenA	average gross population density per acre at trip origins and destinations					
	SHOP	5.744	4.24	0.006	58.26	3145
TRACT LEVEL						
popdenA	average gross population density per acre at trip origins and destinations (based on trip destination data)					
	WORK	6.158	4.361	0.028	40.503	382
	SHOP	6.44	4.767	0.01	46.97	345
popdenA	average gross population density per acre at trip origins and destinations (based on trip origin data)					
	WORK	6.495	4.888	0.006	44.52	443

The two variables presented in Table 7.6 were computed from the population data (U.S. Census) and employment data (Economic Security Department). Residents per acre and employees per acre were added together to create a more encompassing measure of density, which was found to be most significant at the trip level. In addition, a ratio of jobs to households was calculated for each census tract. Census tracts with a ratio of jobs to households of between 0.8 and 1.2 were grouped together and called "balanced." All other census tracts were grouped together and called "unbalanced" with respect to the ratio of jobs to households. This variable was analyzed at the trip level in relation to trip distance and travel time for work trips.

Table 7.5. Trip and Census Tract Level Employment Density Variables

TRIP LEVEL						
Variable Name	**Trip Purpose**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Valid cases**
empdenO	gross employment density per acre at trip origins					
	WORK	14.02	58.88	0.002	401.43	3100
empdenD	gross employment density per acre at trip destinations					
	WORK	37.46	92.61	0.002	401.43	3374
empdenA	average gross employment density per acre at trip origins and destinations					
	SHOP	12.6	41.9	0.002	401.43	2055
TRACT LEVEL						
empdenO	gross employment density per acre at trip origins (based on trip origin data)					
	WORK	9.93	25.94	0.002	401.43	370
empdenD	gross employment density per acre at trip destinations (based on trip destination data)					
	SHOP	7.9	30.02	0.002	401.43	256
empdenA	average gross employment density per acre at trip origins and destinations (based on trip destination data)					
	WORK	9.465	22.26	0.002	232.58	274
	SHOP	12.46	32.7	0.002	287.49	252

Table 7.6. Composite Population and Employment Variables

TRIP LEVEL							
Variable Name	**Trip Purpos e**	**Mean**	**Mode**	**Std Dev**	**Minimum**	**Maximu m**	**Valid cases**
ppempdnO	gross population density (residents per acre) plus gross employment density (employees per acre) at trip origins						
	WORK	20.14		59.82	0.007	410.17	3100
jhratior	ratio of jobs to households per census tract * (1=0.8 - 1.2 "balanced tracts" and 2=<0.8 or >1.2 "imbalanced tracts")						
	WORK	0	2	0.283	0	1	3408
* indicates that the variable is nominal							

When numbers of residents per acre was added to the number of employees per acre (ppempdnO), the mean tract had an overall density of 20.14 persons per acre. The maximum value was 410.17. The mode of 2 for the ratio of jobs to households indicates that the typical census tract where work trips began or ended had a ratio of jobs to households that was lower than 0.8 or greater than 1.2.

Land-Use Mix

Land-use mix was significant at both the trip and tract levels of analysis. It was measured on a scale of between 0 and 0.794 (See table 7.7). Higher values indicate that the square footage of developed space was more equally distributed among different uses (e.g., residential, commercial, industrial). This variable was only available for King county.

At the trip level, land-use mix at trip origins was the only variable found to be significant, and it was related to work travel behavior. The typical work trip originated from a tract with an entropy index (land use mix) of 0.459.

At the tract level, work trip mode choice was found to be related to the land-use mix where trips began and ended. Shopping trips were found to be related to land-use mix only where trips ended. The typical tract had an entropy index of about 0.47, which falls roughly the middle this variable's of range of 0.002 to 0.79.

Land-use mix at work trip origins (mixentO) was the only variable found to be significant at the trip level. The mean value at work trip origins was .459.

At the tract level, land-use mix at trip origins (mixentO) was found to be significantly related to mode choice for work trips when modal proportions for SOV, carpool, transit, and walking were calculated at both trip origins and destinations. Land-use mix at the trip destination (mixentD) was found to be significantly related to mode choice for work and shopping trips when modal proportions were calculated at trip destinations. The maximum value for each of the tract level mixing of use variables was

0.794, the same as that at the trip level. The mean value for land-use mix was approximately the same as that for trip and tract level analyses. This similarity indicates that the distribution of trips for land-use mix for both trip and census tract level analyses were also the same.

Table 7.7. Trip and Census Tract Level Land-Use Mix Variables

TRIP LEVEL						
Variable Name	**Trip Purpose**	**Mean**	**StdDev**	**Minimum**	**Maximum**	**Valid Cases**
mixentO	mixing of uses at trip origin census tracts					
	WORK	0.459	0.176	0.002	0.794	2108
TRACT LEVEL						
mixentO	mixing of uses at trip origin census tracts (based on trip origin data)					
	WORK	0.443	0.185	0.002	0.794	267
mixentO	mixing of uses at trip origin census tracts (based on trip destination data)					
	WORK	0.471	0.128	0.048	0.794	273
mixentD	mixing of uses at trip destination census tracts (based on trip destination data)					
	WORK	0.471	0.178	0.006	0.794	223
	SHOP	0.478	0.166	0.006	0.794	204

CHAPTER VIII

THE RELATIONSHIPS BETWEEN URBAN FORM AND MODE CHOICE

INTRODUCTION

This chapter presents the results of statistical analyses used to test the relationship between urban form and mode choice. Several hypotheses were tested. These were either obtained in the literature, developed through an analysis of descriptive statistics, or generated through field observation. Fundamental to the analysis techniques employed was the notion that both urban form and non-urban form factors are related to mode choice.

This chapter is structured by dependent variable (e.g., percentage of SOV use, carpool use, bus use, and walking), and trip purpose (shopping or work). The best models for studying each of the modes (SOV, carpooling, bus, walking) are presented.

The unit of analysis for mode choice was the census tract. A correlational research design was utilized to relate the percentage of SOV, carpool, bus, and walking trips beginning and ending in each census tract with density and land-use mix. The proportionate shares of SOV use, carpool use, bus use, and walking for work and shopping trips at origin and destination census tracts were tested as dependent variables. Urban form (i.e., density and land-use mix) and non-urban form variables (e.g., average income of households in each tract) were used as independent and control variables, respectively.

The following hypotheses were tested pertaining to mode choice:

- The percentage of trips taken by SOV to or from census tracts decreases as the tracts' population density, employment density, and/or land-use mix increases.
- The percentage of trips taken by carpool to or from census tracts increases as the tracts' population density, employment density, and/or land-use mix increases.
- The percentage of trips taken by bus to or from census tracts increases exponentially as the tracts' population density, employment density, and/or land-use mix increases.

- The percentage of trips taken by foot to or from census tracts increases exponentially as the tracts' population density, employment density, and/or land-use mix increases.
- Average density and/or land-use mix at trip origins and destinations will have a more significant impact on mode choice than density or mix at one trip end alone.
- Urban form and non-urban form variables have significant impacts on mode choice independent of each other.

The four modes (SOV, carpool, bus, and walking) and two trip purposes (work and shopping) created eight separate analyses. Each of these analyses is presented below.

PERCENTAGE OF SOV USE

Work Trips

As stated above, the hypothesis tested was that for work trips, a negative relationship exists between the proportion of SOV usage and land-use density and mix.

Table 8.1 presents the variables that were most highly correlated with the percentage of SOV work trips ending in each census tract.

Table 8.1. Variables Correlated with Percentage of SOV Use for Work Trips

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average employment density at trip origins and destinations	-0.26	274	0
mixing of uses at trip origins	-0.13	273	0.03
households with one adult over 65	-0.16	446	0
has a driver's license	0.25	446	0
average travel time for transit	0.22	77	0.06

There was a statistically significant relationship between SOV usage and urban form, as indicated by the p values of less than .05 (except average travel time for transit). Therefore, the null hypothesis was rejected and these variables were inferred to be correlated with percentage of SOV. All of the significant urban form variables had negative correlations. This result supported the hypothesis that the proportion of SOV usage decreases as density and land-use mix increase.

Average employment density of the trip origins and destinations was the urban form variable most strongly correlated, with a correlation coefficient (r of -0.26). This result also supported the hypothesis that the average of the levels of employment density at both trip ends has a more significant relationship to mode choice than does either end individually.

The percentage of work trips made by SOV was positively correlated with the percentage of trip makers who had a driver's license. In other words, when more of the work travelers to a tract had a driver's license, more of those travelers took an SOV for their trip. Tracts with more journeys to work from households with one adult over the age of 65 had fewer SOV work trips. In addition, the average travel time for bus use was positively associated with the use of an SOV for the journey to work. This result indicated that the more time that is required to get to work for the household, the higher is the tendency to choose an SOV.

The multi-variate model shown in Table 8.2 indicated that the percentage of SOV usage for work trips was negatively related to average employment density at trip origin and destinations, even when non-urban form factors were controlled.

Table 8.2. Multi-Variate Regression Model—Percentage of SOV Work Trips

variables in model

Variable Name	**Sig. T**	**Beta**	**B**
Average employment density at trip origins and destinations	0	-0.29	-0.28
Has a driver's license	0	0.37	0.81
CONSTANT	0.69	n/a	5.31

summary statistics

Adj. R-Sq.	**0.2**
Sig.F	0
F-Value	27.08
Dgrs.Frdm.	207

The magnitude of the relationship between percentage of SOV use and average employment density at origins and destinations was interpreted as follows:

> *An increase in average employment density at trip origins and destinations of 10 employees per acre results in a decrease in SOV usage for work trips of 2.8 percent at trip destinations (all else being equal). This increase in density represents an approximate doubling of what is presently the average value for this variable in the three county area. The model also predicts that increasing this value in the typical tract by ten-fold, by the development of an employment center, would reduce the percentage of auto use from the present level of about 82 percent to a new level of about 57 percent.*

The B coefficient for *has a drivers liscence* (0.81) indicated a positive relationship between percentage of SOV use and possession of a driver's license. It predicted that a 10 percent increase in travelers with licenses would increase SOV use by about 8 percent.

The beta associated with *has a driver's license* (0.37) indicated that this variable contributes more to explaining SOV use than employment density. This result intuitively agrees with the notion that people who have a driver's license are more likely to drive alone.

The regression model had an adjusted r-square of 0.2, meaning that 20 percent of the variation in the percentage of SOV use for work trips could be explained with the two independent variables in the model, shown in Table 8.2.

The null hypothesis that the true population value for R-square is 0, was rejected on the basis of the interpretation of the F-statistic (Sig.F= 0.00) and F-value (27.08).

Shopping Trips

The hypothesis tested was that the percentage of SOV trips decreases as population, employment density, and land-use mix increase. Other hypotheses were that the averaging of land-use density and mix at both trip ends and both urban form and non-urban form characteristics affect percentage of SOV usage for shopping trips.

Table 8.3 presents the variables that were most highly correlated with the proportion of SOV shopping trips.

Table 8.3. Variables Correlated With Percentage of SOV Use for Shopping Trips

VARIABLE	**corr. coeff. (r)**	**tracts (n)**	**sog. (p)**
Employment density at destinations	-0.15	256	0.02
Has a driver's license	0.22	393	0
Employed outside the home	0.23	393	0
Households with one adult between 35 and 64			

There was a statistically significant relationship between SOV usage for shopping trips and urban form, as the urban form variable (*employment density at trip destinations*) had a significance (p) of less than .05. Therefore, the null hypothesis (that there is no association between urban form and percentage of SOV use for shopping trips) was rejected. The urban form variable *employment density at trip destinations* was found to be negatively correlated. This result supported the hypothesis that SOV usage decreases as employment density increases for shopping trips.

Employment density at trip destinations was the most strongly correlated urban form variable, with a correlation coefficient (r) of -0.15. This result refuted the hypothesis that the average of the employment density levels at both trip ends is more significantly related to mode choice than is either end individually for percentage of SOV use for shopping trips.

Tracts that contained more travelers who possessed a driver's license had more SOV shopping trips. Tracts that contained more travelers who were employed outside the home also had more SOV shopping trips. This finding was not surprising because most people who work outside the home drive to work and can thus use their SOV to shop while driving to or from work or lunch.

The multi-variate model shown in Table 8.4 indicated that percentage of SOV shopping trips to census tracts was negatively related to urban form (*employment density at trip destinations*), even when non-urban form factors were controlled.

Table 8.4. Multi-Variate Regression Model: Percentage of SOV Trips at Destinations—Shopping Trips

variables in model

Variable Name	Sig. T	Beta	B
Employment density at trip destinations	0	-0.18	-0.19
Has a driver's license	0	0.23	0.45
Households with one adult between 35 and 64	0	0.21	0.4
Average household income	0.01	0.16	0
CONSTANT	0.75	n/a	3.63

summary statistics

Adj. R-Sq.	0.14
Sig. F	0
F-Value	11.33
Degrs. Frdm.	249

The magnitude of the relationship between percentage of SOV use and average employment density at origins and destinations was interpreted as follows:

> *An increase in average employment density at trip destinations of 10 employees per acre would result in a decrease in SOV usage for shopping trips of 1.9 percent at trip destinations (all else being equal).*

Betas for all of the variables in the models were within a range of 0.16 to 0.23, indicating they made similar contributions to the model.

The three non-urban form variables, *having a driver's license, households with one adult between 35 and 64*, and *average household income* were all positively correlated with percentage of SOV usage for shopping trips. Both the variables *having a driver's license* and *households with one adult between 35 and 64* had the highest beta weights in the model.

The regression model had an adjusted r-square of .14, meaning that 14 percent of the variation in percentage of SOV use for shopping trips could be explained with the four independent variables in the model.

The null hypothesis was rejected on the basis of the interpretation of the F-statistic (Sig.F=0.00) and F-value (that the true population v alue for R-square is 0) 1.33.

The Degrees of Freedom (Degrs. Frdm.) (249) indicated the number of cases (census tracts) within the sample that the model represented. The greater is the percentage of possible cases (574) the model represents, the better is the model.

PERCENTAGE OF CARPOOL USE

Work Trips

As stated previously, the hypotheses tested was a positive relationship between carpool usage and land-use density and mix for work trips.

Table 8.5 presents the variables that were most highly correlated with the use of carpools for work trips.

Table 8.5. Variable Correlated with Percentage of Carpool Use for Work Trips

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
Land-use mix at trip origins	0.18	273	0
Household with one adult over 65	0.18	446	0
Employed outside the home	-0.26	446	0
Has a drivers license	-0.15	446	0

There was a statistically significant relationship between carpool usage for work trips and urban form, as the significance (p) for *mixing of uses at trip origins* was 0.00. Therefore, the null hypothesis, that there is no relationship between percentage of carpool use for work trips and urban form (as measured by land-use mix at trip origins), was rejected. The primary hypothesis being tested, that there is a positive relationship between urban form and percentage of carpool usage, was accepted.

The variable *employed outside the home* had the strongest relationship with percentage of carpool use, with a correlation coefficient of (-0.26). It is likely that tracts where more workers work outside the home (i.e., where there are few workers who work at home) are dense urban tracts. These are not places where most workers carpool. Tracts with many workers who work at home are likely to be suburban and rural tracts. These are places where there is more carpooling. Therefore, it is logical that more employment outside the home is associated with a decline in carpooling. No acceptable multiple regression model could be built with these variables.

Shopping Trips

The hypotheses tested was that the percentage of carpool shopping trips increases as population, employment density, and land-use mix increase. Other hypotheses were that the average of land-use density and mix at both trip ends and both urban form and non-urban form characteristics affect the percentage of carpool usage for shopping trips.

Table 8.6 presents the variables that were most highly correlated with increased carpooling for shopping trips.

Table 8.6. Variables Correlated with Percentage of Carpool Use for Shopping Trips

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
Mixing of uses at trip destinations	0.16	204	0.02
Household with one adult between 35 and 65	-0.21	393	0
Employed outside the home	-0.22	393	0
Travel time for carpool trips	0.12	262	0.06
Has a bus pass	0.17	116	0.06

There was a statistically significant relationship between carpool usage for shopping trips and urban form, as the urban form variable *mixing of uses at trip destinations* had a significance of (p) 0.02. Therefore, the null hypothesis (that there is no linear relationship between urban form and carpool usage for shopping trips) was rejected. The variable *mixing of uses at trip destinations* was found to be positively correlated, supporting the hypothesis that carpooling increases as land-use mix increases.

Tracts that contained more trip ends where individuals were *employed outside the home* had less carpooling for shopping, as was the case with work trips. This finding indicates that places have more carpooling if they also have more at-home workers. These are probably rural and suburban areas where more shopping trips are composed of family carpools, in contrast to urban areas where more shopping trips are made by individuals.

The variable *households with one adult between 35 and 64* generated the least carpool trips for shopping purposes. This phenomenon may be due to the fact that in census tracts with more single adult households, more shopping is done by individuals who drive or walk alone. In addition, *having a bus pass* was positively correlated with carpooling for shopping trips, indicating that in places with more people who have a buspass, more shopping is also done by carpools.

The multi-variate model shown in Table 8.7 indicated that percentage of carpool use for shopping trips was not significantly related to urban form factors when non-urban form factors were controlled. Therefore, the null hypothesis, that there is no linear relationship between percentage of carpool use and urban form for shopping trips was supported. However, the model also indicated some significant non-urban form relationships. The three non-urban form variables *employed outside the home, has a buspass,* and *households with one adult between 35 and 64* were all found to have a good deal of explanatory power over the variation in carpooling behavior for shopping trips.

The regression model had an adjusted r-square of .23, meaning that 23 percent of the variability in percentage of carpool use for shopping trips could be explained with the three independent, non-urban form variables in the model, shown in Table 8.7. The null hypothesis, that the true population value for R-square is 0, was rejected on the basis of the interpretation of the F-statistic (Sig.F) (0.00) and F-value (12.35).

The Degrees of Freedom (Degrs. Frdm.) (115) indicated the number of cases (census tracts) within the sample that the model represented. The greater is the percentage of possible cases (574) the model represents, the better is the model.

Table 8.7. Multi-Variate Regression Model: Percentage Carpool Trips at Destinations—Shopping Trips

variables in model

Variable Name	Sig. T	Beta	B
Employment outside the home	0	-0.27	-0.29
Has a bus pass	0	0.29	0.37
Households with one adult between 35 and 64	0	-0.33	-0.68
CONSTANT	0.06	n/a	20.43

summary statistics

Adj. R-Sq.	0.23
Sig. F	0
F-Value	12.35
Degrs. Frdm.	115

PERCENTAGE OF BUS USE

Work Trips

As stated previously, the hypothesis tested was a positive relationship between work trip usage and land-use density and mix. Other hypotheses were that the average of land-use density and mix at both trip ends and both urban form and non-urban form characteristics affect the percentage of bus use for work trips.

Table 8.8 presents the variables that were most highly correlated with the use of buses for work trips. This table suggests that bus usage for work trips was much more highly correlated with urban form factors than with non-urban form factors. In addition, average population and employment density at both trip ends combined was more highly correlated with percentage of bus usage for work trips than that at either trip end.

Table 8.8. Variables Correlated with Percentage of Bus Use for Work Trips

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
Average employment density at trip origins and destinations	0.59	274	0
Mixing of uses at trip destinations	0.15	223	0.03
Average population density at trip origins and destinations	0.19	382	0
Less than one vehicle available per driver	0.14	446	0
Travel distance for carpool trips	0.14	208	0.05

There was a statistically significant relationship between bus usage for work trips and urban form, as the significance values (p) were less than .05 for *average employment density at trip origins and destinations, mixing of uses at trip destinations,* and *average population density at trip origins and destinations.* This result refuted the null hypothesis, that there is no relationship between percentage of bus usage for work trips and urban form.

The hypothesis that there is a positive relationship between bus usage for work trips and urban form was accepted because of the positive correlation coefficients for *average employment density at trip origins and destinations, mixing of uses at trip destinations,* and *average population density at trip origins and destinations.* The correlation coefficient of 0.59 for *average employment density at trip origins and destinations* suggested a strong relationship between this variable and percentage of bus use for work trips.

The two non-urban form factors found to have the strongest relationship with percentage of bus use for work trips related to vehicle availability and carpooling. The variable *less than one vehicle available per driver* had a positive relationship, suggesting that people who do not always have access to their own car take bus to work. This is intuitively correct. The variable *travel distance for carpool trips* was also positively correlated, suggesting that as travel distance increases for carpool trips, those who choose between carpool and bus find bus more attractive. In this instance travel time for carpooling is acting as a level of service measure, with longer travel times producing a mode shift from carpooling to bus.

The multi-variate model shown in Table 8.9 indicated that percentage of bus usage for work trips was positively related to urban form (*average employment density at trip origins and destinations*), even when non-urban form factors were controlled. The lack of non-urban form variables in the model was due to their lack of influence over the variation in percentage of bus use for work trips. On the other hand, *average employment density at trip origins and destinations* had a great deal of influence on variation in bus usage for work trips. In addition, the significance of *average employment density at trip origins and destinations* indicates the importance of urban form at both trip ends when the percentage of bus use for work trips is the object of analysis.

Table 8.9. Regression Model: Percentage of Bus Trips at Destinations—Work Trips

variables in model

Variable Name	Sig. T	Beta	B
Average employment density at trip origins and destinations	0	0.65	0.1
CONSTANT	0.01	n/a	0.79

Note: log of percent bus yielded a lower r-square of .32 with better residuals

summary statistics

Adj. R-Sq.	0.42
Sig. F	0
F-Value	135.42
Degrs. Frdm.	188

Note: The above model was based upon a test for linearity. An analysis of residuals revealed that a more normal distribution of the residuals occurred when a log of the dependent variable (percentage of bus) was taken. The analysis also resulted in a lower adjusted r-square of .32. This result suggested a non-linear relationship between average employment density at trip origins and destinations and percentage of bus use for work trips.

The B coefficient of 0.1, which indicated the slope of the relationship between percentage of bus use and average employment density at origins and destinations, was interpreted as follows:

An increase in average employment density at trip origins and destinations of 10 employees per acre could result in a 1 percent increase in bus usage for work trips (all else being equal). Such an increase would require roughly a doubling of value for this variable for the typical census tract. However, increasing the value of an average tract tenfold to the level of an employment center could increase bus usage from the present level of 2 percent to a new level of 11 percent.

The beta (0.65) indicated a positive relationship, further supporting the hypothesis that bus usage increases as employment density increases.

The regression model had an adjusted r-square of .42, meaning that 42 percent of the variability in percentage of bus usage for work trips could be explained with the variable *average employment density at trip origins and destinations*.

The null hypothesis, that the true population value for R-square is 0, was rejected on the basis of the interpretation of the F-statistic (Sig.F-0.00 and F-value=135.42).

The Degrees of Freedom (Degrs. Frdm.) (188) indicated the number of cases (census tracts) within the sample that the model represented. The greater is the percentage of possible cases (574) the model represents, the better is the model.

<u>Shopping Trips</u>

The hypotheses tested was that the percentage of bus trips for shopping purposes increases as population, employment density, and land-use mix increase. Other hypotheses were that the average of land-use density and mix at both trip ends and both urban form and non-urban form characteristics affect the percentage of bus usage for shopping trips.

Table 8.10 presents the variables that were most highly correlated with the use of bus for shopping trips.

Table 8.10. Variables Correlated with Percentage of Bus Use for Shopping Trips

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
Average employment density at trip origins and destinations	0.44	252	0
Average population density at trip origins and destinations	0.16	345	0
Travel distance for carpooling	0.39	259	0
Households with one adult under 35	0.22	393	0
Number of vehicles available	-0.21	393	0
Travel time for carpooling	0.2	262	0
Has a drivers license	-0.27	393	0

There was a statistically significant relationship between bus usage for shopping trips and urban form, as the urban form variables *average employment density at trip origins and destinations* and *average population density at trip origins and destinations* had significance levels (p) of approximately 0.00. Therefore, the null hypothesis (that there is no linear relationship between urban form and bus usage for shopping trips) was rejected. Each of these urban form variables was found to be positively correlated with percentage of bus use, supporting the hypothesis that bus usage increases as employment density, population density, and land-use mix increase.

The variable *travel distance for carpool trips* had the highest absolute value for the correlation coefficient (0.39), suggesting that as carpooling distance increases, bus is more often selected for shopping trips. (This relationship was also found for percentage of bus use for working trips.) The variables *households with one adult under 35* and *travel time for carpooling* were also positively correlated with percentage of bus use for shopping trips. The variables *numbers of vehicles available* and *has a driver's license* were negatively correlated with bus use for shopping trips, which is intuitively correct. It is logical to expect individuals who have more cars available and have a driver's license to select other modal options (e.g., SOV) more often.

The multi-variate model shown in Table 8.11 indicated that percentage of bus use for shopping trips was significantly related to urban form factors when non-urban form factors were controlled. Therefore, the null hypothesis (that there is no linear relationship between percentage of bus use and urban form for shopping trips) was refuted. The model strongly suggested that accounting for density (both population and employment) at both trip ends is important when percentage of bus use for shopping trips is analyzed. The hypothesis that urban form and non-urban form factors affect bus usage for shopping trips was accepted.

Table 8.11. Multi-variate Regression Model. Percentage of Bus Use at Trip Destinations—Shopping Trips

variables in model

Variable Name	Sig. T	Beta	B
Average employment density at trip origins and destinations	0	0.32	0.05
Average population density at trip origins and destinations	0	0.19	0.16
Average distance for carpool trips	0	0.51	0.61
CONSTANT	0	n/a	-2.62

summary statistics

Adj. R-Sq.	0.43
Sig. F	0
F-Value	41.92
Degrs. Frdm.	162

A B coefficient of 0.05, which indicated the slope of the relationship between percentage of bus use and average employment density at origins and destinations, was interpreted as follows:

> *An increase in average employment density at trip origins and destinations of 10 employees per acre could result in an increase in bus usage for shopping trips of .5 percent at trip destinations (all else being equal). This increase represents roughly a doubling of the value for this variable in the typical tract. However, the model also predicts that*

> *increasing the value of a typical tract to 100, through the creation of an employment center, would increase bus use from 1.74 percent to 6.12 percent.*

A B coefficient of 0.16, which indicated the slope of the relationship between percentage of bus use and average population density at origins and destinations, was interpreted as follows:

> *An increase in average population density at trip origins and destinations of 10 people (residents) per acre could result in an increase in bus usage for shopping trips of 1.6 percent at trip destinations (all else being equal). Here again, this would equal an increase of about 170 percent in the value of this variable of a typical tract. However, the model predicts that raising this value in a typical tract to 40 through the development of a suburban center would increase bus use from 1.74 percent to about 7 percent. Furthermore, if the increased employment density associated with a center were factored in, bus use could increase to over 11 percent.*

A B coefficient of 0.61 indicated a positive relationship between *average distance for carpool trips* and percentage of bus use for shopping trips.

The regression model had an adjusted r-square of .43, meaning that 43 percent of the variability in percentage of bus usage for shopping trips could be explained with the three independent variables.

The null hypothesis, that the true population value for R-squared is 0, was rejected on the basis of the interpretation of the F-statistic (Sig.F=0.00 and F-value=41.92).

The Degrees of Freedom (Degrs. Frdm.) (162) indicated the number of cases (census tracts) within the sample that the model represented. The greater is the percentage of possible cases (574) the model represents, the better is the model.

PERCENTAGE OF WALK TRIPS

Work Trips—Origins

As stated previously, the hypotheses tested was that a positive relationship exists between percentage of walk trips to work and land-use density and mix. Other hypotheses were that the average of land-use density and mix at both trip ends and both urban form and non-urban form characteristics affect the percentage of walk trips to work.

Table 8.12 presents the variables that were most highly correlated with the percentage of work trips to census tracts that were made by foot. Walking to work was more strongly correlated with urban form factors than non-urban form factors (as was percentage of bus use). In addition, the percentage of walking to work was more highly correlated with average population density at both trip ends than the density at either trip end individually.

Table 8.12. Variable Correlated with Percentage of Walk Trips for Work Trips

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
Employment density at trip origins	0.43	324	0
Average population density at trip origins and destinations	0.34	443	0
Mixing of uses at trip origins	0.21	267	0
Travel time for transit trips	-0.21	150	0.01
Travel distance for transit trips	-0.24	149	0

The relationship between percentage of walking to work and urban form was statistically significant, as the significance coefficient (p) was less than .05 for *employment density at trip destinations, average population density at trip destinations,* and *mixing of uses at trip origins.* This result refuted the null hypothesis that there is no relationship between percentage of walk trips for work and urban form.

The hypothesis that there is a positive relationship between walking to work and urban form was accepted because of the positive correlation coefficients for *employment density at trip destinations, average population density at trip destinations,* and *mixing of uses at trip origins*. The correlation coefficient of 0.43 for *employment density at trip* *destinations* suggested a relatively strong relationship between this variable and percentage of walk trips to work.

The two non-urban form variables found to have the strongest relationship with percentage of walk trips to work related to the amount of time and distance associated with bus trips to each census tract. The negative relationship between percentage of walk trips to work and travel time and distance for bus suggested that walking to work increases as travel time and distance for bus trips decrease. This finding suggests that pedestrian activity is most highly associated with areas where there are short distances between households and workplaces.

The multi-variate model shown in Table 8.13 indicated that percentage of walking to work was positively related to urban form *(average population density at trip origins and destinations, employment density at trip destinations,* and *average mixing of uses at trip origins and destinations),* even when non-urban form factors were controlled. The lack of non-urban form variables in the above model was due to their lack of influence over the variation in percentage of walk trips to work. In addition, the importance of the variables *average population density at trip origins and destinations* and *average mixing of uses at trip origins and destinations* indicated the importance of urban form at both trip ends.

Table 8.13. Multi-Variate Regression Model. Percentage of Walking Trips at Origins—Work Trips

variables in model

Variable Name	Sig. T	Beta	B
Average population density at origins and destinations	0	0.29	0.7
Employment density at origins	0	0.38	0.17
Average mixing of uses at origins and destinations	0.01	0.15	20.41
CONSTANT	0	n/a	-12.87

summary statistics

Adj. R-Sq.	0.31
Sig. F	0
F-Value	33.14
Dgrs. of Frdm.	217

A B coefficient of 0.7, which indicated the slope of the relationship between percentage of walk trips to work and average population density at origins and destinations, was interpreted as follows:

> *An increase in average population density at trip origins and destinations of 10 persons per acre could result in an increase in percentage of walk trips to work of 7.0 percent at trip origins (all else being equal). This increase would represent a density increase of about 170 percent for this variable in the average census tract. In addition, the model predicted that increasing this density to 20 in an average census tract through the development of a suburban center would increase the percentage of work rips made by walking from about 3 percent to about 12 percent.*

A B coefficient of 0.17, which indicated the slope of the relationship between percentage of walk trips and average employment density at trip destinations, was interpreted as follows:

> *An increase in average employment density at trip origins of 10 employees per acre could result in an increase in percentage of walk trips to work of 1.7 percent at trip origins (all else being equal). This would represent an approximate doubling for this density in the typical tract. However, the creation of an employment center with an employment density of 100 employees per acre would increase walking from about 3 percent to about 18 percent in a typical tract.*

A B coefficient of 20.41, which indicated the slope of the relationship between percentage of walking trips to work and average land-use mix at trip origins and destinations, was interpreted as follows:

> *An increase in average mixing of uses at trip origins and destinations of .1 on the normalized scale (0-1) could result in an increase in percentage of walk trips to work of 2.04 percent at trip origins (all else being equal).*

The regression model had an adjusted r-square of .31, meaning that 31 percent of the variability in percentage of walk trips to work could be explained with the three urban form variables in the model

The null hypothesis, that the true population value for R-squared is 0, was rejected on the basis of the interpretation of the F-statistic (Sig.F=0.00 and F-value=135.42).

The Degrees of Freedom (Degrs. Frdm.) (217) indicated the number of cases (census tracts) within the sample that the model represented. The greater is the percentage of possible cases (574) the model represents, the better is the model.

Shopping Trips

The hypotheses tested was that the percentage of walk trips for shopping purposes increases as population, employment density, and land-use mix increase. Other hypotheses were that the average of land-use density and mix at both trip ends and both urban form and non-urban form characteristics affect the percentage of walking to shopping.

Table 8.14 presents the variables that were most highly correlated with the percentage of shopping trips to census tracts made by foot.

There was a statistically significant relationship between percentage of walk trips to shopping and urban form, as the urban form variables *average population density at trip origins and destinations* and *employment density at trip destinations* had a significance (p) of approximately 0.00. Therefore, the null hypothesis (that there is no linear relationship between urban form and walking to shopping) was rejected. Each of

Table 8.14. Variables Correlated with Percentage of Walk Trips for Shopping

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
Average population density at trip origins and destinations	0.31	345	0
Employment density at trip destinations	0.24	256	0
Less than one vehicle available per driver	0.22	392	0
Age	-0.17	393	0
Trip maker is a student	0.16	393	0
Has a drivers license	-0.43	393	0
Has a buspass	0.37	116	0
Households with one adult less than 35	0.22	393	0

these urban form variables was found to be positively correlated with percentage of walk trips, supporting the hypothesis that walking increases as population density and employment density increase. Measures of population density had the strongest correlation coefficient (0.31). The hypothesis that walking to shopping increases as land-use mix increases was not supported by these findings.

The variables *has a driver's license* and *age* were negatively correlated, indicating that walking to shopping decreases as people obtain driver's licenses and age. On the other hand, walking to shopping increases if people *have a bus pass, have less than one vehicle per driver,* or *live in one-adult households and are under 35.*

The multi-variate model shown in Table 8.15 indicated that the percentage of walk trips to shopping was significantly related to urban form factors when non-urban form factors were controlled. Therefore, the null hypothesis (that there is no linear relationship between percentage of walking and urban form for shopping trips) was rejected. The model suggested that the variable *average population density at trip origins and destinations* had a stronger influence over percentage of walking to shopping than did population density at either trip end alone. The hypothesis that urban form and non-urban form factors affect walking for shopping trips was accepted.

Table 8.15. Multi-variate Regression Model. Percentage of Walking Trips at Destinations—Shopping Trips

variables in model

Variable Name	Sig. T	Beta	B
Average population density at origins and destinations	0	0.26	0.89
Employment density at trip destinations	0	0.19	0.11
Less than one vehicle available per a driver	0	0.15	0.12
Age of tripmaker	0.01	-0.13	-0.18
Has a driver's license	0	-0.4	-0.45
CONSTANT	0	n/a	47.68

summary statistics

Adj. R-Sq.	0.35
Sig. F	0
F-Value	28.85
Dgrs. of Frdm.	254

A B coefficient of 0.89, which indicated the slope of the relationship between percentage of walking and average population density at origins and destinations, was interpreted as follows:

> *An increase in average population density at trip origins and destinations of 10 people per acre could result in an increase in walking for shopping trips of 8.9 percent at trip destinations (all else being equal). This represents a density increase of about 170 percent in the typical census tract. The model also predicts that, in a typical tract, increasing the value for this variable to 20 by creating a suburban center would change the percentage of shopping trips by walking from about 6 percent to about 18 percent.*

A B coefficient of 0.11, which indicated the slope of the relationship between percentage of walk trips to shopping and employment density at trip destinations, was interpreted as follows:

> *An increase in employment density at trip destinations of 10 people (residents) per acre could result in an increase in walking to shopping of*

1.1 percent at trip destinations (all else being equal). This represents a density increase of about 125 percent in the typical tract. The creation of an employment center with an employment density of 100 workers per acre would increase shopping trips by walking from about 6 percent to about 16 percent in the typical tract.

The regression model had an adjusted r-square of .35, meaning that 35 percent of the variability in percentage of walking trips to shopping could be explained with the five independent variables in the model.

The null hypothesis, that the true population value for R-squared is 0, was rejected on the basis of the interpretation of the F-statistic (Sig.F=0.00 and F-value=28.85).

SUMMARY

The variables that were found to have the strongest statistical relationships with the percentage of trips by mode for both work and shopping are presented in Table 8.16. The collective influence that these variables had over the variation in the use of each mode is the adjusted r-square for each regression model. Regression analysis revealed that both urban form and non-urban form variables were significantly related with percentage of SOV use, percentage of bus use, and percentage of walking. No urban form variables were significantly related with percentage of carpool use. The variables presented in Table 8.16 that were related to percentage of carpool use had linear correlations. The beta weights from the regression models for percentage of SOV use, percentage of bus use, and percentage of walking follow each variable and represent that variable's relative contribution to the overall model. The adjusted r-squares for percentage of SOV use, percentage of bus use, and percentage of walking allow comparisons of the overall strength of each model between modes and trip purposes. Correlation coefficients are presented for each variable that correlated with percentage of carpool use.

Table 8.16. Summary of Variables Related to Each Mode by Trip Purpose

	% SOV (regression betas)	**% CARPOOL (correlation coefficients)**	**% TRANSIT (regression betas)**	**% WALK (regression betas)**
WORK TRIPS	average employment density at trip origins and destinations (-0.29), has a driver's license (0.37)	mixing of uses at trip origins (r=0.18), single adult households over 65 (r=0.18), employed outside the home (r=-0.26), has a driver's license (-0.15)	employment density at trip origins and destinations (0.65)	employment densit at trip origins (0.38), population density at trip origins and destinations (0.29), mixing of uses at trip origins and destinations (0.15)
adj. r-sq.	0.2	n/a	0.42	0.31
SHOP TRIPS	employment density at trip destinations (-0.18), has a driver's license (0.23), single adult households between 35-64 (0.21), household income (0.16)	mixing of uses at trip destinations (r=0.16), single adult households between 35-64 (r= -0.21), employed outside the home (r= -0.22), has a buspass (r=0.17), carpool travel time (r=0.12)	employment density at trip origins and destinations (0.32), population density at trip origins and destinations (0.19), distance for carpool trips (0.61)	employment density at trip destinations (0.19), population density at trip origins and destinations (0.26), less than 1 vehicle available (0.15), age (-0.13), has a driver's license (-0.4)
adj. r-sq.	0.14	n/a	0.43	0.35

The findings presented in this chapter suggest that the percentages of bus use and walking (for both work and shopping) had the highest correlations with the urban form variables. Percentage of bus use for both work and shopping use appeared to be positively related to employment density. Percentage of walking was positively related to employment density, population density, and land-use mix.

The relationship between employment density at trip origins and destinations and percentage of bus use for work trips was the strongest relationship between urban form and mode choice.

CHAPTER IX

THE DISTRIBUTION OF SOV, CARPOOL, BUS, AND WALK TRIPS AT DIFFERENT LEVELS OF EMPLOYMENT AND POPULATION DENSITY:

THRESHOLDS ASSOCIATED WITH NON-LINEARITY

Findings from the previous chapter led to the identification of the four urban form variables that were most often correlated with mode choice variables:

- average employment density at trip origins and destinations for work trips,
- average population density at trip origins and destinations for work trips,
- employment density at trip destinations for shopping trips, and
- average population density at trip origins and destinations for shopping trips.

The focus of the analysis reported in this chapter was the relationships among these four urban form variables and among each of the four modes: SOV, carpool, bus, and walking. These relationships were assessed in terms of linearity versus non-linearity. This analysis identified thresholds in which shifts from one mode (SOV) to another (bus or walking) occured as a function of population or employment density.

The unit of analysis for the four urban form variables studied was the trip. The trips (work and shopping) were distributed among the total number of census tracts in the work or shopping trip subsets. Both population and employment density variables were recoded from continuous variables into ordinal variables with eight groups or intervals.

WORK TRIPS

Employment Density

SOV

Figure 9.1 documents that SOV trips represented approximately 80 percent of the modal share between 0 and 50 employees per acre. Once average employment densities exceeded 50 employees per acre, the proportion of SOV trips dropped to 60 percent at 75 employees per acre. Once employment densities exceeded 125 employees per acre, the proportion of SOV trips dropped dramatically, to under 30 percent at the highest density range. This finding indicates that there is a non-linear, declining relationship between average employment density at trip origins and destinations and the percentage of SOV trips. Overall, SOV usage dropped from 80 percent to 29 percent (a decline of 51 percent) as employment densities rose from 0 to 250 employees per acre.

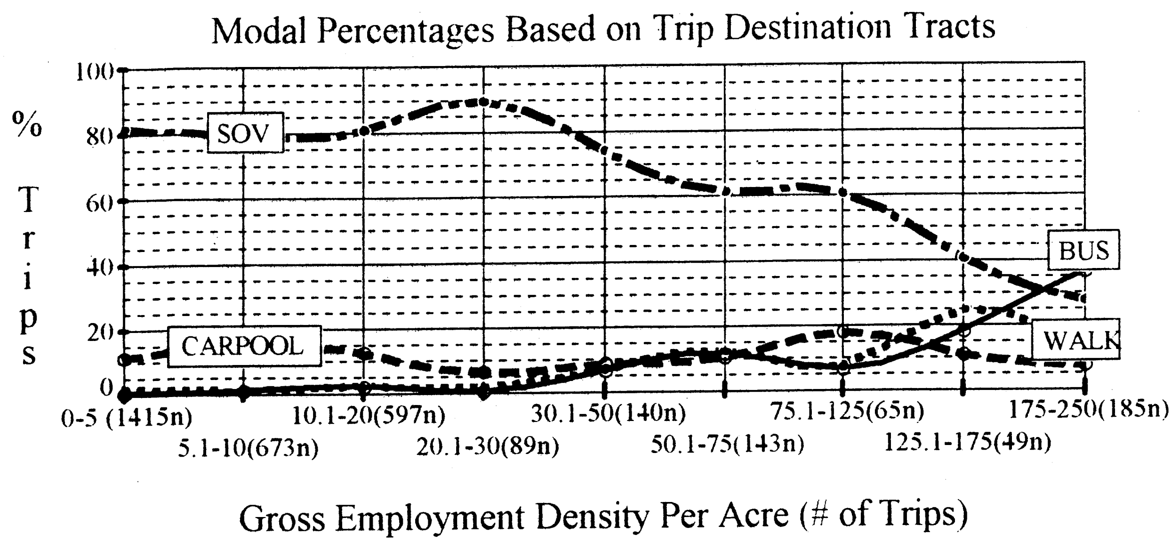

Figure 9.1. Average Employment Density for Trip Origins and Destinations and Mode Choice for Work Trips.

Carpool

Carpool trips represented between 10 percent and 15 percent of the work trips in the survey, and they were not affected by average employment density at trip origins and destinations.

Bus

The findings from this research indicated that increased bus usage does not begin to occur until employment densities reach 30 employees per acre. Between 30 and 125 employees per acre, bus usage increased from approximately 0 percent to 10 percent of the modal share. Once employment densities increased to over 125 employees per acre, bus usage began to increase dramatically. Between 125 and 250 employees per acre, the proportion of work trips made by bus increased by nearly 30 percent. This result indicates that there is a non-linear, increasing relationship between average employment density at trip origins and destinations and the percentage of bus trips.

Walking

The findings from this research indicated that the proportion of walk trips is nearly identical until employment densities reach 125 employees per acre. Between 125 and 175 employees per acre, the proportion of work trips made by foot increased by nearly 15 percent to 25 percent of the modal share. From 175 to 250 employees per acre, the proportion of walking trips fell by 15 percent, back down to under 10 percent of the modal share. This reduction of walking trips at the highest range of densities was the result of an increasing percentage of bus trips; it does not represent a modal shift to SOV. These findings indicate that there is a non-linear, increasing relationship between average employment density at trip origins and destinations and the percentage of walking trips.

Population Density

SOV

The information presented in Figure 9.2 indicates a non-linear relationship between the proportion of SOV trips and average population density at trip origins and destinations. SOV trips represented approximately 80 percent of the modal share between 0 and 9 people or residents per acre. Once average population density exceeded 9 people or residents per acre, the proportion of SOV trips dropped dramatically to 50 percent (between 13.1 and 18 people per acre). At this point, the modal share for SOV trips increased to 62 percent. This increase appears to be due a tradeoff between SOV use and carpooling (see Figure 9.2). An overall reduction in SOV usage of approximately 16 percent occurred from the lowest to the highest levels of population density.

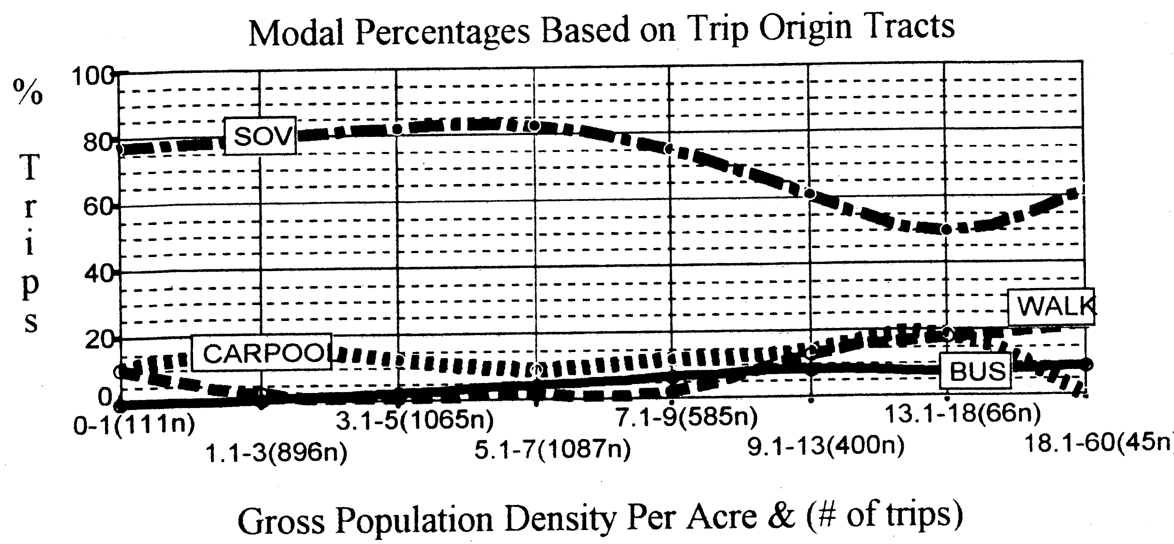

Figure 9.2. Average Popluation Density for Trip Origins and Destinations and Mode Choice for Work Trips

Carpool

The carpool mode split for work trips fluctuated between 10 percent and 20 percent until the average population density at trip origins and destinations reached 13.1 to 18 people per acre. Carpool trips decreased to 0 percent above a gross population density per acre value of 13.1 to 18. This suggests a non-linear relationship between the percentage of carpool trips and average gross population density at trip origins and destinations for work trips.

Bus

Bus Trips represented approximately 0 percent of the trips at the lowest gross population density range. The proportion of bus trips increased steadily, to 10 percent of the modal share, at the highest level of population density. This does not suggest a non-linear relationship between the percentage of bus trips and average gross population density at trip origins and destinations for work trips.

Walking

Walking trips represented 10 percent of the modal share at the lowest level of gross population density. The percentage of walking trips decreased to approximately 2 percent until gross population density reached 7 to 9 people or residents per acre. At this point, the percentage of walking trips increased dramatically, to approximately 22 percent at the highest population density interval. This suggests a non-linear relationship between the percentage of walking trips and average gross population density at trip origins and destinations for work trips.

SHOPPING TRIPS

Employment Density

SOV

Figure 9.3 indicates that SOV trips fluctuated between 50 percent and 60 percent of the modal share for employment densities of up to 50 employees per acre. Throughout this range of values, modal shifts appeared to alternate between carpooling and SOV

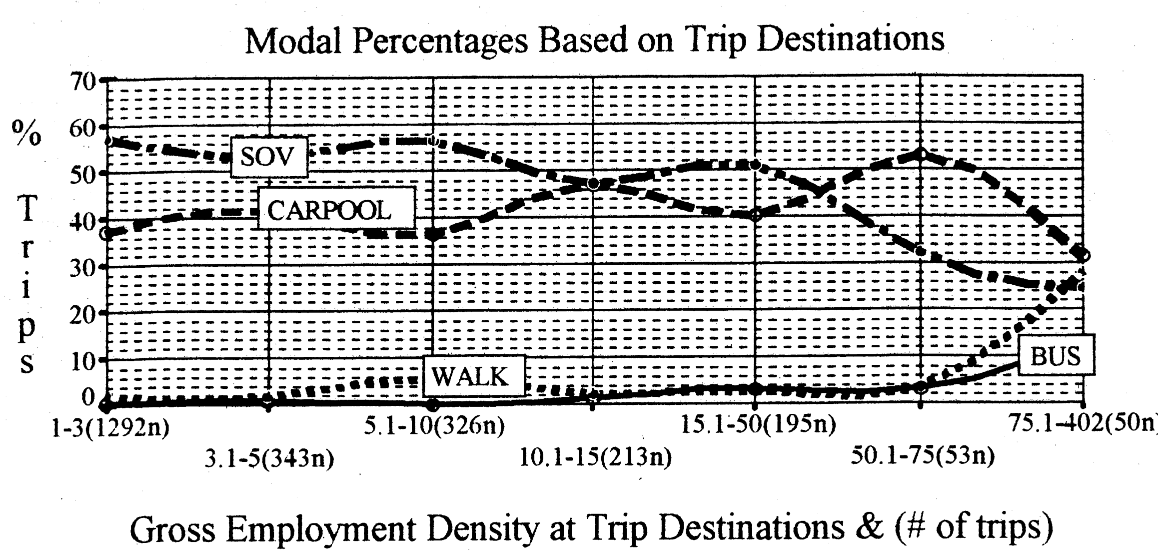

Figure 9.3. Employment Density at Trip Destinations and Mode Choice for Shopping Trips

trips. Once employment densities at trip destinations exceeded 50 employees per acre, the proportion of SOV trips dropped dramatically, to 24 percent at the highest density range. This indicates that there is a non-linear, declining relationship between employment density at trip destinations and the percentage of SOV trips.

Carpool

Carpool trips fluctuated around 40 percent of the total shopping trips until employment densities exceeded 50 employees per acre. Between 50 and 75 employees per acre, the modal share for carpool trips increased to 53 percent. Between 50 and 402 employees per acre, the modal share for carpooling declined to 32 percent of the modal share. Although there was considerable fluctuation in the level of carpooling as density increased, it was somewhat random and a function of SOV use trade-off. On the basis of these trends, there does not appear to be a non-linear relationship between the percentage of carpool trips and employment density at trip destinations for shopping trips. This is consistent with the findings from the correlation and regression analysis presented in Tables 8.6 & 8.7 which excludes employment density because it was not significantly related with percent carpool.

Bus

Bus trips represented less than 4 percent of the shopping trips until employment density at trip destinations exceeded 75 employees per acre. At that point there was a dramatic increase in the proportion of shopping trips by bus. Between 75 and 402 employees per acre, bus usage increased to 13 percent. This suggests a high degree of non-linearity between bus usage and employment density at trip destinations for shopping trips.

Walking

Walking trips represented approximately 5 percent of the modal share for shopping trips until employment densities at trip destinations reached 75 employees per acre. Between 75 and 402 employees per acre, walking trips increased dramatically to 28 percent of total shopping trips. This suggests an extremely high degree of non-linearity between walking trips and employment density at trip destinations for shopping trips.

Population Density

SOV

Figure 9.4 indicates that SOV trips represented approximately 55 percent of the modal share between 0 and 13 people/residents per acre. Between 9 and 60 people per acre, the modal share for SOV trips declined to 44 percent.

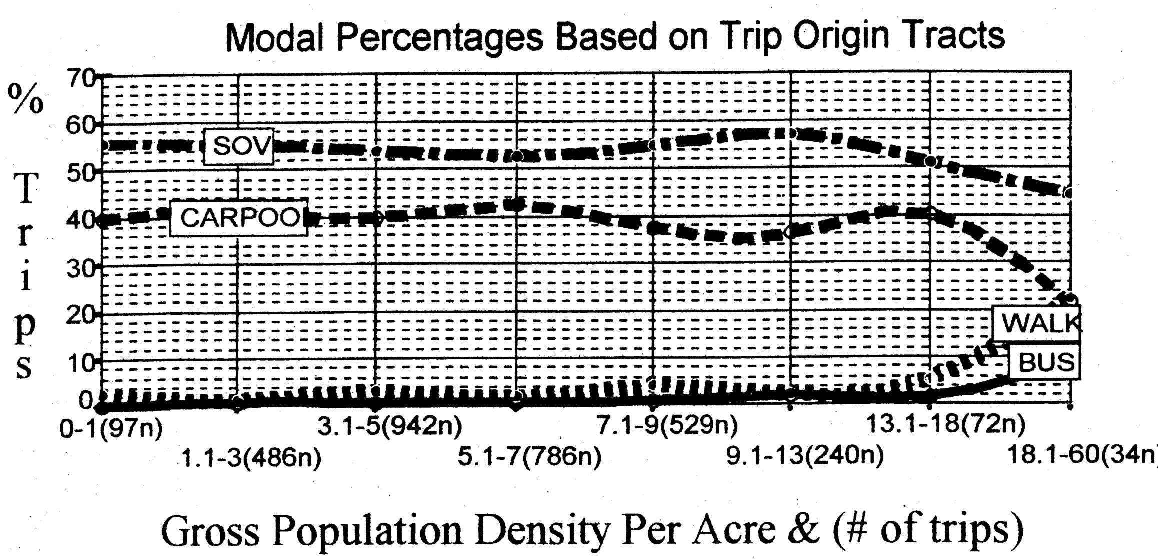

Figure 9.4. Average Population Density of Trip Origins and Destinations and Mode Choice for Shopping Trips

Carpool

The percentage of carpool trips for shopping fluctuated near 40 percent of the modal share until gross population densities exceeded 18.0 people per acre. At that point the percentage of carpool trips decreased to 22 percent of the modal share. This finding suggests a strong non-linear relationship between carpooling and average gross population density at trip origins and destination for shopping trips.

Bus

Bus trips represented 2 percent or fewer of the shopping trips until gross population density reached 18 people per acre. At that point, the modal share of bus trips increased to 10 percent at the highest level of population density shown in this study. This suggests a relatively strong non-linear relationship between the percentage of bus trips and average gross population density at trip origins and destinations for shopping trips.

Walking

Walking trips fluctuated between 0 percent and 6 percent of the modal share for shopping trips until gross population density reached 18 people per acre. Then the percentage of walking trips increased dramatically, to approximately 22 percent of the modal share. This suggests a very strong non-linear relationship between the percentage of walking trips and average gross population density at trip origins and destinations for shopping trips.

SUMMARY

Throughout the analysis, low densities were associated with the highest level of SOV dominance. As density increased, the proportionate share of trips by SOV decreased; at the same time the proportionate share of bus use and walking increased. Generally, density had the least impact on the proportion of carpool trips. (See Appendices B, C, and D for information about the relationship between mode choice and other urban form variables that measure population and employment density for work, shaping, and all trips).

The proportions of SOV, bus, and walking trips for work and shopping were found to have non-linear relationships with employment and population density. This non-linearity has significant implications for land-use policies intended to reduce SOV dependence.

The proportion of SOV trips (for both work and shopping) began to decline significantly as employment densities exceeded 50 employees per acre. Bus use and walking appeared to increase significantly once employment densities exceeded 75 employees per acre. Carpooling did not appear to have an identifiable non-linear relationship with employment density.

Population density appeared to have a significant non-linear relationship with the proportion of SOV and walking trips for both work and shopping. Population density appeared to have a significant non-linear relationship with bus use for shopping trips. Findings from this analysis suggest that SOV usage begins to decline as population density exceeds 7 people or residents per acre for work trips and 13 people or residents per acre for shopping trips. Walk trips begin to increase once population densities exceed 7 people per acre for work trips and 13 people per acre for shopping trips. Bus trips begin to increase once population densities exceed 13 people per acre for shopping trips.

CHAPTER X

TESTING TRIP GENERATION, TRIP DISTANCE, AND TRAVEL TIME RELATIONSHIPS WITH URBAN FORM

This chapter presents research findings from statistical analyses of the relationship between urban form and trip generation, trip distance, and travel time. Several hypotheses were tested; these were either obtained from the literature, developed through an analysis of descriptive statistics, or gathered through field observation. These hypotheses stated assumptions regarding the relationships between the variables population density, employment density, land-use mix, and jobs-housing balance and the variables trip generation, trip distance, and travel time. Although it is not discussed here, the relationship between urban form and vehicle occupancy was analyzed. However, the findings from that analysis suggested that there is no distinguishable relationship between urban form and vehicle occupancy.

Fundamental to the analysis techniques employed was the notion that both urban form and non-urban form factors are related to trip generation, trip distance, and travel time. This idea provided a framework under which variables related to each of the dependent mode choice variables could be identified. This chapter is structured by dependent variable (e.g., trip generation, trip distance, and travel time) and trip purpose (work or shopping). Correlation matrices are presented for each of the dependent variables. Partial correlation is shown to test the effect of urban form while controlling for non-urban form factors. The magnitudes of the relationships between urban form and travel behavior variables are presented in terms of the strength of the correlation coefficient that resulted from the partial correlation.

The ratio of jobs to households was calculated for each census tract to test the hypothesis that work trips are shorter in distance and time when they originate or end in census tracts whose number of jobs and households are more evenly balanced. This analysis was limited to the relationship between jobs-housing balance and trip distance and travel time for work trips made by SOV, carpool, bus, and walking. A t-test was used to compare the mean travel distance and travel time between tracts that had a ratio of jobs to households of between 0.8 and 1.2 and tracts whose ratio was less than 0.8 and greater than 1.2. This method was consistent with methods used in the literature to test the relationship between jobs-housing balance and trip distance and travel time (Cervero, 1988).

No regression models are presented in this chapter because of the extremely low confidence, or adjusted r-squares, that resulted from using this statistical method. While the predictive power of these models was weak, information pertaining to statistics associated with their variables was still useful.

The unit of analysis for trip generation, trip distance, and travel time was the trip. A correlational research design was utilized to compare the distribution of trip ends among the 574 possible census tract in the study. Urban form characteristics (e.g., levels of average gross population density per acre) were examined at both trip ends. Non-urban form factors (e.g., the household income of the trip maker) were also examined for each trip. Therefore, the findings presented in this chapter were the result of a disaggregate analysis.

PER CAPITA TRIP GENERATION

The general hypothesis stated in Figure 10.1 regarding trip generation was further refined into three hypotheses.

- A significant relationship between per capita trip generation and urban form (population density, employment density, and land-use mix) exists.
- Per capita trip generation declines as population density, employment density, and land-use mix increase.
- A significant relationship exists between per capita trip generation and urban form (employment density, population density, and/or land-use mix), even when significant non-urban form variables are controlled.

Table 10.1 presents the variables that were most highly correlated with per capita trip generation for work and shopping trips. Findings related to the hypotheses stated previously are presented below by trip purpose (work and shopping).

TRIP GENERATION RATES

Per capita trip generation rates are lower in census tracts with higher population density, employment density, and/or land-use mix, even when intervening non-urban form factors are controlled.

TRIP DISTANCE

Work and shopping trips that originate or end in census tracts with higher population density, employment density, and/or land-use mix have shorter travel times, even when intervening non-urban form factors are controlled.
Work trips that originate or end in census tracts with a greater balance between jobs and households have shorter trip lengths.

TRAVEL TIME

Work and shopping trips that originate or end in census tracts with higher population density, employment density, and/or land-use mix have shorter travel times, even when intervening non-urban form factors are controlled.
Work trips that originate or end in census tracts with a greater balance between jobs and households have shorter travel times.

OTHER

The average level of densities and/or land-use mix from both trip origins and destinations may have a more significant impact than the density at one trip end alone.
Both urban form and non-urban form variables have significant impacts on trip frequency, trip length, and/or travel time.

Figure 10.1. Hypotheses Tested Pertaining to Trip Generation, Distance, and Travel Time

Table 10.1. Variables Correlated with Per Capita Trip Generation

VARIABLE	corr. coeff. (r)	weighted trips (n)	sig. (p)
WORK TRIPS			
Mixing of uses at trip origins	0.1128	2108	0
Employment density at trip origins	0.1196	3100	0
Population and employment density at trip origins	0.1228	3100	0
SHOPPING TRIPS			
Age group	-0.1486	3692	0

Work Trips

Significance of the Relationship Between Per Capita Trip Generation and Urban Form

There was a statistically significant relationship between per capita trip generation and urban form. The significant urban form variables *employment density*, *population density*, and *mixing of uses* are shown in Table 10.1. Therefore, the null hypothesis (that there is no linear relationship between per capita trip generation and urban form for work trips) was rejected.

Relationship Between Per Capita Trip Generation and Urban Form

Each of the urban form variables was found to be positively correlated with per capita trip generation, providing reason to reject the hypothesis that per capita trip generation decreases as employment density, population density, and land-use mix increase. To the contrary, as density and mix increase so does the per capita work trip generation rate when all modes are combined in the analysis.

Significance of Per Capita Trip Generation and Urban Form Relationship When Non-Urban Form Factors are Controlled

No significant relationship existed between the non-urban form variables within this database and per capita trip generation for work trips. This finding refuted the hypothesis that there is a significant relationship between travel time and both urban form and non-urban form variables. The variables in the database represented a variety of trip makers' demographic characteristics. Therefore, this analysis indicates reason to accept the hypothesis that there is a significant relationship between urban form and per capita trip generation for work trips, even when non-urban form factors are taken into account.

Shopping Trips

Significance of the Relationship Between Per Capita Trip Generation and Urban Form

There was no statistically significant relationship between per capita trip generation for shopping trips and urban form. Therefore, the null hypothesis (that there is no linear relationship between per capita trip generation and urban form for shopping trips) was accepted.

Non-Urban Form Variable(s)

Age group was negatively correlated with per capita trip generation, indicating that people in higher age groups take fewer shopping trips. Age group was the variable most significantly correlated with per capita trip generation.

TRIP DISTANCE

The first hypothesis stated in Figure 10.1 regarding trip distance was further refined into three hypotheses.

- A significant relationship between trip distance and urban form (population density, employment density, and land-use mix) exists.
- Trip distance declines as urban form variables (population density, employment density, and land-use mix) increases.
- A significant relationship exists between trip distance and urban form (employment density, population density, and/or land-use mix), even when significant non-urban form variables are controlled.

Work Trips

Significance of Trip Distance and Urban Form Relationship

There was a statistically significant relationship between trip distance and urban form for work trips. The significant urban form variables *employment density*, *population density*, and *mixing of uses* are shown in Table 10.2. These variables had a population correlation coefficient of approximately 0, indicating a statistically significant relationship. Therefore, the null hypothesis (that there is no linear relationship between trip distance and urban form for work trips) was rejected.

Table 10.2. Variables Correlated with Trip Distance

VARIABLE	corr. coeff. (r)	weighted trips (n)	sig. (p)
WORK TRIPS			
Mixing of uses at trip origins	-0.1922	2098	0
Population density at trip origins	-0.1671	4205	0
Employment density at trip origins	-0.1343	3071	0
Level of service for transit: distance to nearest bus stop	0.1244	4739	0
SHOPPING TRIPS			
Level of service for transit: distance to nearest bus stop	0.1358	3669	0
Average population density at trip origins and destinations	-0.1615	3145	0

All of the urban form variables that were significantly correlated with trip distance were at the trip origin. This finding refuted the hypothesis that the average levels of density and /or land-use mix at both trip origins and destinations has a stronger relationship with trip distance for work trips then do the average levels at either end alone.

Relationship Between Trip Distance and Urban Form

Urban form variables were found to be significantly negatively correlated with trip distance, supporting the hypothesis that trip distance decreases as employment density, population density, and land-use mix increase. Land-use mix at trip origins was the variable most significantly negatively correlated with trip distance for work trips ($r = -0.1922$).

Significance of Urban Form and Per Capita Trip Generation Relationship When Non-Urban Form Factors Are Controlled

Both urban form and non-urban form factors had a significant relationship with trip distance for work trips. The variable *level of service for bus* (as measured by the distance from the trip origin to the nearest bus stop) was found to be significantly positively correlated with trip distance, indicating that trip distance increases as distance to the nearest bus stop increases. Partial correlation was used to identify the impacts that this variable has on the relationship between trip distance and the urban form variables in Table 10.3 for work trips.

All of the urban form variables remained statistically significant, with correlation coefficients varying by a maximum of 0.05. Correlation coefficients for land-use mix and population density at trip origins decreased, and employment density at trip origins increased. These findings supported the hypothesis that a significant relationship exists between trip distance and urban form (employment density, population density, and/or land-use mix at trip origins), even when significant non-urban form variables are controlled.

Table 10.3. Partial Correlation of Level of Service for Bus for Trip Distance

WORK TRIPS

VARIABLE	corr. coeff. (r)	weighted cases (n)	sig. (p)
Mixing of uses at trip origins	-1618	1725	0
Population density at trip origins	-1185	1725	0
Employment density at trip origins	-1716	1725	0

Jobs-Housing Balance

The second hypothesis related to trip distance (shown in Figure 10.1) dealt with the relationship between jobs-housing balance and trip distance. This hypothesis was further refined to state that trip distance is shorter for work trips that end in census tracts whose levels of jobs and housing are evenly balanced. The analysis conducted to test the relationship between trip distance and jobs-housing balance at work trip origins produced results that were less significant than results related to work trip destinations. Therefore, only the findings from the analysis of the relationship between jobs-housing balance and trip distance at the destination are presented here. Table 10.4 presents findings from a t-test that compared the mean work trip distance between balanced tracts with a balanced jobs to households ratio (0.8-1.2) and tracts with an imbalanced ratio (less that 0.8 and greater than 1.2).

The population correlation coefficient (p=0.00) indicated a significant difference in work trip distance between "balanced" and "unbalanced" census tracts. This finding refuted the null hypothesis, that there is no relationship between jobs-housing balance and trip distance for work trips. The mean average trip distance for work trips that ended in census tracts with an unbalanced jobs to households ratio was 2.72 miles longer than work trips that ended in balanced tracts. In other words, the average travel distance for work trips that ended in unbalanced tracts was 28 percent longer than that for trips that ended in balanced tracts. This finding can be translated into vehicle miles traveled and, therefore, has significant implications for air quality attainment and other policy objectives.

Table 10.4. Jobs-Housing Balance and Trip Distance at Destinations

WORK TRIPS

VARIABLE	mean trip distance (miles)	weighted cases (n)
Balanced tracts (jobs:houshold ratios of between 0.8 and 1.2)	6.87	290
Unbalanced tracts (jobs:houshold ratios of less than 0.8 and greater than 1.2)	9.59	3030

sig. (p)	% change in trip distance
0	28%

Shopping Trips

Significance of Trip Distance and Urban Form Relationship

There was a statistically significant relationship between trip distance and urban form for shopping trips. The only significant urban form variable, *average population density at trip origins and destinations,* is shown in Table 10.2. This variable had a population correlation coefficient of approximately 0, indicating a statistically significant relationship. Therefore, the null hypothesis (that there is no linear relationship between trip distance and urban form for shopping trips) was rejected. This finding also supported the hypothesis that the average population density at both trip origins and destinations has a stronger relationship with trip distance for shopping trips than does the density at either trip end independently.

Relationship Between Trip Distance and Urban Form

The urban form variable *average population density at trip origins and destinations* was found to be significantly negatively correlated with trip distance for shopping trips ($r = -0.1615$) supporting the hypothesis that trip distance decreases as population density increases.

Significance of Relationship Between Urban Form and Per Capita Trip Generation When Non-Urban Form Factors are Controlled

Both urban form and non-urban form factors were found to have significant relationships with trip distance for shopping trips. The variable *level of service for bus* (as measured by the distance from the trip origin to the nearest bus stop) was found to be significantly positively correlated with trip distance for shopping trips, indicating that trip distance increases as distance to the nearest bus stop increases. Partial correlation was used to identify the impacts that this variable had on the relationship between trip distance and average population density at trip origins and destinations for shopping trips.

Table 10.5. Partial Correlation of Level of Bus Service for Trip Distance

SHOPPING TRIPS

VARIABLE	corr. coeff. (r)	weighted cases (n)	sig. (p)
Average population density at trip origins and destinations	-0.1325	3142	0

The information presented in Table 10.5 indicates that under partial correlation analysis, average population density at trip origins and destinations remained significantly correlated with trip distance for shopping trips, with the correlation coefficient reduced by less than 0.03. This finding supported the hypothesis that a significant relationship exists between trip distance and urban form (population density), even when the most significant non-urban form variable is controlled.

TRAVEL TIME

The first hypothesis stated in Figure 10.1 regarding travel time was further refined into three hypotheses:

- A significant relationship between travel time and urban form (population density, employment density, and land-use mix) exists.

- Travel time declines as urban form variables (population density, employment density, and land-use mix) increase.
- A significant relationship exists between travel time and urban form (employment density, population density, and/or land-use mix), even when significant non-urban form variables are controlled.

Work Trips

Significance of Travel Time and Urban Form Relationship

There was a statistically significant relationship between travel time and urban form for work trips. The significant urban form variables, *mixing of uses at trip origins* and *employment density at trip destinations* , are shown in Table 10.6. These variables had a population correlation coefficient of approximately 0, indicating a statistically significant relationship with travel time. Therefore, the null hypothesis (that there is no linear relationship between travel time and urban form for work trips) was rejected.

Table 10.6. Variables Correlated with Travel Time

VARIABLE	corr. coeff. (r)	weighted cases (n)	sig. (p)
WORK TRIPS			
Mixing of uses at trip origins	-0.1629	2107	0
Employment density at trip destinations	0.1882	3370	0
SHOPPING TRIPS			
Number of vehicles available	0.1262	2448	0
Average employment density at trip origins and destinations	0.1262	2448	0

The urban form variables that were significantly correlated with travel time were at each trip end independently. This finding refuted the hypothesis that the average levels of densities and/or land-use mix at both trip origins and destinations has a stronger relationship with work trip travel time than do these variables at either trip end independently.

Relationship Between Travel Time and Urban Form

Land-use mix was found to be negatively correlated (r = -0.1538) with travel time for work trips, supporting the hypothesis that travel time decreases as land-use mix at trip origins increases. Employment density was found to positively correlated (r = 0.1788) with travel time, refuting the hypothesis that travel time decreases as employment density increases for work trips. This finding suggested that people spend more time commuting to major employment locations that have extremely high employment densities. This problem is most likely due to the traffic congestion associated with travel to these locations during AM and PM peaks and the geographic magnitude of the labor shed of large and dense employment centers. This finding was consistent with findings from past research on travel behavior for the journey to work (see Pivo 1987).

Significance of Relationship Between Urban Form and Travel Time When Non-Urban Form Factors are Controlled

No significant relationship existed between the non-urban form variables within this database and travel time for work trips, refuting the hypothesis that there is a significant relationship between travel time and both urban form and non-urban form variables. The variables presented in the database represented a variety of trip makers' demographic characteristics. Therefore, the hypothesis that there is a significant relationship between urban form and travel time for work trips, even when non-urban form factors are taken into account, was accepted.

Jobs-Housing Balance

The second hypothesis related to travel time dealt with the relationship between jobs-housing balance and travel time. This hypothesis was further refined to state that *travel time is shorter for work trips that end in census tracts whose jobs and housing are more evenly balanced.* An analysis was conducted to test the relationship between travel time and jobs-housing balance at trip origins for work trips. The results were that the relationship was less significant at the trip origin than at the destination. Therefore, only the findings from the analysis of the relationship between jobs-housing balance and travel time at the destination are presented here. Table 10.7 presents findings from a t-test that compared the mean work trip distance between tracts with a balanced ratio of jobs to households (0.8-1.2) and tracts with an imbalanced ratio (less than 0.8 and greater than 1.2).

Table 10.7. Jobs-Housing Balance and Travel Time at Destinations

WORK TRIPS

VARIABLE	mean travel time (minutes)	weighted cases (n)
Balanced tracts (jobs:houshold ratios between 0.8 and 1.2)	17.29	290
Imbalanced tracts (jobs:houshold ratios less than 0.8 and greater than 1.2)	22.88	3030

sig. (p)	% change in travel time
0	24%

The population correlation coefficient (p=0.00) indicated a significant difference in work trip travel time between "balanced" and "unbalanced" census tracts. This finding refuted the null hypothesis that there is no relationship between jobs-housing balance and travel time for work trips. The mean average travel time for work trips that ended in census tracts with an unbalanced jobs to households ratio was 5.59 minutes longer than work trips that ended in balanced tracts. In other words, the average time for work trips that ended in unbalanced tracts was 24 percent longer than that for trips that ended in balanced tracts. This finding was consistent with the findings from the analysis of the relationship between jobs-housing balance and trip distance.

Shopping Trips

Significance of the Relationship Between Travel Time and Urban Form

There was a statistically significant relationship between trip distance and urban form for shopping trips. The only significant urban form variable, *average employment density at trip origins and destinations,* is shown in Table 10.6. This variable had a population correlation coefficient of approximately 0, indicating a statistically significant relationship with travel time. Therefore, the null hypothesis (that there is no linear relationship between travel time and urban form for shopping trips) was rejected. This finding also supported the hypothesis that the average levels of employment density at both trip origins and destinations is more strongly related to travel time for shopping trips than is employment density at either trip end independently.

Relationship Between Travel Time and Urban Form

The urban form variable (average employment density at trip origins and destinations) was found to be significantly positively correlated ($r = 0.1154$) with travel time, refuting the hypothesis that trip distance decreases as employment density increases.

Significance of the Relationship Between Urban Form and Travel Time When Non-Urban Form Factors are Controlled

Both urban form and non-urban form factors were found to have a significant relationship with travel time for shopping trips. *Number of household vehicles* was found to be significantly positively correlated with travel time for shopping trips, indicating that travel time increases as the number of household vehicles increase. Partial correlation was used to identify the impacts that this variable has on the relationship between travel time and *employment density at trip origins and destinations for shopping trips.*

Table 10.8. Partial Correlation of Number of Household Vehicles for Travel Time

SHOPPING TRIPS

VARIABLE	corr. coeff. (r)	weighted cases (n)	sig. (p)
Average employment density at trip origins and destinations	0.1155	2052	0

The information presented in table 10.8 indicates that correlation coefficients for both urban form variables were virtually unchanged when the *number of household vehicles* was controlled. These findings supported the hypothesis that a significant relationship exists between travel time and urban form, even when significant non-urban form variables are controlled.

SUMMARY

The key findings regarding urban form relationships with per capita trip generation, trip distance and travel time for work and shopping trip purposes are presented in Tables 10.9 and 10.10. The findings pertaining to trip distance and travel time also included information obtained from the descriptive statistics in the appendices. Non-urban form relationships with trip distance and travel time are also presented below.

Analysis revealed that urban form affects trip generation rates for work trips but not shopping trips. More significant was the finding that per capita trip generation increases as employment density, population density, and land-use mix increase. This finding alone suggests that vehicle miles traveled increase through greater SOV usage.

Table 10.9. Key Findings: Per Capita Trip Generation

WORK	SHOPPING
Per capita trip generation increases as employment density, population density, and mixing of uses increase *Employment density, population density, and mixing of uses were found to be most correlated at trip origins*	*No significant relationship between urban form and per capita trip generation was found* *Individuals in higher age groups make fewer shopping trips*

Table 10.10. Key Findings: Trip Distance

WORK	SHOPPING
Trip distance decreases as mixing of uses, population density, and employment density increase	*Trip distance decreases as average population density at trip origins and destinations increases*
Mixing of uses, population density, and employment density were most significantly correlated at trip origins	*Population density was most significantly correlated when averaged both trip ends*
Trip distance increases as LOS for bus decreases	*Trip distance increases as LOS for bus decreases*
Controlling for LOS of bus did not significantly affect correlations between urban form and trip distance	*Controlling for LOS of bus did not significantly affect the correlation between population density and trip distance*
Trips ending in census tracts with a jobs to households ratio of between 0.8 and 1.2 had an average trip distance of 2.72 miles, 28 percent shorter than trips ending in tracts whose ratio was <0.8 or >1.2	*Jobs-housing balance ratios were not applied to trip distance for shopping trips*
More than 60 percent of all trips in the survey were less than 5 miles long	

However, research on mode choice at varying levels of population and employment density indicated that SOV usage decreases and both bus use and walking trips increase as population density and employment density increase. Taken together, these findings indicate that although denser and more mixed areas generate more work trips, a higher proportion of these work trips are by walking and bus.

The variables *employment density*, *population density*, and *mixing of uses* were all found to be most correlated at work trip origins. This finding was consistent with findings for per capita trip generation. *Employment density*, *population density*, and *mixing of uses* were also negatively correlated, supporting the hypothesis that trip distance decreases as density and land-use mix increase. *Employment density*, *population density*, and *mixing of uses* were also found to be significantly correlated even when level of bus service was controlled. The distribution of trips in the survey favored shorter trips, as more than 60 percent were less than 5 miles long. Tracts whose jobs to households ratio was more balanced had an average work trip distance that was 28 percent shorter than the work trip distance for tracts whose jobs to households ratio was less balanced.

The primary hypotheses tested were related to a reduction in travel time associated with higher population density, employment density, land-use mix, and levels of jobs-housing balance. Findings presented in Table 10.11 indicate that travel time for work trips increases as employment density at trip destinations increases, refuting the hypothesis that travel time decreases as employment density increases. Shopping trips were more sensitive to average trip end urban form characteristics than work trips. This was consistent with findings pertaining to trip distance.

The mean travel time for work trips that ended in census tracts that had a greater balance between the numbers of households and jobs was found to be significantly shorter than the mean time for trips that ended in census tracts that were less balanced. This finding suggests that time savings could be achieved if more census tracts had a jobs to household ratio of between 0.8 and 1.2. This finding has significant implications for the designation of locations for additional jobs and households.

Table 10.11. Key Findings: Travels Time

WORK	SHOPPING
Employment density at trip destinations is associated with longer travel times *Mixing of uses at trip origins is associated with shorter travel times*	*Average employment density at trip origins and destinations is associated with longer travel times* *Employment density was most significantly correlated when both trip ends were averaged*
Trips ending in census tracts with a jobs to households ratio of between 0.8 and 1.2 had an average travel time of 5.59 minutes, 24 percent shorter than trips that ended in tracts whose ratio was <0.8 or >1.2	*Jobs-housing balance ratios were not applied to travel time for shopping trips*
More than 90 percent of all trips in the survey were less than 30 minutes long	

Most of the trips in the survey were brief (less than 30 minutes). This indicates that people place a high value on the amount of time they devote to travel. In addition, this finding, together with those presented under trip distance, suggest that costly infrastructure improvements to support longer trips with longer travel times would only serve a small percentage of the total trips.

CHAPTER XI

REVIEW OF FINDINGS AND IMPLICATIONS ON THEORY, PRACTICE AND FUTURE RESEARCH

This research indicated that travel behavior is associated with urban form for work and shopping trips, even when non-urban form factors are controlled. Furthermore, where SOV travel decreases as population density, employment density, and land-use mixing increase, bus use and walking increase. Trip distance and travel time decrease as the ratio between jobs and households becomes more balanced.

Findings from this research project were generated through an analysis of information from previous studies, the development of a database that utilized existing data, and original empirical research to isolate relationships between urban form and travel behavior. Below is a summary of the findings generated in this study, followed by a critical discussion of implications for the planning community in terms of:

- the evolution of explanatory theory that relates travel behavior to urban form typologies;
- policy and planning level work that relate urban form to travel behavior; and
- future research questions that need to be addressed to more fully understand the relationships between urban form and travel behavior.

SUMMARY OF EMPIRICAL RELATIONSHIPS BETWEEN URBAN FORM, NON-URBAN FORM, AND TRAVEL BEHAVIOR

The research found empirical relationships between aspects of urban form and travel behavior. This section reviews these findings, beginning with a presentation of correlation coefficients by trip purpose (work and shopping) between each aspect of urban form and travel behavior. A more in-depth discussion of relationships between urban form and mode choice, per capita trip generation, trip distance, and travel time follows. Where possible, relationships between findings from this research and past research efforts are documented.

Empirical relationships based on simple linear correlation between urban form and travel behavior variables for work trips are presented in Table 11.1. This method of presentation allows relationships between urban form and travel behavior variables to be compared and also creates a visual map of where these relationships are present or absent and their relative strength.

Table 11.1. Summary of Correlation Coefficients Between Urban Form and Travel Behavior Variables-Work Trips

TRAVEL BEHAVIOR VARIABLES	**EMPLOYMENT DENSITY**	**POPULATION DENSITY**	**MIXING OF USES**	**JOBS HOUSING BALANCE**
% SOV USE	-0.26	-	-0.13	n/a
% CARPOOL USE	-	-	0.18	n/a
% BUS USE	0.59	0.19	0.15	n/a
% WALKING	0.43	0.34	0.21	n/a
TRIP GENERATION	0.12	0.12	0.11	n/a
TRIP DISTANCE	-0.13	-0.17	-0.19	t-test shows reduction
TRAVEL TIME	0.19	-	-0.16	t-test shows reduction
VEHICLE OCCUPANCY	-	-	-	n/a

na=not tested

Mode choice was measured in this study in terms of the proportion of trips in the sample (work trips) taken to or from a census tract by SOV, carpool, bus, and walking. With the exception of percentage of carpool use, each of the travel behavior variables were significantly related to at least two of the urban form variables, and half of them were related to employment density, population density, and mixing of uses. Jobs-housing balance was only tested in relation to trip distance and travel time using a t-test. Both trip distance and travel time were found to decrease as jobs housing balance increased. An analysis of the relationship between vehicle occupancy and urban form determined that no significant relationships existed in this database. Non-urban form variables were also found to be significantly correlated with each travel behavior variable. The non-urban form variables found to be related to travel behavior included household type, age, possessing of a driver's license, vehicle availability, level of service for bus, and working at home. More detailed information is provided on the use of non-urban form variables as "controls" in measuring urban form and travel behavior relationships in chapters 8 and 10.

Empirical relationships based on simple linear correlation between urban form and travel behavior variables for shopping trips are presented in table 11.2.

Table 11.2. Summary of Correlation Coefficients Between Urban Form and Travel Behavior Variables-Shopping Trips

TRAVEL BEHAVIOR VARIABLES	EMPLOYMENT DENSITY	POPULATION DENSITY	MIXING OF USES	JOBS-HOUSING BALANCE
% SOV USE	-0.15	-	-	NA
% CARPOOL USE	-	-	0.16	NA
% BUS USE	0.44	0.16	-	NA
% WALKING	0.24	0.31	-	NA
TRIP GENERATION	-	-	-	NA
TRIP DISTANCE	-	-0.17	-	NA
VEHICLE OCCUPANCY	-	-	-	NA
TRAVEL TIME	0.13	0.12	-	NA

na = not tested

For each urban form travel behavior relationship, the correlation coefficients for shopping trips were consistently in the same direction as those for work trips. The percentages of walking and bus trips had the highest correlation with any urban form variables. Mixing of uses was found to be far less correlated with travel behavior variables for shopping trips than for work trips. Trip generation was not found to be correlated with urban form at all for shopping trips. Travel time was positively correlated with both population and employment density for shopping trips. This result supports the finding that density can be associated with an overall increase in travel time. However, it does not indicate that vehicle miles traveled increase as density increases. A decrease in trip distance counters this effect, as does a reduction in SOV travel and increase in bus use and walking associated with higher densities. Greater travel time is probably caused by the greater congestion associated with higher employment densities. Overall, this research concluded that employment density at trip destinations has a stronger relationship with travel behavior than that at trip origins. Future development patterns need to account for this relationship to foster significant reduction in SOV dependence.

MODAL CHOICE RELATIONSHIPS WITH URBAN FORM

Modal choice was analyzed at the census tract level by using the proportion of trip origins or destinations for SOV use, carpool use, bus use, and walking per census tract as dependent continuous variables. Carpooling was not found to be significantly related to employment and population density, while SOV, bus, and walking trips were. Relationships between employment density, population density, mixing of uses and SOV usage were found to be consistently negative for both work and shopping trips. The relationships between employment density, population density, mixing of uses and bus use and walking was consistently positive for both work and shopping trips.

One over-riding question is whether prescribing higher densities and greater mixing of uses will reduce travel demand and promote sustainability. This point becomes even more important when the results from this research are analyzed closely. Positive relationships were found to exist between employment density and trip generation and travel time for work trips and employment/population density and travel time for shopping trips. These positive relationships must be analyzed more closely to determine the actual effects of densification on travel time and trip generation by mode. More specifically, is the increase in travel time only for certain modes and can enhancing LOS for bus and walking effectively reduce travel time? In addition, is the increase in trip generation associated with higher densities only for bus use and walking and therefore not a negative impact? If trip generation for SOV is positively associated with higher densities, then what is the overall effect of many shorter trips on air quality (i.e. cold starts)?

General findings identified in the analysis of modal choice were supported through the analysis of descriptive statistics, correlation analysis, and regression analysis. These findings are presented in Figure 11.1.

56 percent of trips (weighted) in this survey were SOV types and 36 percent were carpool types
Bus use, walking, and other modes made up approximately 8 percent of all trips (weighted).
Average employment density at trip origins and destinations was highly correlated with mode choice for bus use, walking, and SOV use.
Urban form variables had a higher correlation with bus use and walking rather than SOV use.
Carpool trips were least sensitive to urban form factors
Urban form factors were consistently negatively correlated with SOV trips and positively associated with bus use and walking trips.
Non-urban form factors were significantly correlated with mode choice for SOV use, carpooling, bus use, and walking.
Population and employment density had a non-linear relationship with mode choice for SOV use, carpooling, bus use, and walking.

Figure 11.1. General Findings Pertaining To Mode Choice

Findings from this general review of modal choice indicate that only a small subset of the trips in the database were bus and walking trips. This subset of trips (bus and walking) was found to have a stronger relationship with urban form than SOV trips. Carpooling was not found to be significantly correlated with density but was found to be significantly correlated with land use. Carpooling was found to have strong relationships with non-urban form factors, including household type, employed outside the home, possession of a driver's license or buspass, and travel time for carpooling. This suggests that policies intended to encourage carpooling (e.g., Washington State's Commute Trip Reduction Law) will be more effective if they account for these factors.

Relationships Between Modal Choice and Employment Density

Findings from the analysis of linear and non-linear relationship between employment density and modal choice are summarized below. Linear relationships are presented in terms of the rate of change or steepness of the slope, between employment density and percentage of SOV use, bus use and walking. These findings are supported by the interpretation of the coefficients in linear multiple regression models. These coefficients allow one to make inferences regarding the amount of change in the use of a particular mode that would result from a given increase in employment density while other factors were held constant.

Past research and findings from this analysis suggested that the relationship between modal choice and employment density is non-linear. Therefore, an analysis was conducted to identify thresholds where change would occur in SOV use, bus use, or walking as a function of employment density.

Linear Relationships Between Modal Choice and Employment Density

Figure 11.2 documents findings associated with the amount of change that could be anticipated in mode choice with a change in employment density. This information may be useful to planners who want to estimate the amount of change in travel behavior that can be expected from a particular change in employment density. One application of this information is the Growth Management planning framework, in which comprehensive planning is being conducted to create consistency between land use and transportation elements.

The mean employment density for the census tracts in the sample is about 10 employees per acre for work trips and shopping trips. Findings presented in Figure 11.2 are based on interpretation of coefficients generated in a linear statistical environment. Findings from previous research and those presented in Chapter 9 indicates that the relationship between employment density and mode choice for SOV use, bus use, and

EMPLOYMENT DENSITY IMPACTS ON WORK TRIPS

An increase in average employment density at trip origins and destinations of 10 employees per acre could result in (all else being equal)

1) an increase in bus use trips of 1.7 percent at origins and 6.5 percent at destinations,
2) a decrease in SOV use trips of 2.1 percent at origins and 2.8 percent at destinations,

An increase in employment density at trip origins of 10 employees per acre could yield an increase in walking trips of 1.7 percent (all else being equal).

EMPLOYMENT DENSITY IMPACTS ON SHOPPING TRIPS

An increase in average trip end employment density of 10 employees per acre could yield a 7.6 percent increase in transit trips at destinations (all else being equal)

An increase in employment density at trip destinations of 10 employees per acre could yield (all else being equal)

1) a 1.9 percent decrease in SOV use trips,

2) a 1.1 percent increase in walking trips.

Figure 11.2. Magnitude of Employment Density and Modal Choice Relationships

walking is non-linear. Therefore, it is likely that the magnitude of change in ridership for a particular mode would be less than the estimated change presented here at lower employment densities and greater at higher employment densities. Given these caveats, the findings suggest that doubling the average tract's employment density could result in an increase of up to 6.5 percent in the modal share for bus use for work trips to that tract. Overall, an increase in employment density was found to have a greater impact on mode choice at trip destinations than at trip origins for work trips. Increasing employment density at trip destinations was also found to have the potential to significantly increase bus usage for shopping trips.

Non-Linear Relationships Between Modal Choice and Employment Density

Correlation and regression analysis shows that average employment density at trip origins and destinations for work trips and employment density at trip destinations for shopping trips had the strongest relationships with modal choice. Therefore, these variables were analyzed in greater detail in terms of their non-linear relationships with modal choice. Employment density was recoded into intervals to allow trips distributed among various modes to be assessed at different levels of employment density. A detailed description of this procedure and the findings from this analysis are presented in Chapter 9. This analysis showed that the relationship between employment density and mode choice was non-linear for SOV use, Carpool use, bus use, and walking for both work and shopping trips. Employment density thresholds where significant changes between modes occur are portrayed graphically for work and shopping trips in Chapter 9. Gross employment density thresholds identified by mode for work trips are presented in Table 11.3 below.

The findings shown in Table 11.3 represent two thresholds for each mode analyzed in this study. SOV use continuously decreased while bus use and walking increased with employment density. On the other hand, carpooling was most popular in moderately high density locations and dropped off dramatically at the highest employment density interval. This may indicate that the ridesharing programs in the metropolitan centers (Bellevue or Tacoma) were more effective programs than those found in Downtown Seattle. Further analysis of the findings in Chapter 9 suggested that the decrease in carpooling versus an increase in bus ridership and walking at the highest employment density interval.

Other findings from this analysis indicated that walking trips trends were similar to those of bus trips at the lower densities. The implications of this finding are significant for policies intended to foster bus usage. According to this research, the same minimum threshold of between 20 and 50 employees per acre would yield an increase in both bus and walking trips.

Table 11.3. Gross Employment Density at Trip Origins And Destinations—Thresholds Associated With Modal Shifts

WORK TRIPS - DESTINATIONS TRACTS

MODE VARIABLE	DENSITY RANGE (EMPLOYEES PER ACRE)	PERCENTAGE OF CHANGE IN MODAL SHARE
% SOV TRIPS	20-75	from 90% to 60%
% SOV TRIPS	125 to 250	from 60% to 33%
% CARPOOL TRIPS	75 to 175	from 8% to 22%
% CARPOOL TRIPS	175 to 250	from 22% to 8%
% TRANSIT TRIPS	20 to 50	from 0% to 9%
% TRANSIT TRIPS	75 to 250	from 9% to 35%
% WALK TRIPS	20 to 50	from 0% to 9%
% WALK TRIPS	75 to 175	from 9% to 25%

Findings from the analysis of thresholds associated with gross employment density at shopping trip destinations indicated that a minimum employment density of 50 employees per acre is necessary for significant shifts to begin to occur for SOV use, bus use, and walking. The most compelling of the findings presented in Table 11.4 is the dramatic increase in the proportion of walking trips that occurred as employment density at trip destinations increased to over 50 employees per acre.

Gross employment density thresholds identified by mode for shopping trips are presented in Table 11.4 .

<u>Relationships Between Modal Choice and Population Density</u>

Linear and non-linear relationships between population density and mode choice are presented below. Where employment density was found to be more significantly related to bus usage, population density was found to have a stronger relationship to SOV usage and walking.

Table 11.4. Gross Employment Density At Trip Destinations: Thresholds Associated With Modal Shifts

SHOPPING TRIPS - DESTINATION TRACTS

MODE VARIABLE	DENSITY RANGE (EMPLOYEES PER ACRE)	PERCENTAGE OF CHANGE IN MODAL SHARE
% SOV TRIPS	50-402	from 52% to 30%
% CARPOOL TRIPS	15-402	from 50% to 25%
% TRANSIT TRIPS	50-402	from 3% to 14%
% WALK TRIPS	50-402	from 3% to 28%

Linear Relationships Between Modal Choice and Population Density

Through the analysis of coefficients assigned to population density variables in the regression models, it was determined that changes in population density were also associated with changes in modal choice. In fact, the steepness of the slope between the dependent mode choice variables (percentage SOV use, percentage bus use, and percentage walking) and population density, as shown in Figure 11.3 was greater than the slope associated with employment density.

The information in Figure 11.3 should not be interpreted to mean that mode choice had a stronger relationship with population density than with employment density. Beta weights for employment density variables in the regression models presented in Chapter 8 had higher overall absolute values than those of population density variables (except for percentage of walking for shopping trips). These values indicate the opposite; modal choice was found to have a stronger relationship with employment density than with population density.

Where the rate of change between employment density and bus usage was higher, the rate of change between population density and SOV usage and walking was higher.

POPULATION DENSITY IMPACTS ON WORK TRIPS

An increase in average population density at trip origins and destinations of 10 people per acre could result in (all else being equal):

1) a 6.7 percentage decrease in SOV trips at destinations

2) a 7 percentage increase in walking trips at origins

An increase in population density at trip destinations of 10 people per acre could result in an increase in walking trips of 2.5 percentage (all else being equal)

POPULATION DENSITY IMPACTS ON SHOPPING TRIPS

An increase in average trip end population density of 10 people per acre could result in (all else being equal):

1) an 8.9 percentage increase in walking trips at destinations

2) an 1.9 percentage increase in transit trips at destinations

An increase in population density at trip origins of 10 people per acre could result in a 5 percentage reduction in SOV trips (all else being equal)

Figure 11.3. Magnitude of Population Density and Modal Choice Relationships

This finding may be useful to indicate which "policy lever" to pull depending on the desired change in travel behavior. For example, where policies are concerned more with a reducing SOV usage, increasing population density may be the best mechanism. On the other hand, increasing employment density may be a more useful tool for increasing bus ridership.

<u>Non-Linear Relationships Between Modal Choice and Population Density</u>

The measure of population density that was found to have the strongest relationship with mode choice in correlation and regression analyses was average gross population density at trip origins and destinations for both work and shopping trips. Therefore, this measure of population density was selected for the analysis of non-linear relationships with modal choice for work and shopping trips. This analysis resulted in the identification of non-linear relationships for SOV use, carpool use, and walking for work trips and SOV use, carpool use, bus use and walking for shopping trips. Where non-linear relationships were found to exist, a more detailed analysis was conducted (within the limitations of the numbers of trips per population density interval) to identify more specific thresholds where modal shifts occurred. A detailed description of this procedure and associated findings are presented in Chapter 9. Table 11.5 list the major thresholds identified in the analysis of population density relationships with work trips.

Table 11.5. Gross Population Density At Trip Origins And Destinations—Thresholds Associated With Modal Shifts

WORK TRIPS - ORIGIN TRACTS

MODE VARIABLE	DENSITY RANGE (RESIDENTS PER ACRE)	PERCENTAGE OF CHANGE IN MODAL SHARE
% SOV TRIPS	5 to 18	from 81% to 50%
% SOV TRIPS	18 to 60	from 50% to 60%
% CARPOOL TRIPS	18 to 60	from 20% to 0%
% WALK TRIPS	7 to 18	from 0% to 19%

The population density ranges presented in Table 11.5 are very broad because of the lack of trips that originated in census tracts with higher density levels. Their breadth limited the ability to draw specific policy implications regarding population density and mode choice. Given this limitation, a set of more general trends were identified. SOV usage consistently declined until the highest interval of population density, where it began to increase. This change was a function of a trade-off between SOV use and carpooling, suggesting that carpooling to and from locations with the highest levels of population density was less popular than in locations with slightly lower densities. The percentage of walking trips increased significantly once population density reached 7 residents per acre. Bus usage appeared to have a linear relationship with population density for work trips; therefore, no thresholds were identified. Table 11.6 lists the major thresholds identified in the analysis of population density and shopping trips.

Table 11.6. Gross Population Density At Trip Origins and Destinations—Thresholds Associated With Modal Shifts

SHOPPING TRIPS - ORIGIN TRACTS

MODE VARIABLE	DENSITY RANGE (RESIDENTS PER ACRE)	PERCENTAGE OF CHANGE IN MODAL SHARE
% SOV TRIPS	9 to 60	from 58% to 44%
% CARPOOL TRIPS	13 to 60	from 40% to 20%
% TRANSIT TRIPS	13 to 60	from 1% to 12%
% WALK TRIPS	13 to 60	from 5% to 22%

The analysis identified non-linear relationships between all four modes and population density for shopping trips. Walking trips was again the most sensitive to increases in population density. Carpool usage declined as population density increases over 13 residents per acre which is consistent with findings from the analysis of population density relationships with work trips.

Relationships Between Modal Choice and Land-Use Mix

Land-use mix is defined in this research to include both residential and non-residential land uses. Interpretation of the rate of change, or the steepness of the slope, of land-use mix variables in the mode choice regression models in Chapter 8 was limited by the fact that the units by which land-use mix was measured were decimals on a normalized scale between 0-1. The meaning of these units could not be readily interpreted. For example, where employment density was measured in terms of employees per acre, land-use mix was measured along an abstract continuum from low (0.00) to high (0.794). Determining the difference between census tracts with land-use mix ratings of 0.4 and 0.5 could only be done through an analysis of selected cases. Further research is necessary to identify the typologies that correspond to the different levels of mix identified in this research. Until this is accomplished, this measure of land use mix will be difficult to communicate to decision makers and the general public.

An analysis of non-linear relationships between land-use mix and mode choice was conducted for all trips, work trips, and shopping trips. The analysis determined that no detectable non-linear relationship existed. This result suggests that the geographic unit of analysis (the census tract) may have been too large to fully detect the non-linear effect of land-use mix on modal choice. If subsequent research of the relationships between land-use mix and modal choice (at smaller geographic units of analysis) also reveals a linear relationship, then policies can be developed solely on the basis of the strength of the relationship. These policies will not need to identify specific levels of mix necessary to affect modal choice for percentage of SOV, percentage of carpooling, percentage of bus, and percentage of walking.

These limitations in no way indicate that land-use mix is not related to modal choice. Findings from this research indicated that land-use mix was correlated with modal choice and that the relationship between land-use mix and the choice to use an SOV was negative. They also indicated a positive relationship between land-use mix, carpooling, bus use, and walking. These relationships were consistent with the relationships of population and employment density with mode choice (with the exception of carpooling, with which only land-use mix was significantly correlated). The measure for land-use mix developed at the tract level had the following correlations with each mode for work and/or shopping trips:

- percentage of SOV use for work trips (r= -0.13)
- percentage of carpool use for work (r= 0.18) and shopping trips (r= 0.16)
- percentage of bus use for work trips (r= 0.15)
- percentage of walking for work trips (r= 0.21).

These relationships indicated that land-use mix can be measured at the census tract scale; however, the relationships are relatively weak with mode choice. Only the relationship between average land-use mix at origins and destinations and percentage of walking for work trips was significant enough to make it into a regression model. The result of the model was a beta weight of 0.15, which was the weakest value in that model (see Chapter 8).

Relationships With Past Efforts to Analyze Modal Choice

The findings of this project support the work of Puskarev and Zupan, who discovered non-linear relationships between bus ridership and density. Discrepancies between the density measures Pushkarev and Zupan used and those used in this study elude exact comparison of minimum density thresholds. Pushkarev and Zupan found that a minimum population density of 7 households per acre was required to sustain significant bus use. This value corresponds with the findings from this study presented in Chapter 9 for shopping trips. According to these findings, an average population density for shopping trip origins and destinations of 13 residents or 7 households per acre was the threshold at which bus usage began to increase. Population density at trip origins and destinations for work trips did not show a non-linear relationship with bus ridership. This result may have been a function of averaging the trip end population densities and/or the data within the work trip subset. In an analysis of all trips (see appendices) 13 residents or approximately 7 dwelling units appeared to be the threshold where bus usage began to increase. This threshold was associated with the relationship between population density at trip destinations for all trip purposes and bus ridership.

Findings from the analysis of land-use mix also supported work of Dr. Robert Cervero, which revealed that increasing the level of land-use mix at employment centers would reduce mid-day SOV travel. Findings from this analysis suggested that as land-use mix increased at trip destinations, SOV usage decreased. Trip destinations for work trips were interpreted to indicate employment centers.

PER CAPITA TRIP GENERATION RELATIONSHIPS WITH URBAN FORM

Trip generation was found to be significantly positively related to urban form for work trips but not for shopping trips. This positive relationship indicated that the number of trips per person increased as density and land-use mix increased. This findings could be easily misconstrued to mean that travel demand in the form of vehicle miles traveled (VMTs) increases with density and land-use mix. Findings from past research (see Deutschman and Jaschik below) and from this project have indicated that SOV travel decreases as density and land-use mix increase, while bus usage and walking increase. This means that the increase in trip generation is primarily in the form of bus and walking trips. Whether this increase in trip generation was a function of higher density and mix or other associated factors remains unclear. More specifically, we still don't know which aspects of trip generation are most sensitive to which particular conditions associated with density and mix. The increase in trip generation in dense, highly mixed areas could have been a function of people's tendency to make many short, single purpose trips as opposed to lower density, single-use areas where people link trips to increase efficiency. This research did not sufficiently address this issue; therefore, it is impossible to provide a meaningful answer to more targeted questions about trip generation/urban form relationships for work trips. A more specific analysis that focused on travel behavior activities within selected urban form typologies (e.g., dense, highly mixed areas) would provide more answers. Research conducted in Portland, Oregon, as part of the Land Use Transportation and Air Quality Connection (LUTRAQ) may provide more answers to these questions. METRO (the MPO for the Portland Area) has re-callibrated its 400 zone model to include an index of pedestrian accessibility and land-use mix (LUTRAQ, 1993). This model provides the opportunity to select out particular zones on the basis of accessibility by a particular mode, intensity of development, and the intermix of uses. Using trip generation patterns from a subset of zones to compare accessibility by mode with high density and mix would provide more information about these relationships. Given that amount of information presently available, one thing is certain: the positive relationship between density, mix, and trip generation is an extremely important finding that links trip making behavior to more subtle factors embedded within urban form. A major concern is that without further research the findings presented here could be misinterpreted to mean that increasing density and mix increases environmental impacts more than does sprawl. However, this research is not sufficiently conclusive to make that case. This question is a critical component of the puzzle that needs to be assembled to understand the relationship between environmental conditions (urban form) and our behavior.

The lack of a relationship between urban form and trip generation for shopping trips indicated that the number of per capita shopping trips was not affected by employment density, population density and land-use mix. However, per capita trip generation for shopping trips was significantly related to one non-urban form variable age group.

Per capita work trip generation was significantly related to three urban form variables population and employment density at trip origins (r = 0.1228), employment density at trip origins (r = 0.1196), and land-use mix at trip origins (r = 0.1128). The presence of measures that included employment density, population density, and land-use mix indicated a strong overall relationship between urban form and per capita trip generation for work trips.

Past Analyses of Urban Form Relationships with Per Capita Trip Generation

The findings from this study that indicated a positive relationship between trip generation and urban form variables were consistent with work done in the late 1960s by Deutschman and Jaschik. That study found that the total number of vehicle trips for households that owned no automobiles more than doubled as residential density increased from 1 to 300 persons per square mile. Findings from the present research (see Chapter 9) suggested that the increase in trip generation associated with higher densities occurs primarily in the form of bus and walking trips.

TRIP DISTANCE RELATIONSHIPS WITH URBAN FORM

Land-use mix (r = -0.1922), population density (r = -0.1671), and employment density (r = -0.1343) were all found to be significantly negatively correlated with work trip distance. Level of service for bus use (measured by the distance from trip origins to the nearest bus stop) was found to be positively correlated with work trip distance. Level of service for bus was measured by the distance from trip origins to the nearest bus stop. This variable was found to be significantly positively correlated with work trip distance. A partial correlation was conducted to determine whether the relationship between urban form and trip distance was affected by the level of bus service. Findings from this test indicated that population density, employment density, and land-use mix was related to work trip distance, even when level of bus service (LOS) was controlled. This indicates that potential reductions in vehicle miles traveled (VMTs) for shopping trips could result from increased population density.

Jobs-housing balance was negatively related to work trip distance. A comparison was conducted between the mean travel distance for balanced tracts (with ratios between jobs and households of between 0.8 and 1.2) and that for unbalanced tracts (with ratios between jobs and households of < 0.8 and > 1.2). This comparison showed that balanced tracts had a mean work trip distance (for work trip destinations) that was 28 percent shorter than that of unbalanced tracts. These finding support policies that target densification, land-use mix, and jobs-housing balance as a mechanism to reduce vehicle miles traveled.

Shopping trip distance was negatively correlated with average population density at trip origins and destinations (r = -0.1615) and positively correlated with LOS for bus (r

= 0.1358). When bus LOS was controlled, population density remained significantly correlated.

TRAVEL TIME RELATIONSHIPS WITH URBAN FORM

Work and shopping trip travel times were related to urban form even when significant non-urban form factors were controlled. Land-use mix at trip origins was negatively correlated (r = -0.1629), and employment density at trip destinations was positively correlated (r = 0.1882) with work trip travel time. These results indicated that travel time increased as employment density increased at trip destinations. That finding is consistent with previous research conducted at the University of California at Berkeley by Dr. Gary Pivo. Pivo's research focused on journey to work relationships to suburban employment centers and concluded that larger and denser employment centers drew from a larger labor shed and were associated with increased levels of traffic congestion, which resulted in longer average travel times than other employment locations (Pivo, 1986).

Jobs housing balance was also found to have a significant relationship with travel time for work trips. A comparison was conducted between the mean travel time (in minutes) for balanced tracts (with ratios between jobs and households of between 0.8 and 1.2) and that for unbalanced tracts (with ratios between jobs and households of < 0.8 and > 1.2). This comparison determined that the mean travel time of balanced tracts was 24 percent shorter than that of unbalanced tracts. This finding (coupled with travel distance findings associated with jobs-housing balance) supports policies that target jobs-housing balance as a mechanism to reduce travel demand.

Both urban form and non-urban form variables were found to be significantly positively correlated with travel time for shopping trips. Urban form variables were average population density at trip origins and destinations (r = 0.1205) and average employment density at trip origins and destinations (r = 0.1262). The only non-urban form variable that was significantly correlated was the number of vehicles available (r =

0.1262). Both population and employment density variables remained significantly correlated with travel time when the number of vehicles available was controlled.

IMPLICATIONS OF FINDINGS ON THEORY, PRACTICE, AND FUTURE RESEARCH

IMPLICATIONS OF FINDINGS ON THEORY

The majority of the relationships between travel behavior and urban form found in this research could be explained with compensatory or micro-economic theory. Simply put, most of the travel choices made by the participants in the Puget Sound Transportation Panel (PSTP) were rationally related to pecuniary and non-pecuniary (time) costs. This research dealt primarily with costs that were measured through variations in population density, employment density, land-use mix, and jobs-housing balance. For example, higher densities are associated with higher costs for automobile travel (parking costs and longer travel time) and lower costs for bus service (higher LOS). This study concluded that a much higher proportion of the trips originating or ending in high density census tracts were made by bus and foot trips originating or ending in lower density tracts. This finding is consistent with micro-economic theory prediction that choices are based on the relative costs of the available alternatives. Note, however, that low r-squares indicated that other factors related to mode choice were not accounted for in this research.

Several hypotheses were posed at the beginning of chapters 8 and 10 to explain the relationships of mode choice, trip generation, trip distance, and travel time with aspects of urban form. Findings supported the hypothesis that SOV usage declines while bus use and walking increases as density and land-use mix increase. Carpool usage was less affected by urban form, indicating that the choice to carpool is a function of non-urban form factors, most of which may not have been present in the database developed for this project.

Another hypothesis tested in relation to modal choice was that averaging levels of density and land-use mix at both trip ends better explains modal choice than at trip origin or destination independently. This hypothesis was found to be true, further supporting the premise that modal shifts from SOVs to bus or walking occur in response to cost differentials between bus or walking and SOV travel associated with higher densities and land-use mix. These differentials take the form of decreasing costs for bus use and walking and increasing costs for SOV use as density and land-use mix increase. Land-use mix tends to be greater where densities are higher and land is more valuable. These locations are associated with higher levels of bus service and higher costs associated with SOV travel (e.g., parking and travel time). More specifically related with land-use mix is the concept of intervening opportunity. This concept is exemplified by highly mixed locations where a trip maker can walk to a nearby store for milk rather than having to travel a longer distance for the same product. The nearby store intervenes in the geographically based trip decision. If an individual resides in a strictly residential location, he or she may have to travel a mile or so to get some milk. Walking is not as appealing a mode choice in this less mixed scenario.

This study also tested hypotheses related to per capita trip generation, trip distance, and travel time based on micro-economic cost minimization principals. The increase in trip generation associated with increased levels of density and land-use mix refuted the hypothesis that trip generation declines under these urban form conditions. Given further consideration and comparisons with findings from other studies, this can be explained through micro-economics principals. The findings from this research indicated that bus and walking increased as density and land-use mix increased, while SOV usage declined. Therefore, the increase in trip generation that was realized in the form of bus and walking trips in dense highly mixed locations could have been a function of:

- latent demand
- available opportunity or

- lower costs associated with shorter distances.

This finding could be interpreted to indicate that people in low density locations would walk more if destinations are nearby and sidewalks exist along the way (LOS for walking). The same interpretation for bus usage may not be as easily tested. Cultural factors, more successfully explained through behavioral theory, have been found to be significant in suburban locations. These factors include attitudes toward riding bus.

Trip distance uniformly decreased as density and land-use mix increased, supporting the notion that travel demand (in the form of vehicle miles traveled) could be reduced by increasing densities, to the extent that travel time was not significantly increased. Travel time was found to be positively correlated with employment density for work trips and positively correlated with employment and population density for shopping trips. This finding could be interpreted to indicate that efficiency may be lost as employment densities reach an extremely high level. However, high levels of density are associated with extremely large employment centers; therefore, the magnitude of the employment center rather than employment densities may actually cause increased travel times. Past research has indicated that trip distance is related to the size of the employment center. In fact, trip distance has been found to have a stronger relationship with employment center size than with employment density (Pivo, 1987). In terms of micro-economic theory, highly dense employment locations (which also usually happen to be quite large) are drawing employees from greater distances because the benefits of working in these locations outweigh the travel time costs. Future research that controls for the number of jobs within a census tract to isolate the effect of employment and population density on travel time and trip distance will provide insight on the actual relationships between travel behavior (trip distance and travel time) and urban form (density and center size).

IMPLICATIONS OF FINDINGS ON PRACTICE

The practical applications of this research are many. This project provided a case study of the central Puget Sound region and tested policy objectives embedded in the Washington State Growth Management Act (GMA) and Vision 2020. These objectives include a reduction in SOV travel through land-use strategies such as densification and land-use mix. Findings from this study have already been incorporated into a large set of factors that will help establish guidelines as part of the implementation of Vision 2020. Particularly useful will be an empirical basis by which to substantiate the adoption of minimum population and employment density thresholds for various center typologies in Vision 2020. Findings from this research suggested that the employment density thresholds currently being proposed for metropolitan centers are too low. Current employment density thresholds are set at 50 employees per acre, whereas findings from this research indicated that 75 employees per acre are necessary to increase bus use and walking. A rough estimate of the projected employment densities in these metropolitan centers in 2020 (based on significant improvements in bus and strong land-use policies) is 60 to 70 employees per acre. This estimate indicates that the minimum threshold could be moved up from 50 employees per acre to somewhere above 60 employees per acre, depending on the willingness of local jurisdictions. In addition to Vision 2020, countywide planning policies may include minimum densities for the development of centers. The findings from this research will be helpful in identifying these minimum thresholds. The establishment of policies to encourage infill in areas outside of designated centers will be aided by the relationships between lower level density and mode choice identified in this research.

To make these findings meaningful it is critical to relate them to the regional form "as is." Relatively few census tracts in the study fell into the highest population and employment density categories in the threshold analyses (Chapter 9). Ten census tracts in the study had gross employment densities of above 50 employees. Fourteen census tracts had population densities of above 18 residents per acre. While a significantly larger proportion of trips were generated by and attached to these tracks, the reality is that achieving these densities is difficult. This problem suggests that analyzing relationships between modal choice and lower levels of density offers more useful findings, given the current urban form in the central Puget Sound region.

On an applied level, a city could make constructive use of this information. With a PC-based Geographic Information System (GIS), thematic maps have been created that geographically present the four urban form variables: population density, employment density, land-use mix, and jobs-housing balance (see Appendix E). These maps give planners and decision makers contextual information about planning areas and their adjacent urban form conditions. When a specific project of regional significance is proposed to affect one or more of these urban form factors, it is helpful to identify the level of density, mix, or balance that currently exists in these areas. One application has been to compare the jobs-housing totals proposed by a major redevelopment project in downtown Seattle (Seattle Commons Project) to existing ratios between jobs and housing in the project area. The City of Seattle anticipates an approximate ratio of three jobs to every household within the redevelopment area. This study found that census tracts with ratios of between 0.8 and 1.2 had significantly lower trip lengths and travel times than did less balanced tracts. This comparison made it possible to determine that the market driven project mix would exacerbate travel demand. The effect of this imbalance in favor of jobs would be exponentially increased because the project abuts the job rich Seattle CBD. The potential benefit of this project from a transportation perspective would be to balance the jobs in the CBD with housing. As a result of this analysis, a suggestion was forwarded to the Planning Staff at the City of Seattle to model a land-use alternative that was "housing rich" as part of the Environmental Impact Review Process. Another application is to the use data generated on land-use mix by census tract to identify types and amounts of land uses needed to increase the level of land-use mix within census tracts.

This research will also be useful to planners and elected officials who are focused on the promotion of particular modes of travel. Correlation and multiple regression analyses for carpooling, bus, and walking identified a wide array of factors that affect the choice to use each of these modes. Both urban form and non-urban form variables and their ability to predict variation in the use of particular modes were identified. This research provided empirically grounded results to guide the development of policies that promote non-SOV travel. For example, one model for predicting the choice to carpool for shopping trips found that people who work outside the home, live alone, and are between the ages of 35 and 64 are least likely to carpool. Thus it identified market conditions unfavorable for carpooling.

Modeling travel behavior associated with shopping trips aid city planners, retailers, and economic analysts making location decisions about shopping facilities to attract non-SOV trips. Travel behavior-based decisions regarding locations may allow developers to decrease the number of parking stalls and be assured that more patrons will arrive by modes other than the SOV.

Other applications of the findings from this research include the substantiation of land-use strategies, including the use of jobs-housing balance and land-use mix as viable means of reducing travel demand. In addition, the methods used to integrate urban form and travel behavior data can be applied in other regions of the United States. Several regions in the United States currently collect travel panel data on a regular basis. These regions could use census, employment, and parcel level data to construct similar databases at the census tract scale.

IMPLICATIONS OF FINDINGS ON FUTURE RESEARCH

Further research is needed to refine the findings identified in this research and to explore relationships between aspects of urban form and travel behavior that were not investigated in this project. A set of research topics were identified in this study that would provide extremely useful and in some cases essential knowledge on which to base urban form policies directed at reducing SOV travel and overall travel demand. These topics are presented below.

The Selection of Groups of Census Tracts for More Detailed Analyses

Focusing analyses on selected groups of census tracts within King, Pierce, and Snohomish counties would enhance the applicability of the findings from this research to the study area. Four research projects come to mind:

- the selection of census tracts found to have the highest levels of bus ridership and walking and the lowest levels of SOV
- the selection of census tracts with the highest levels of density, land-use mix, and jobs-housing balance
- the selection of census tracts that roughly correspond with the geographic locations of targeted centers under Vision 2020 and
- the selection of census tracts that roughly correspond to jurisdictional boundaries to allow the assessment of consistency requirements mandated by the Growth Management Act (GMA).

Each of these projects would provide greater understanding of the urban form characteristics of these tracts and the contextual relationships between these tracts and the region as a whole.

The first project would compare of census tracts that fostered some desired form of travel behavior and would allow inferences to be made about their common urban form, non-urban form, and regional location characteristics. This could be achieved through the use of thematic urban form maps (see Appendix E). Analysis at a more microscopic level would allow the identification of urban form characteristics such as traffic network patterns. Traditional neighborhood development versus conventional suburban development, the presence of continuous non-motorized systems, or other common attributes of these tracts could be identified.

The second project would select a subset of tracts on the basis of urban form characteristics. Analysis of census tracts within this subset could follow the same type of procedure as the analysis of desired travel behavior. A comparison could be made between the characteristics found to be common within each set to determine the factors outside of density, mix, and jobs-housing balance that were associated with reduced travel demand.

The third project would be useful to document existing urban form and travel behavior relationships within census tracts that formed targeted centers in Vision 2020. In addition to providing a baseline for trends to be monitored over time, this subset could be used as a partial basis for performance monitoring efforts to measure the achievement of targeted levels of density and land-use mix in Vision 2020.

The fourth project would involve the selection of a subset of census tracts that corresponded to jurisdictional boundaries to test requirements mandated by the Growth Management Act (GMA) within local comprehensive plans. This would require the calculation of population density, employment density, land-use mix, and jobs-housing balance ratios within each census tract in the study area. These values could then be put into models developed for work and shopping trips in this study from a "region wide" focus. As a result, inferences could be made about the travel behavior patterns that would result from the land-use elements within the comprehensive plans. The consistency of these travel behavior patterns with the objectives of the GMA could then be determined on the basis of empirical evidence.

Non-Linearity and Density Thresholds

The identification of more specific non-linear relationships between mode choice and both population and employment density would be extremely helpful for the establishment of guidelines. The ability to more precisely isolate the density thresholds at which modal shifts begin to occur is limited by the number of trip ends in higher density census tracts. This limitation could be overcome through the use of non-linear logistic regression analysis techniques not explored in this project.

Trip Chaining

The trips in the Puget Sound Transportation Panel (PSTP) used in this research were coded independently and did not account for the location of an individual trip within a chain of trips. This inability to account for "trip chaining" can distort findings. Trip chaining happens for all the modes of travel studied in this study and, therefore, may have had little net effect on mode choice. However, it would be helpful to triangulate the findings from this study with a smaller subset of data in which all trips within trip chains were coded as one trip.

Analysis of the Cost Effectiveness of Implementing Urban Forms That Reduce Travel Demand

With the establishment of several relationships between aspects of urban form and travel behavior, the question then cries, "What levels of employment density, population density, land-use mix, and jobs-housing balance are cost effective to pursue." This subject was not addressed in this research project but would be a logical follow-up study to determine the ability to implement the findings from this research. External economic forces, institutional and individual inertia to change, and cultural factors all need to be addressed to determine how many of the findings from this project actually could be implemented.

Analysis of Different Measures of Density

This project used only gross measures of employment and population density, while other measures of density are required for policy implementation. Analysis of relationships between the same travel data used in this study and other vectors of density would allow comparisons between these measures and would ultimately provide the capability to create a conversion factor between different density measures. More specifically, *the density of developed land* and *net density* could be analyzed with the 1989 wave of the Puget Sound Transportation Panel (PSTP), allowing the relationships between different density measures to be assessed. Using the same travel data and methodologies as those used in this research would provide a controlled research design for this comparison. The integration of parcel level data into the data set would provide a means to find the land area devoted to particular land uses within each tract.

Identifying Examples of Different Levels of Land-Use Mix

While this research was able to identify a relationship between land-use mix and mode choice, trip distance, and other factors, the ability to implement policies pertaining to land-use mix is limited. Land-use mix is measured for each tract on a normalized scale from 0-1. The fractions used for measuring land-use mix are difficult to understand. Where employment density is based on the number of jobs per acre, land-use mix is more abstract and difficult to comprehend. This obstacle could be overcome by identifying different examples of land-use mix associated with the low, medium, and high ranges found (per census tract) in this research. In addition, comparing the effects that different combinations of land uses have on travel behavior would help identify how various land-use mixes affect specific aspects of travel behavior.

Analysis at the Block or Block Group Level

While the census tract proved to be a valid unit of analysis in this research, studying urban form and travel behavior relationships at the block or block group level would provide important additional information. In particular, a smaller geographic unit might be more effective for analyzing land-use mix. This relationship could be characterized by the difference between having retail services six blocks from ones home or within two blocks. The presence of services within two blocks might provide a greater incentive to walk than that of services six blocks away.

Need for the Development of a Comprehensive Level of Service Measure

More refined research is necessary to isolate the relationship between urban form and travel behavior from costs associated with various levels of density. This could be achieved by developing better level of service (LOS) measures for various modal options. This would be an extremely complex task, but it would be necessary to accurately account for the costs and trade-offs associated with each mode of travel. It would also be important in relating the findings from this research to micro-economic theory premised on utility optimization. One method would be to create an inter-zonal (census tract) accessibility index based on travel time. The purpose of this index would be to account for the travel time from each tract (by mode) to other tracts in the region. This could be simplified to account for the travel time from each tract to selected centers within the region on a modal basis.

Analysis of Relationship Between Trip Generation, Travel Time and Urban Form

Analysis of trip generation by mode would help to determine whether the positive relationship between employment density and trip generation was a function of SOV, bus, and/or walking trips. This research would be essential for identifying the implications of densification on VMTs. Travel time was also found to be positively correlated with employment density for work trips. This relationship needs to be analyzed by mode to determine the relative effect of employment density on the choice to travel by SOV, carpool, bus, or foot. One possible implication of this research could be the ability to document the benefits of HOV improvements. This would require testing the hypothesis that HOV improvements reduce travel time for bus and carpooling relative to the SOV to locations of higher employment densities. Controlling for the amount of employment within each census tract would allow the effect of density to be isolated from the effects of economies of scale associated with larger employment centers.

CLOSING REMARKS

Institutional resistance to altering the status quo has resulted in the stagnation of policy development that could alleviate excessive waste and inefficient consumption of scarce resources. Research has already confirmed the steps that need to be taken to establish a society that lives within the bounds of the resources it has available. The term "sustainable development" emerged in the late 1980s in response to this idea. Several research efforts were undertaken during the late 1980s and early 1990s to support this concept (Newman, 1990; Newman, 1991, Rees, 1991; Lowe, 1989).

In a recent article Anthony Downs posited that the greatest challenge to meet the goals of a more livable less automobile-dominated environment rests on our ability to develop a working vision that incorporates the realities of the American consumer and the needs of increased efficiency. Flaws with the current vision of metropolitan development involve excessive travel (Downs, 1991). Down's criteria for the new ideal vision were that it

- must encourage individuals and households to take into account the collective costs of their behavioral choices
- must contain sizable areas of at least moderately high density development, especially of housing but also of workplace
- must provide incentives for people to live closer to where they work and
- must result in reduced travel and congestion.

In conclusion, Downs cited the need to replace the current vision with a persuasive vision that offers real gains not just sacrifices. Findings from this research suggested that policies directed at marginal increases in employment density, population density, land-use mix, and jobs-housing balance can offer these real gains. Furthermore, this research indicated that a comprehensive approach to policy development would be most successful at reducing SOV dependence.

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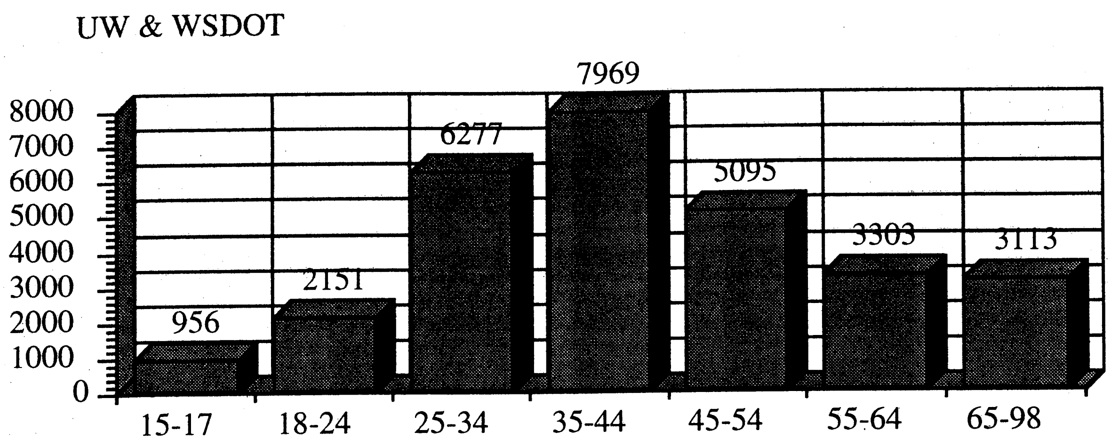
APPENDIX A

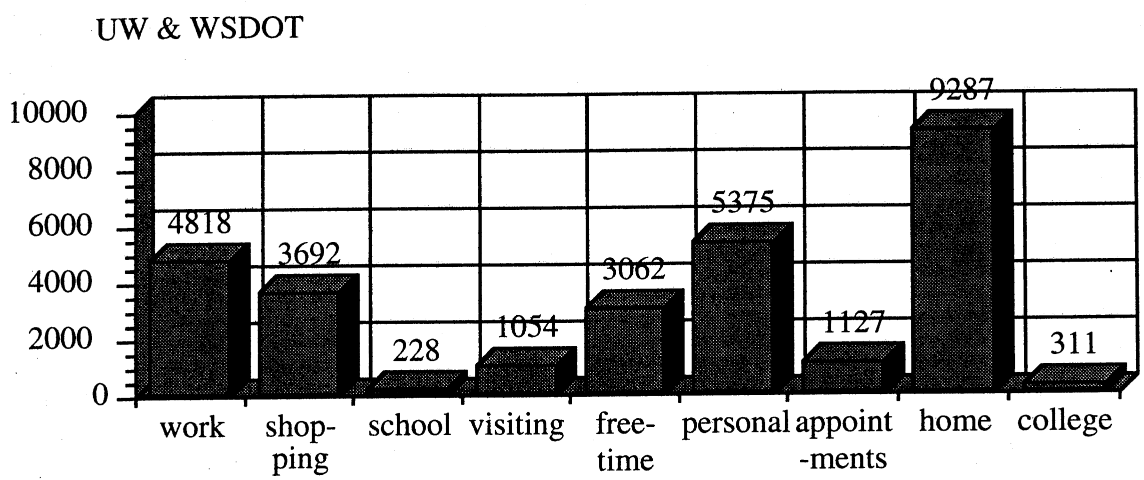
GRAPHICALLY PRESENTED DESCRIPTIVE STATISTICS FOR CATEGORICAL VARIABLES

Number of Trips by Age Group



Urban Form: Travel Behavior
(Puget Sound Transportation Panel - PSCOG; 1989)
Total Valid/Weighted Trips = 28955

Trip Purpose



Urban Form: Travel Behavior
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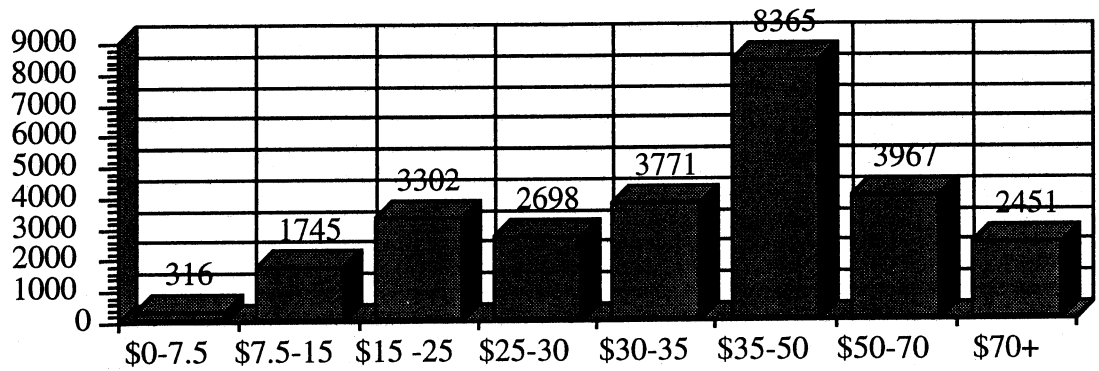
Total Valid/Weighted Trips = 28955

of Trips per Household Income (in thousands)

UW & WSDOT



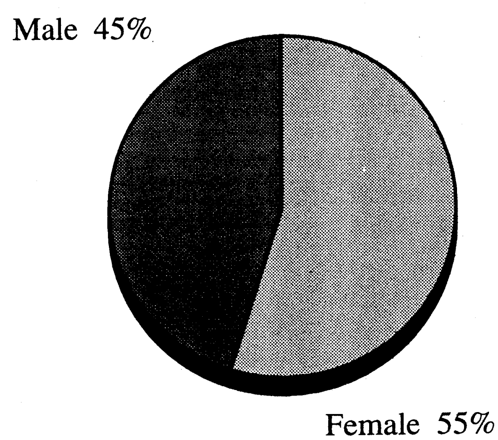
Urban Form: Travel Behavior
(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 28955

of Trips per Gender

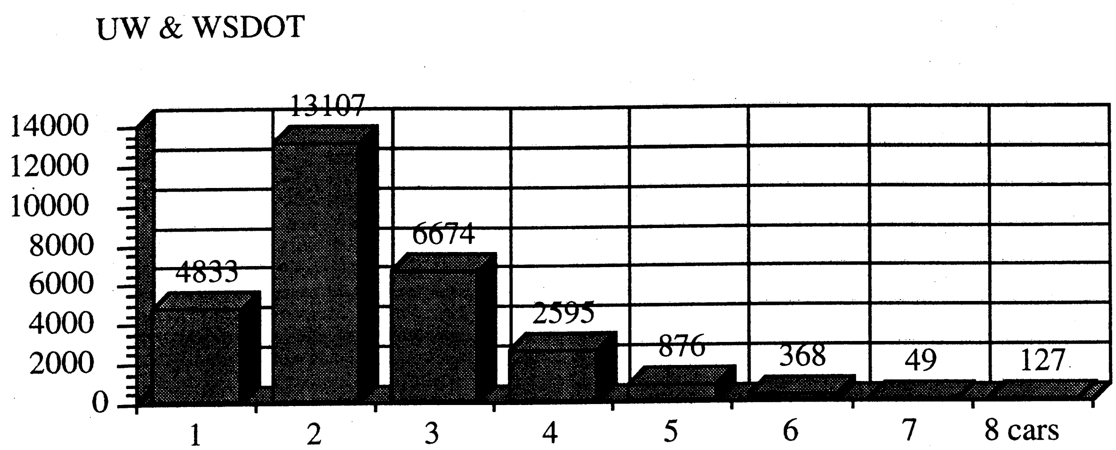
UW & WSDOT

Urban Form: Travel Behavior

(Puget Sound
Transportation Panel
PSCOG; 1989)
Total Valid/Weighted Trips
= 28955

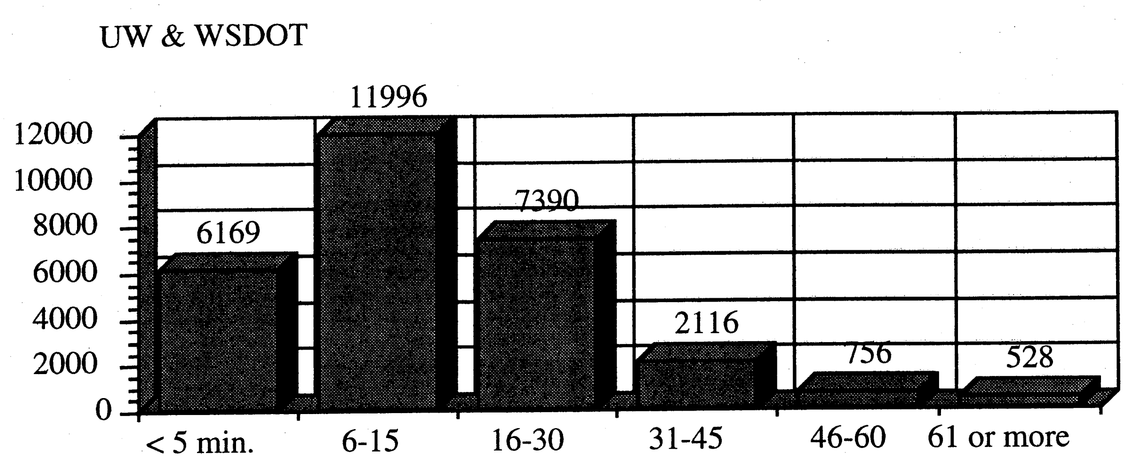


Number of Trips per Household
Vehicle Availability



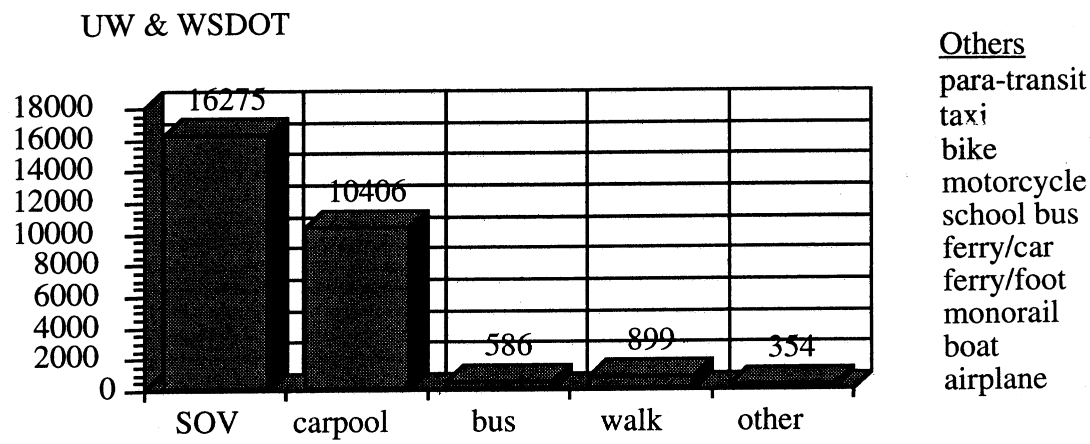
Urban Form: Travel Behavior
(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 28629

Number of Trips by Travel Time



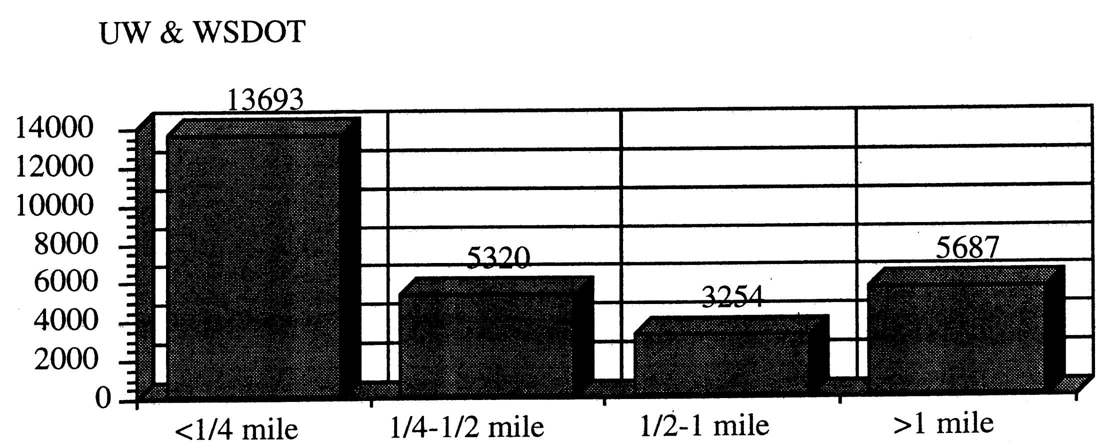
Urban Form: Travel Behavior
(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 28955

Trips per Mode



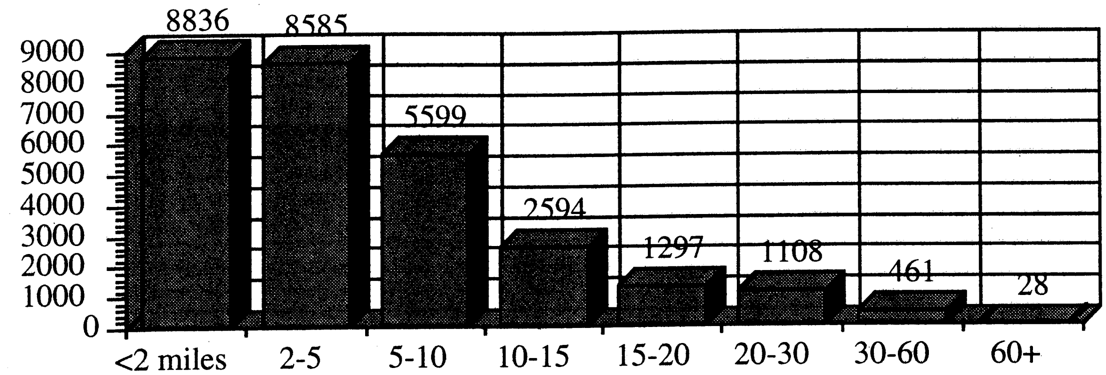
Urban Form: Travel Behavior
(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 28955

\# of Trip Origins at Varying Distances to Bus Service



Urban Form: Travel Behavior
(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 27954

Number of Trips by Trip Distance



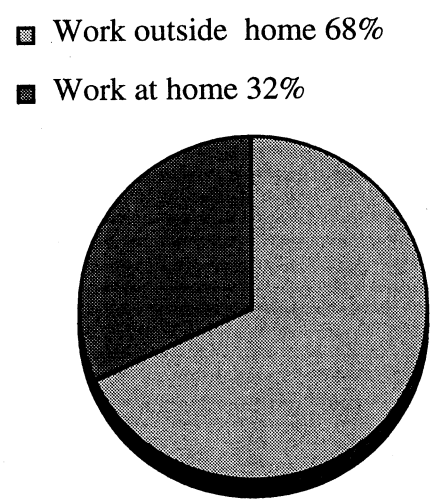
Urban Form: Travel Behavior
(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 28504

Proportion of Trips and Home Employment

UW & WSDOT

Urban Form: Travel Behavior

(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 28934



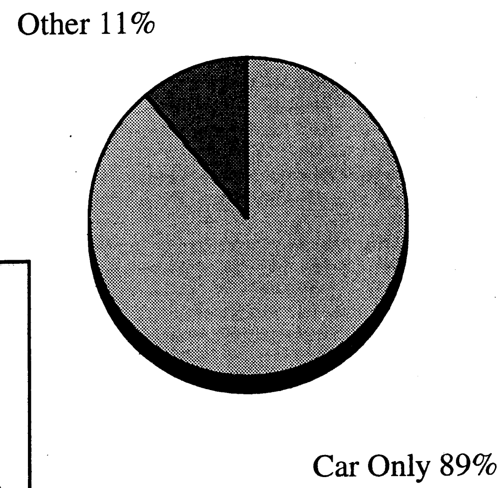
Primary Mode to Work

UW & WSDOT

Urban Form: Travel Behavior

(Puget Sound Transportation Panel
PSCOG; 1989)
Total Valid/Weighted Trips = 18854

Other	
Bus	2.5%
Car & Bus	2.5%
Motorcycle	.2%
Bicycle	.5%
Walk	1.0%
Other	.1%

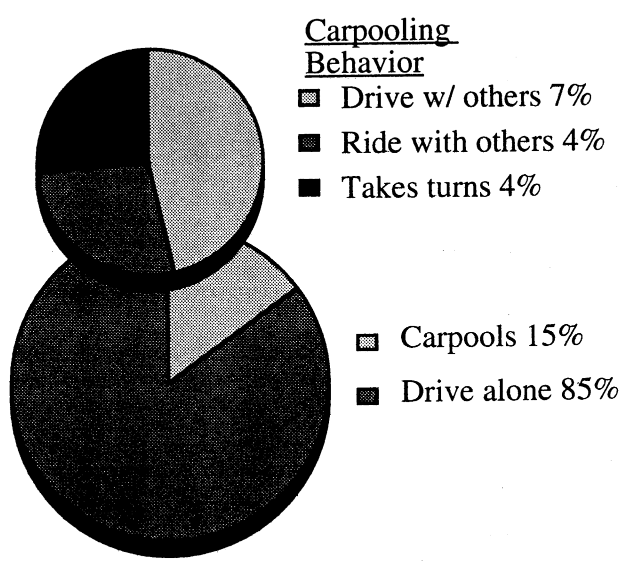


Vehicle Occupancy for the Journey to Work

UW & WSDOT

Urban Form: Travel Behavior

(Puget Sound
Transportation Panel
PSCOG; 1989)
Total Valid/Weighted Trips
= 17250



Car Requirement for the Journey to Work

UW & WSDOT

Urban Form: Travel Behavior

(Puget Sound
Transportation Panel
PSCOG; 1989)
Total Valid/Weighted Trips
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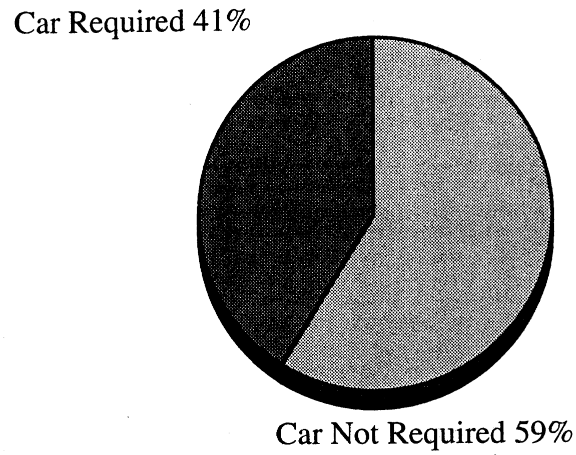
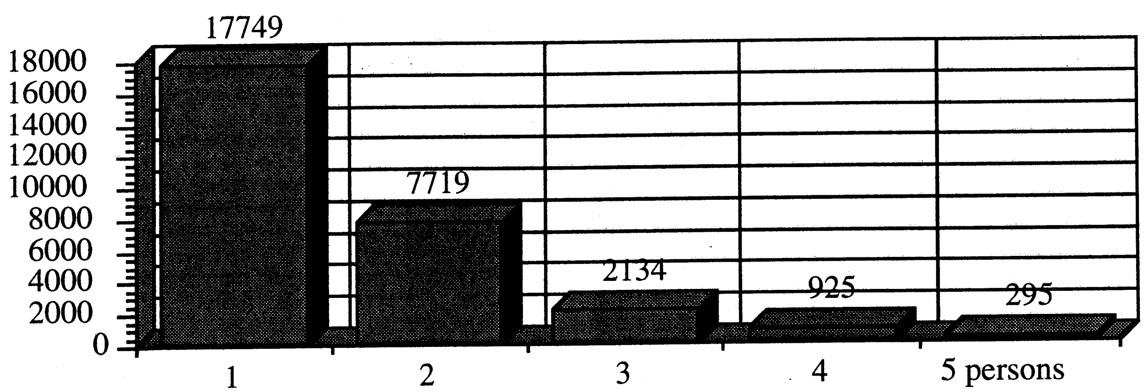


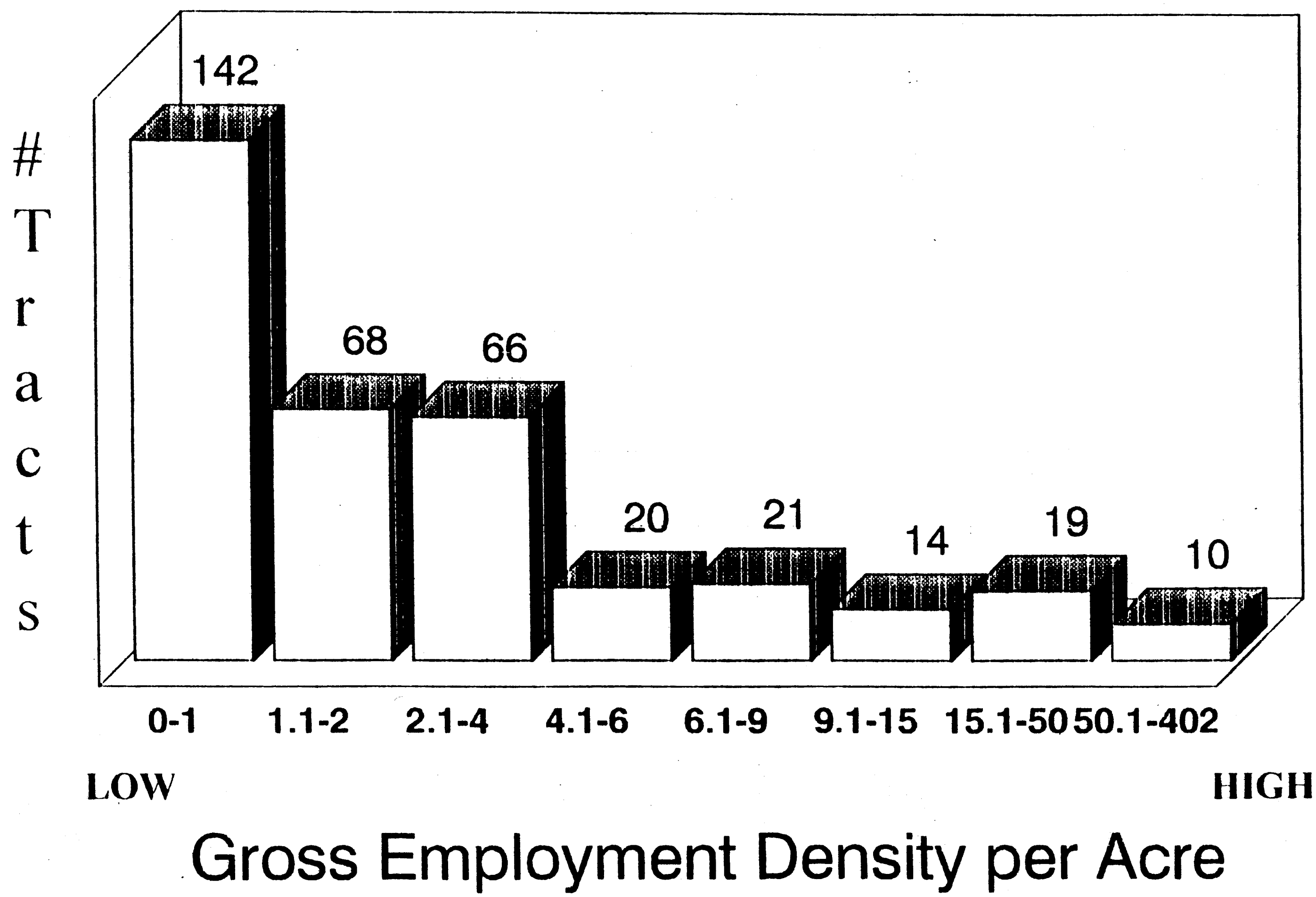
Trips per Vehicle Occupancy Rate

UW & WSDOT

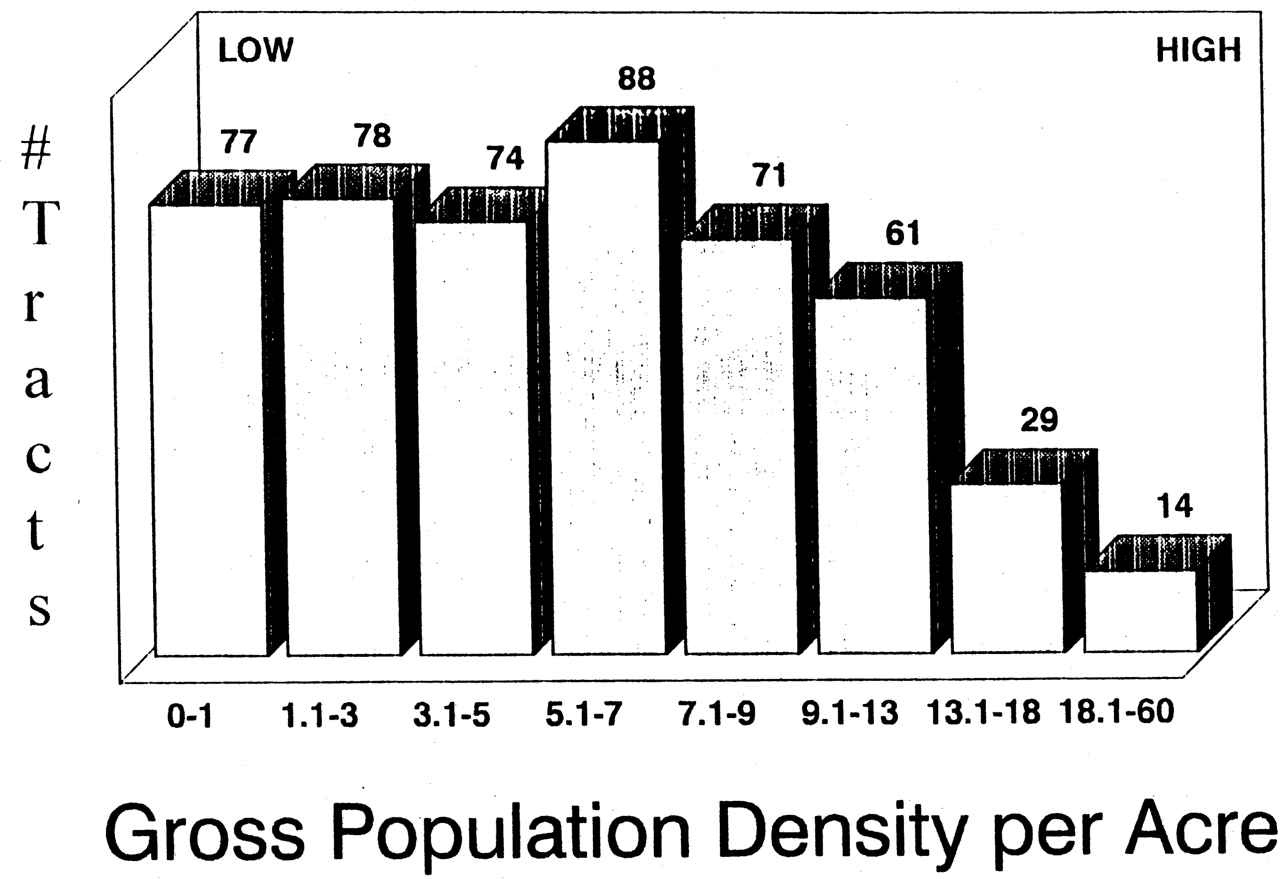


Urban Form: Travel Behavior
(Puget Sound Transportation Panel PSCOG; 1989)
Total Valid/Weighted Trips = 28823

NUMBER OF TRACTS PER EMPLOYMENT DENSITY GROUP



NUMBER OF TRACTS PER POPULATION DENSITY GROUP



APPENDIX B

WORK TRIP CORRELATIONS, MULTIVARIATE REGRESSION MODELS, AND DENSITY THRESHOLDS

VARIABLES CORRELATED WITH % SOV

WORK TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average population density at trip origins and destinations	-0.24	443	0
average employment density at trip origins and destinations	-0.35	317	0
mixing of uses at trip origins	-0.2	267	0
employer density at trip destinations	-0.32	448	0
has a drivers license	0.22	509	0
less than one vehicle available per driver	-0.25	509	0
average travel time for transit	0.24	150	0
average travel distance for transit	0.21	149	0.01

%SOVWKO.XLS

Multi-Variate Regression Model

% SOV Trips at Origins

JOURNEY TO WORK

variables in model

Variable Name	Sig. T	Beta	B
mixing of uses at trip origins	0	-0.17	-28.67
average population density at origins and destinations	-0.03	-0.14	-0.67
average employment density at trip origins and destinations	0	-0.31	-0.21
less than one vehicle available per driver	0.01	-0.17	-0.23
CONSTANT	0	n/a	100.42

summary statistics

Adj. R-Sq.	0.22
Sig. F	0
F-Value	15.96
Degrs. Frdm.	218

VARIABLES CORRELATED WITH % CARPOOL

WORK TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
less than one vehicle available per driver	0.1	509	0.02
age	-0.12	509	0
level of service for transit	0.11	506	0.02
travel time for carpooling	0.13	272	0.03

VARIABLES CORRELATED WITH % CARPOOL

WORK TRIPS -DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
mixing of uses at trip origins	0.18	273	0
ratio of jobs to households	0.15	257	0.02
household with one adult over 65	0.18	446	0
employed outside the home	-0.26	446	0
hs a drivers license	-0.15	446	0

%CPLWKD.XLS

VARIABLES CORRELATED WITH % TRANSIT

WORK TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average population density at trip origins and destinations	0.2	443	0
employment density at trip destinations	0.46	448	0
less than one vehicle available per driver	0.24	509	0
has a drivers license	-0.36	509	0

%BUSWKO.XLS

Multi-Variate Regression Model

% Transit Trips at Origins

JOURNEY TO WORK

variables in model

Variable Name	Sig. T	Beta	B
average employment density at trip origins amddestinations	0	0.45	0.17
less than one vehicle available	0.02	-0.11	0.08
households with one adult over 65	0.01	0.11	0.52
hs a drivers license	0	-0.41	-0.52
CONSTANT	0	n/a	50.51

summary statistics

Adj. R-Sq.	0.41
Sig. F	0
F-Value	56.14
Degrs. Frdm.	316

VARIABLES CORRELATED WITH % WALK TRIPS

WORK TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
employment density at trip origins	0.43	324	0
average population density at trip origins and destinations	0.34	443	0
mixing of uses at trip origins	0.21	267	0
employer density at trip origins	0.45	324	0
travel time for transit trips	-0.21	150	0.01
travel distance for transit trips	-0.24	149	0

Multi-Variate Regression Model
Walking

JOURNEY TO WORK

variables in model

Variable Name	Sig. T	Beta	B
average population density at origins and destinations	0	0.29	0.7
employment density at origins	0	0.38	0.17
mixing of uses at trip origins	0.01	0.15	20.41
CONSTANT	0	N/A	-12.9

summary statistics

Adj. R-Sq.	0.31
Sig. F	0
F-Value	33.14
Dgrs. of Frdm.	217

VARIABLES CORRELATED WITH % WALK TRIPS

WORK TRIPS - DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average employment density at trip origins and destinations	0.2	274	0
average population density at trip origins and destinations	0.18	382	0
employer density at trip destinations	0.19	285	0
households with one adult between 35-64	0.15	446	0
has a drivers license	-0.22	446	0

%WLKWKD.XLS

Multi-Variate Regression Model

% Walking Trips at Destinations

JOURNEY TO WORK

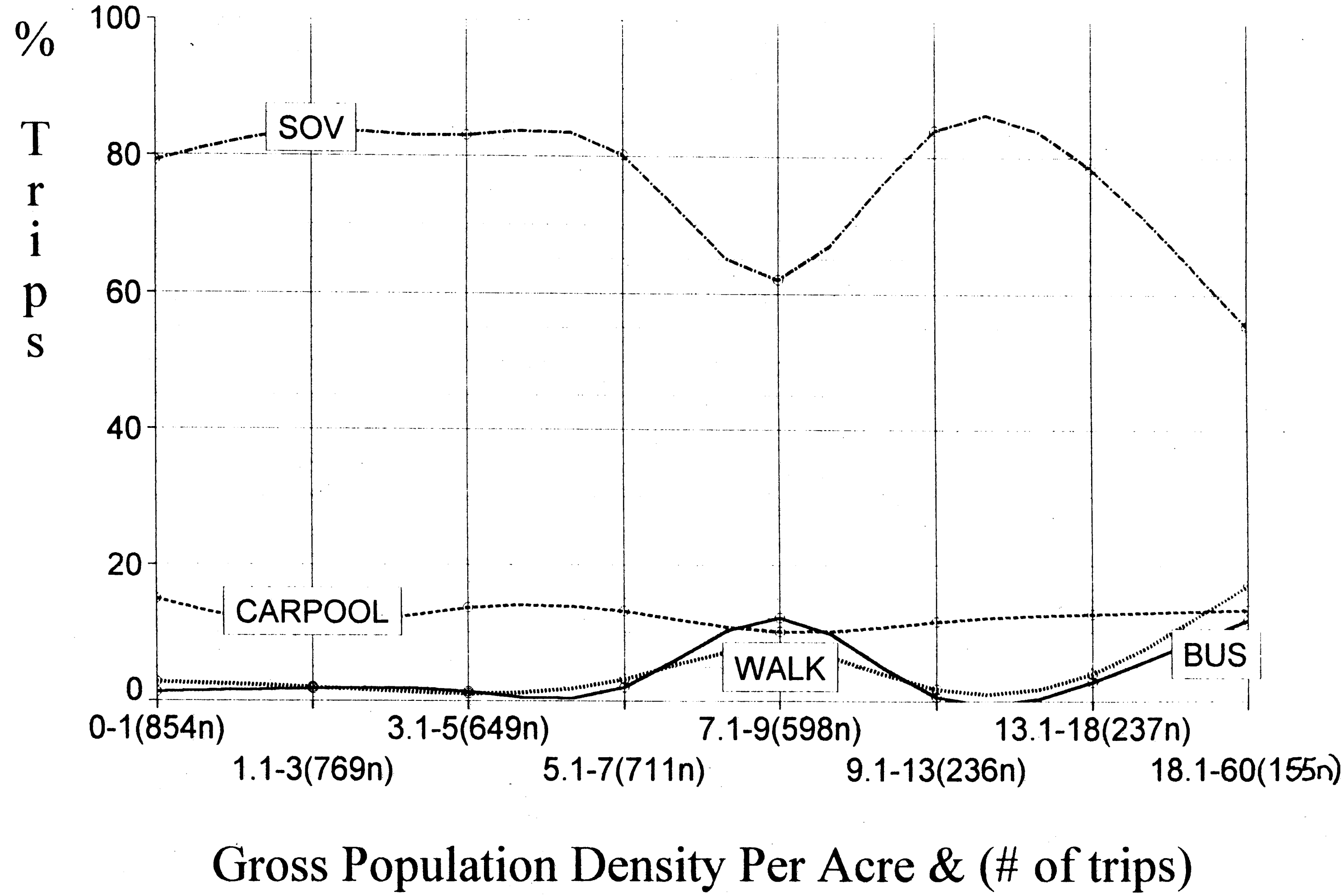
variables in model

Variable Name	Sig. T	Beta	B
has a drivers license	0	-0.32	-0.39
average employmenr density at origins and destinations	0.01	0.16	0.09
population density at destinations	0.02	0.14	0.25
CONSTANT	0	n/a	38.92

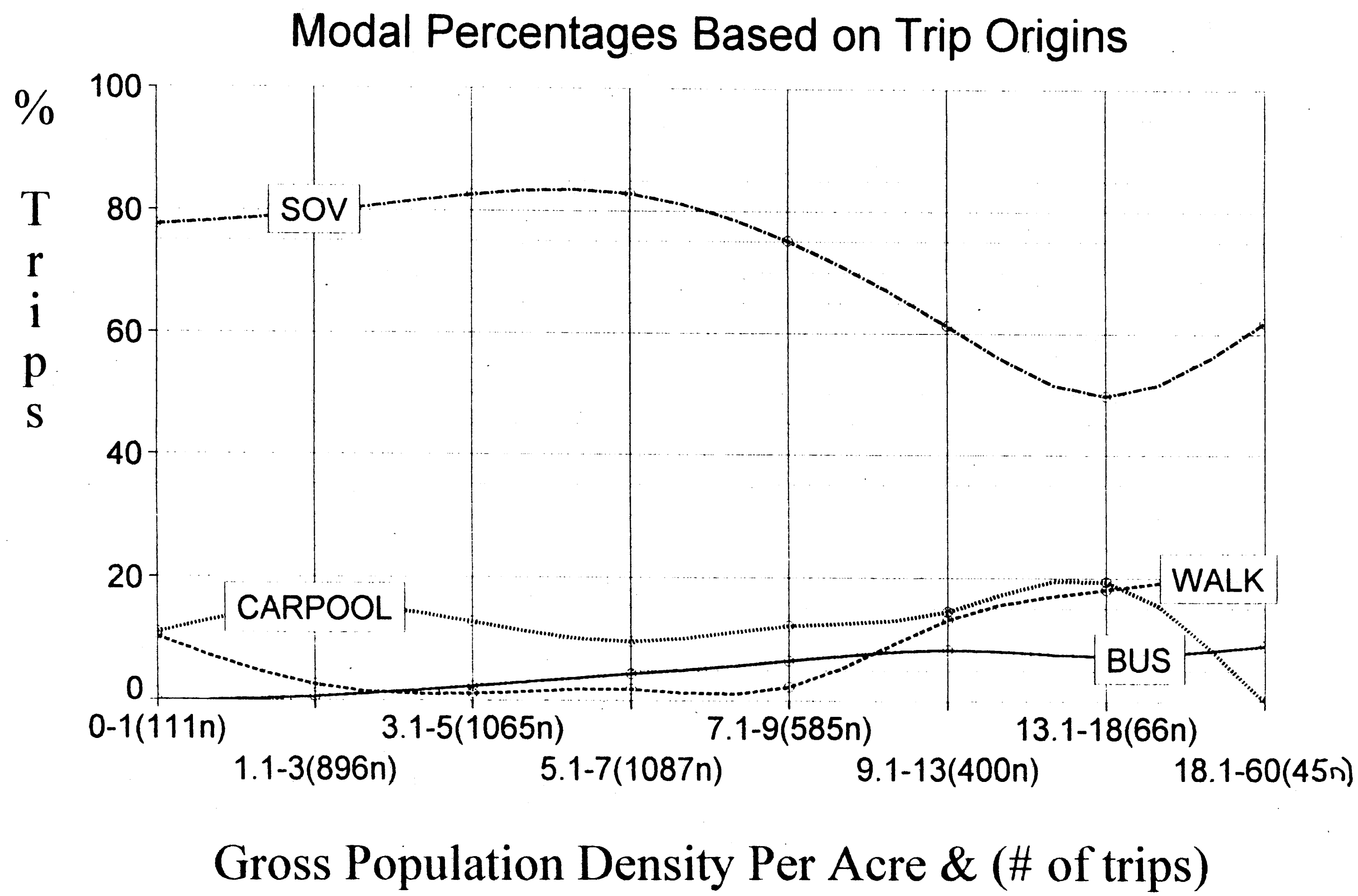
summary statistics

Adj. R-Sq.	0.14
Sig. F	0
F-Value	16.32
Dgrs. of Frdm.	273

POPULATION DENSITY AT TRIP DESTINATIONS AND MODE CHOICE FOR WORK TRIPS

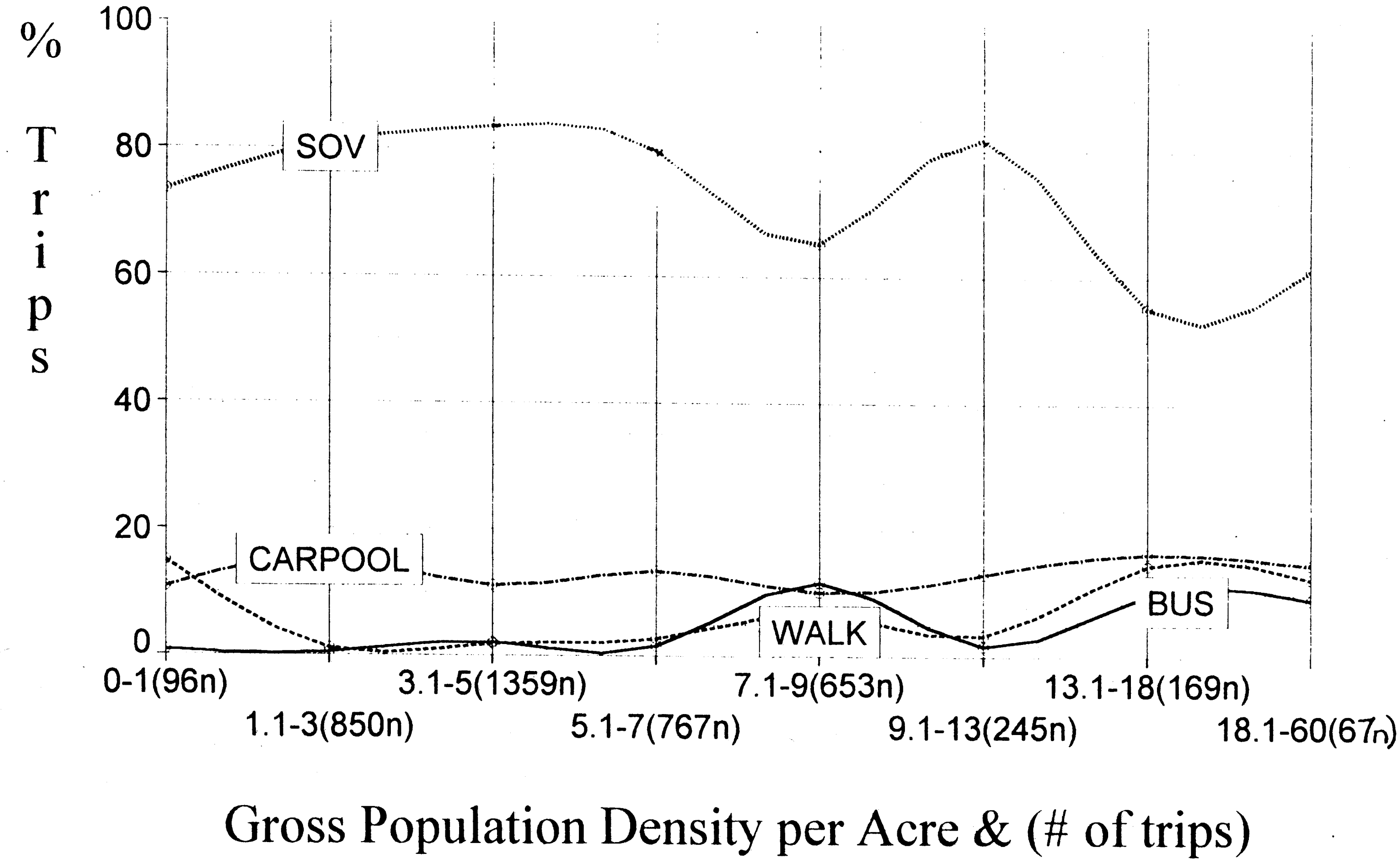


AVERAGE POPULATION DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR WORK TRIPS

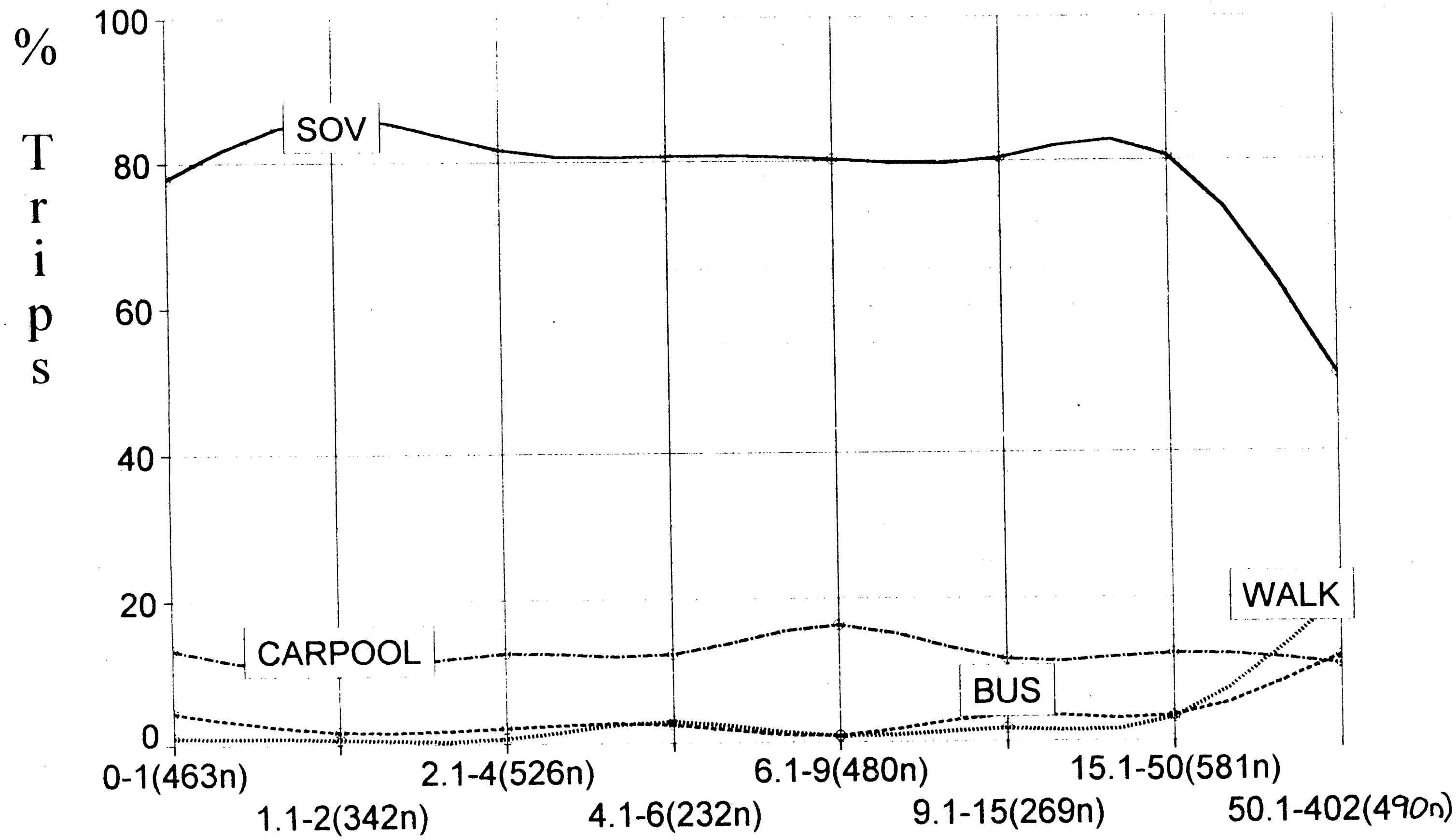


AVERAGE POPULATION DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR WORK TRIPS

Modal Percentages Based on Trip Destination Tracts

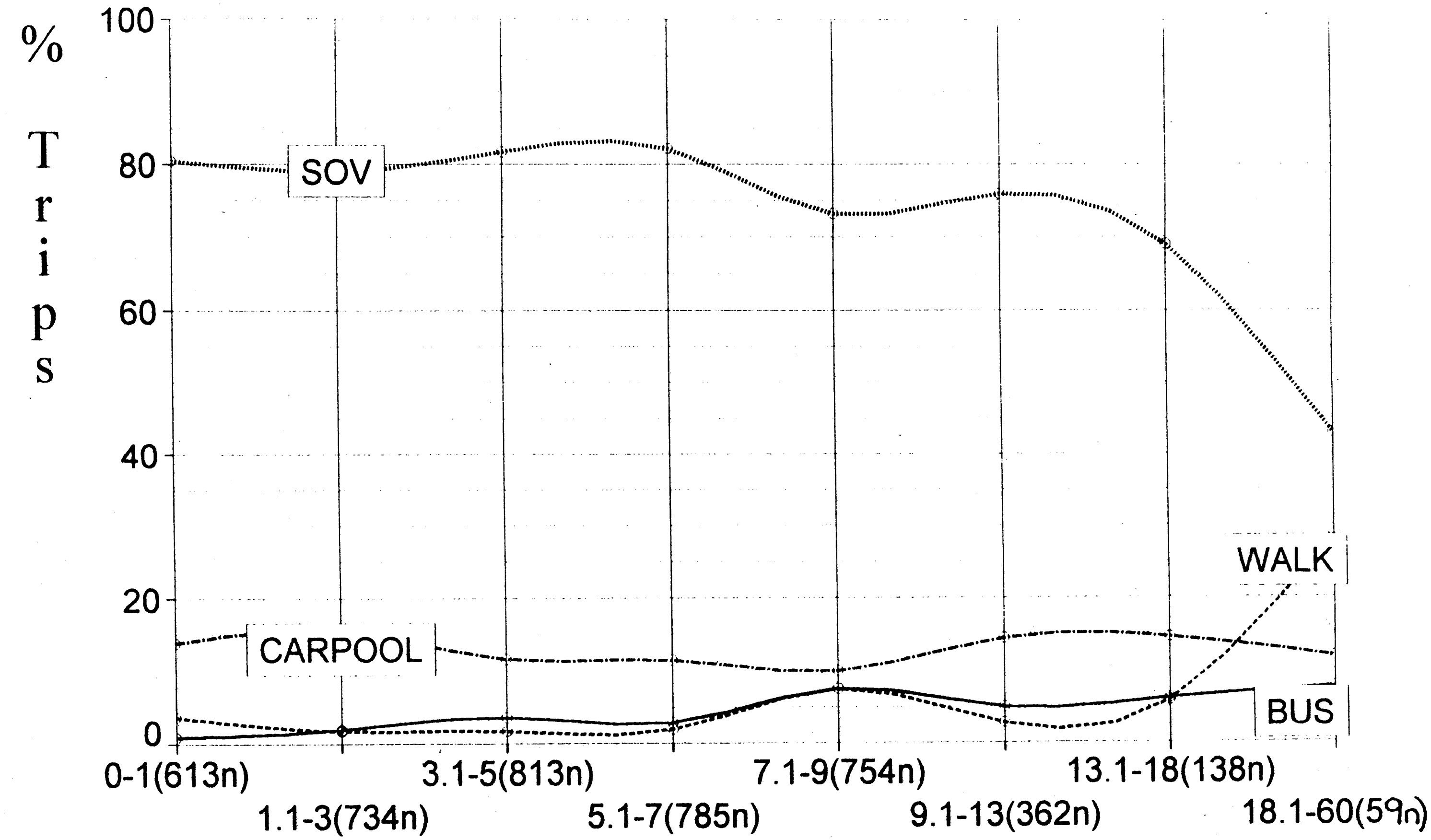


EMPLOYMENT DENSITY AT TRIP DESTINATIONS AND MODE CHOICE FOR WORK TRIPS



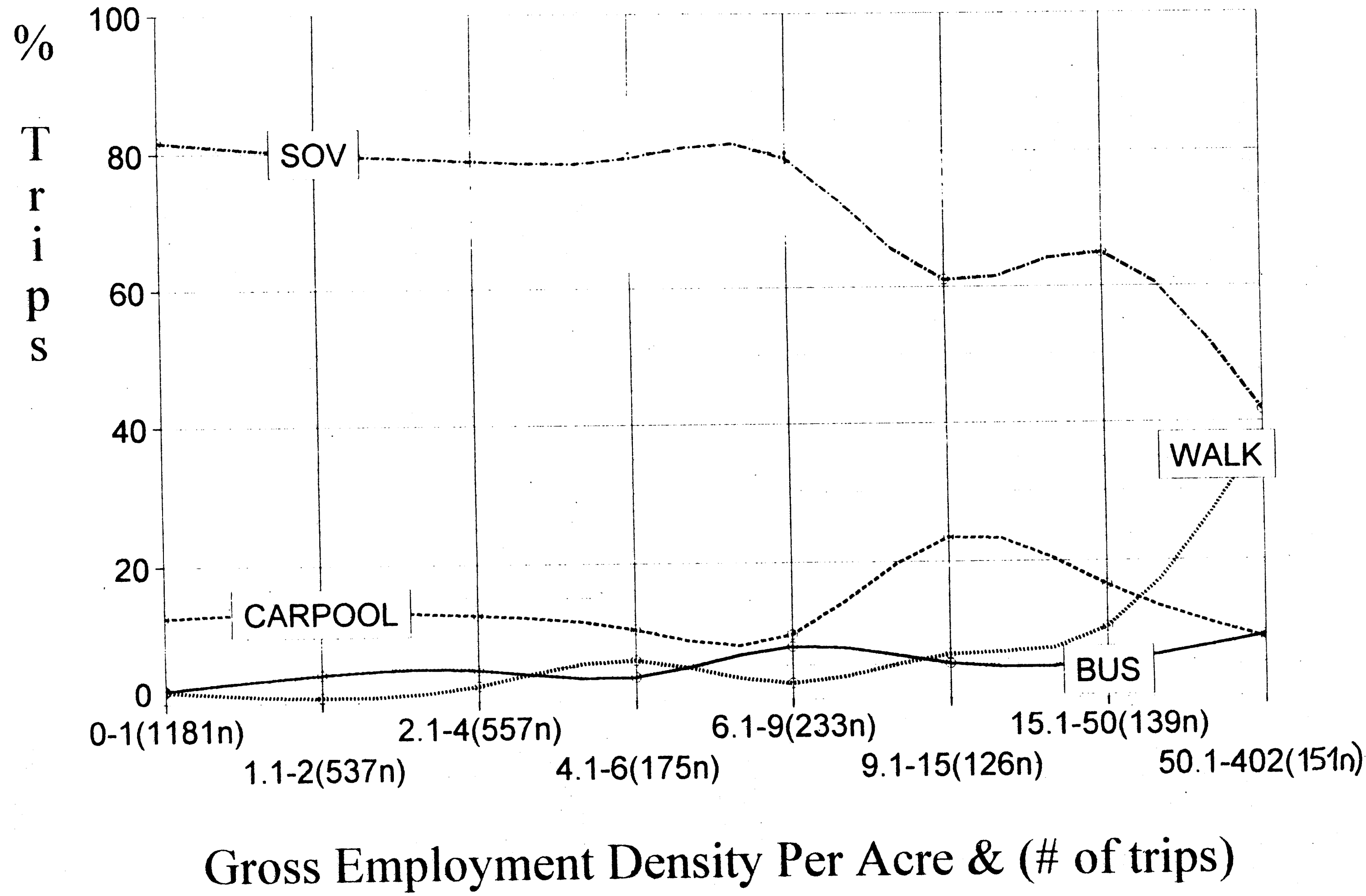
Gross Employment Density per Acre & (# of trips)

POPULATION DENSITY AT TRIP ORIGINS AND MODE CHOICE FOR WORK TRIPS



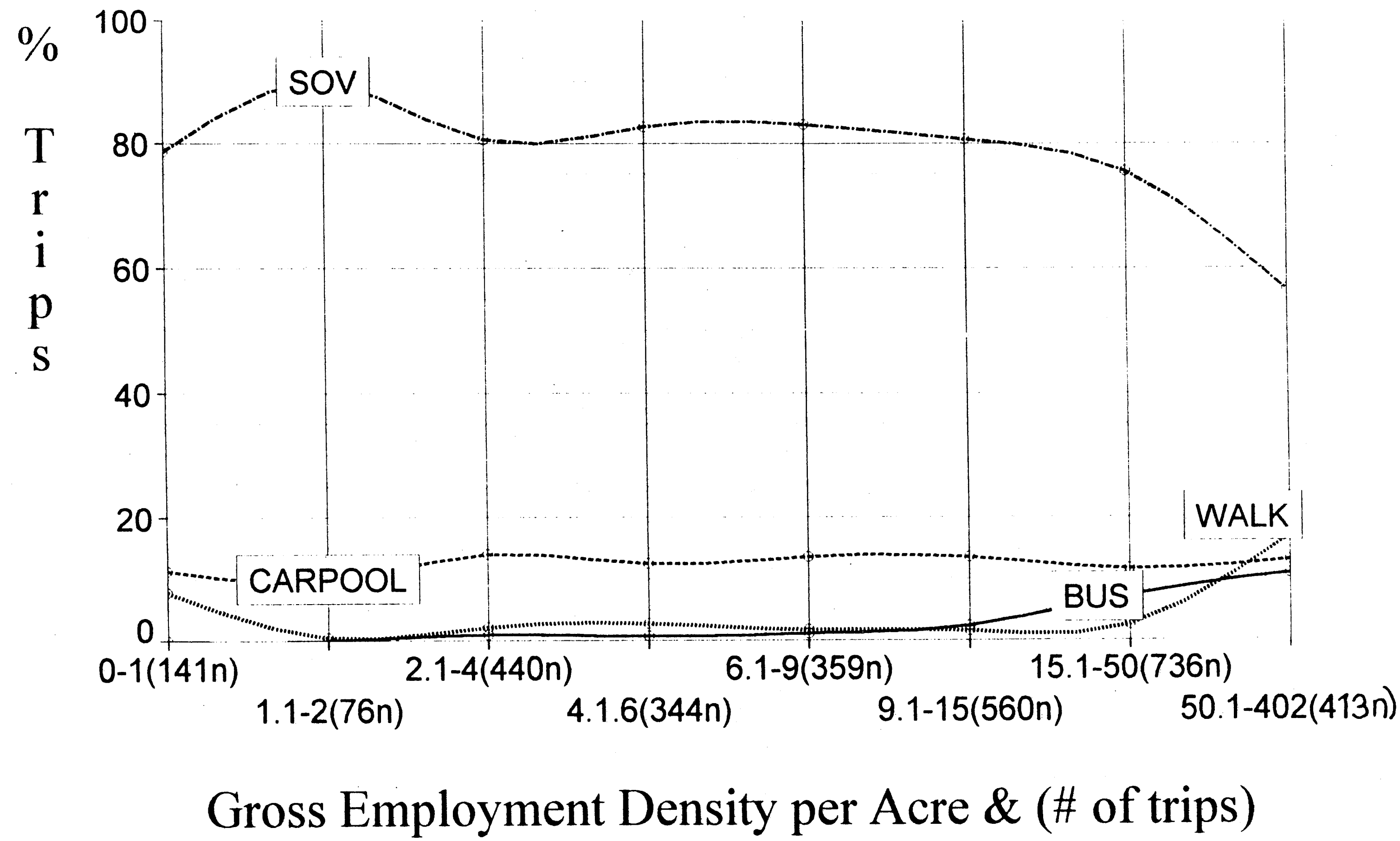
Gross Population Density Per Acre & (# of trips)

EMPLOYMENT DENSITY AT TRIP ORIGINS AND MODE CHOICE FOR WORK TRIPS



AVERAGE EMPLOYMENT DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR WORK TRIPS

Modal Percentages Based on Trip Origin Tracts



APPENDIX C

SHOPPING TRIPS CORRELATIONS, MULTIVARIATE REGRESSION MODELS, AND DENSITY THRESHOLDS

VARIABLES CORRELATED WITH % SOV

SHOPPING TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
population density at trip origins	-0.15	434	0
average employment density at trip origins and destinations	-0.14	313	0.02
travel distance for SOV trips	0.13	456	0
household size	-0.14	497	0
household income	0.15	490	0
employed outside the home	0.16	497	0
has a drivers license	0.26	497	0
less than one vehicle available per driver	-0.2	496	0.01

%SOVSHO.XLS

Multi-Variate Regression Model
% SOV Trips at Origins
SHOPPING TRIPS

variables in model

Variable Name	Sig. T	Beta	B
population denity at trip origins	0.01	-0.12	-0.56
average household income	0.02	0.11	0
has a drivers license	0	0.22	0.69
less than one vehicle available per driver	0.01	-0.13	-0.19
one adult between 35 and 64	0	0.22	0.43
CONSTANT	0.38	n/a	-12.18

summary statistics

Adj. R-Sq.	0.14
Sig. F	0
F-Value	14.6
Degrs. Frdm.	425

VARIABLES CORRELATED WITH % SOV

SHOPPING TRIPS - DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
employment density at destinations	-0.15	256	0.02
has a drivers license	0.22	393	0
employed outside the home	0.23	393	0

Multi-Variate Regression Model
% SOV Trips at Destinations
SHOPPING TRIPS

variables in model

Variable Name	Sig. T	Beta	B
has a drivers licence	0	0.23	0.45
employment density at trip destinations	0	-0.18	-0.19
households with one adult between 35 and 64	0	0.21	0.4
average household income	0.01	0.16	0
CONSTANT	0.75	n/a	3.63

summary statistics

Adj. R-Sq.	0.14
Sig. F	0
F-Value	11.33
Degrs. Frdm.	249

VARIABLES CORRELATED WITH % CARPOOL

SHOPPING TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
less than one vehicle available per driver	0.17	496	0
households with one adult between 35-64	-0.18	497	0
households with two adults over 65	0.18	467	0
employed outside the home	-0.17	497	0
has a buspass	0.16	124	0.09

%CPLSHO.XLS

Multi-Variate Regression Model
% Carpool Trips at Origins

SHOPPING TRIPS

variables in model

Variable Name	Sig. T	Beta	B
has a buspass	0.07	0.15	0.19
household size	0	0.26	9.97
less than one vehicle available per driver	0.06	0.16	0.19
employed outside the home	0	-0.27	-0.32
CONSTANT	0.59	n/a	7.71

summary statistics

Adj. R-Sq.	0.17
Sig. F	0
F-Value	7.2
Degrs. Frdm.	123

VARIABLES CORRELATED WITH % TRANSIT

SHOPPING TRIPS - ORIGINS

VARIABLE	**corr. coeff. (r)**	**tracts (n)**	**sig. (p)**
average employment density at trip origins and destinations	0.43	313	0
population density at trip origins	0.27	434	0
households with one adult over 65	0.2	497	0
number of vehicles available	-0.13	497	0.01
has a buspass	-0.55	124	0
has a drivers license	-0.17	497	0

%BUSSHO.XLS

Multi-Variate Regression Model

% Transit Trips at Origins

SHOPPING TRIPS

variables in model

Variable Name	Sig. T	Beta	B
average employment density at trip origins and destinations	0	0.31	0.05
has a drivers license	0	-0.26	-0.14
has a buspass	0	0.58	.-0.12
CONSTANT	0	n/a	25.85

summary statistics

Adj. R-Sq.	0.59
Sig. F	0
F-Value	37.85
Degrs. Frdm.	78

VARIABLES CORRELATED WITH % TRANSIT

SHOPPING TRIPS - DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average employment density at trip origins and destinations	0.44	252	0
average population density at trip origins and destinations	0.16	345	0
travel distance for carpooling	0.39	259	0
households with one adult under 35	0.22	393	0
number of vehicles available	-0.21	393	0
travel time for carpooling	0.2	262	0
has a drivers license	-0.27	393	0

Multi-Variate Regression Model

% TRANSIT AT TRIP DESTINATIONS - SHOPPING TRIPS

variables in model

Variable Name	Sig. T	Beta	B
average employment density at trip origins and destinations	0	0.32	0.05
average population density at trip origins and destinations	0	0.19	0.16
average distance for carpool trips	0	0.51	0.61
CONSTANT	0	n/a	-2.62

summary statistics

Adj. R-Sq.	0.43
Sig. F	0
F-Value	41.92
Degrs. Frdm.	162

VARIABLES CORRELATED WITH % WALK TRIPS

SHOPPING TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
population density at trip destinations	0.4	452	0
average employment density at trip origins and destinations	0.26	313	0
level of service for transit: distance to nearest bus stop	-0.16	497	0
household size	-0.13	497	0
number of vehicles available	-0.18	497	0
has a drivers license	-0.29	497	0
travel distance for carpool trips	-0.14	355	0.01
travel distance for transit trips	0.27	52	0.05

%WLKSHO.XLS

Multi-Variate Regression Model

% Walking Trips at Origins

SHOPPING TRIPS

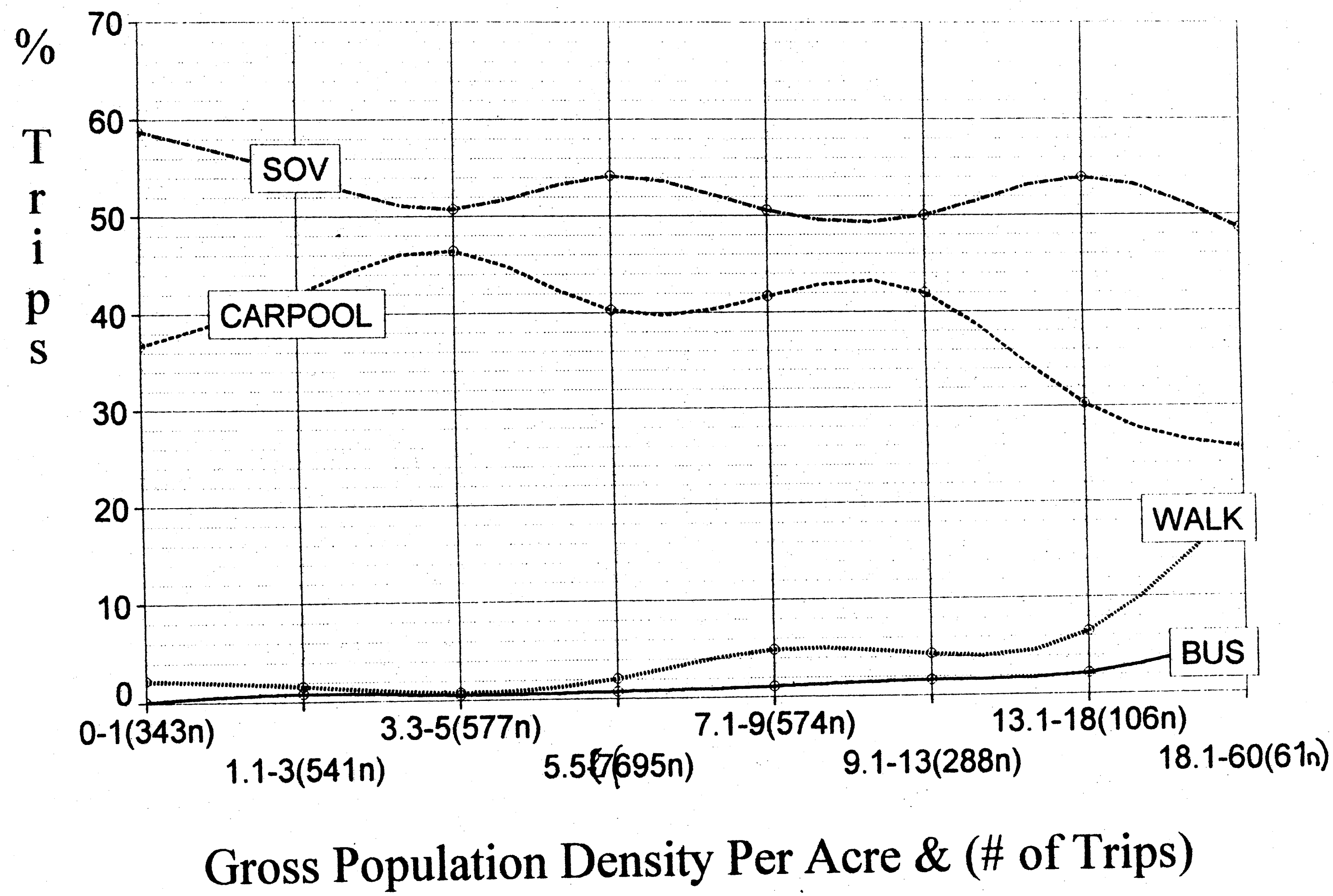
variables in model

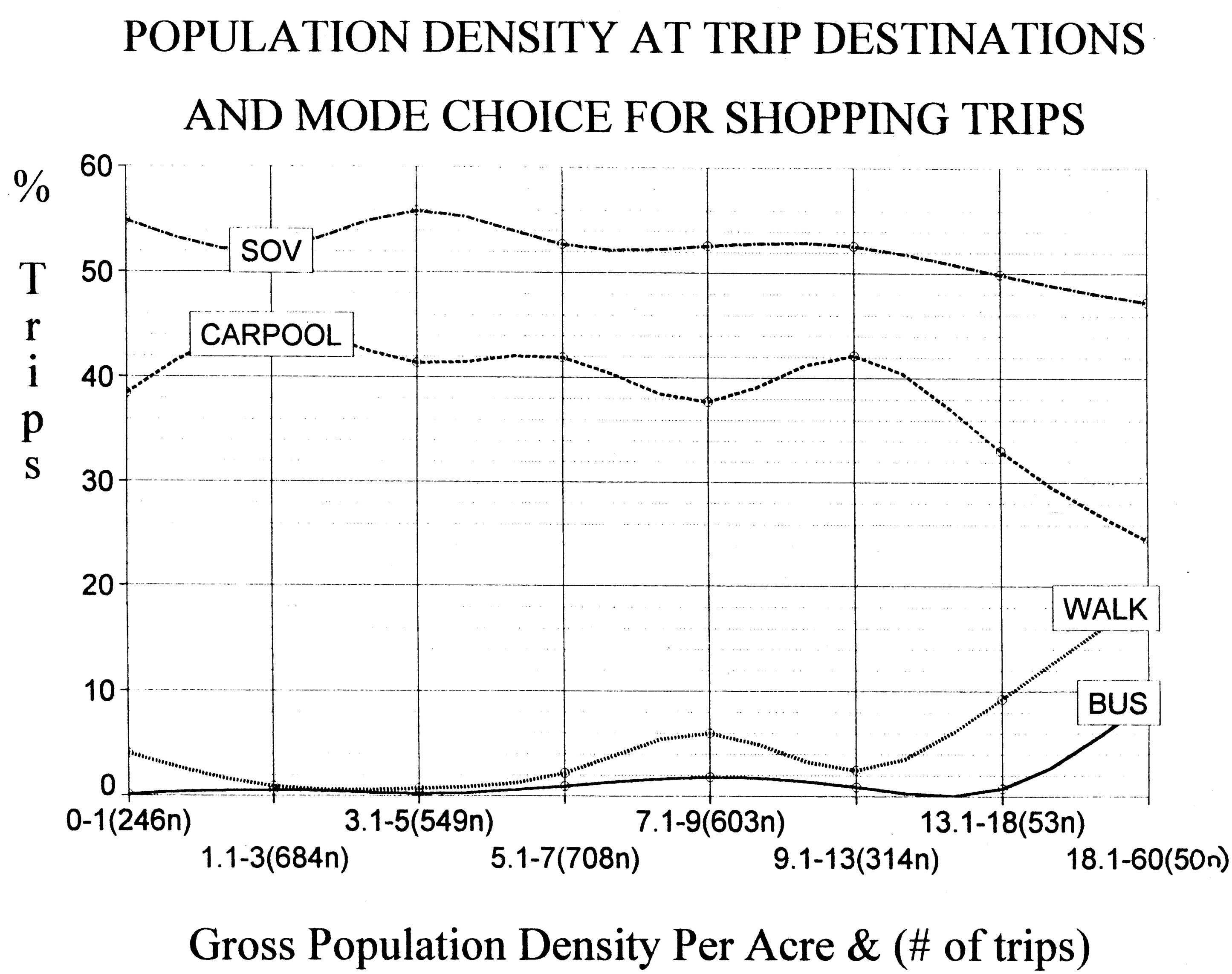
Variable Name	Sig. T	Beta	B
average employment density at origins and destinations	0	0.22	0.07
population density at trip destinations	0	0.39	0.82
CONSTANT	0	n/a	-2.8

summary statistics

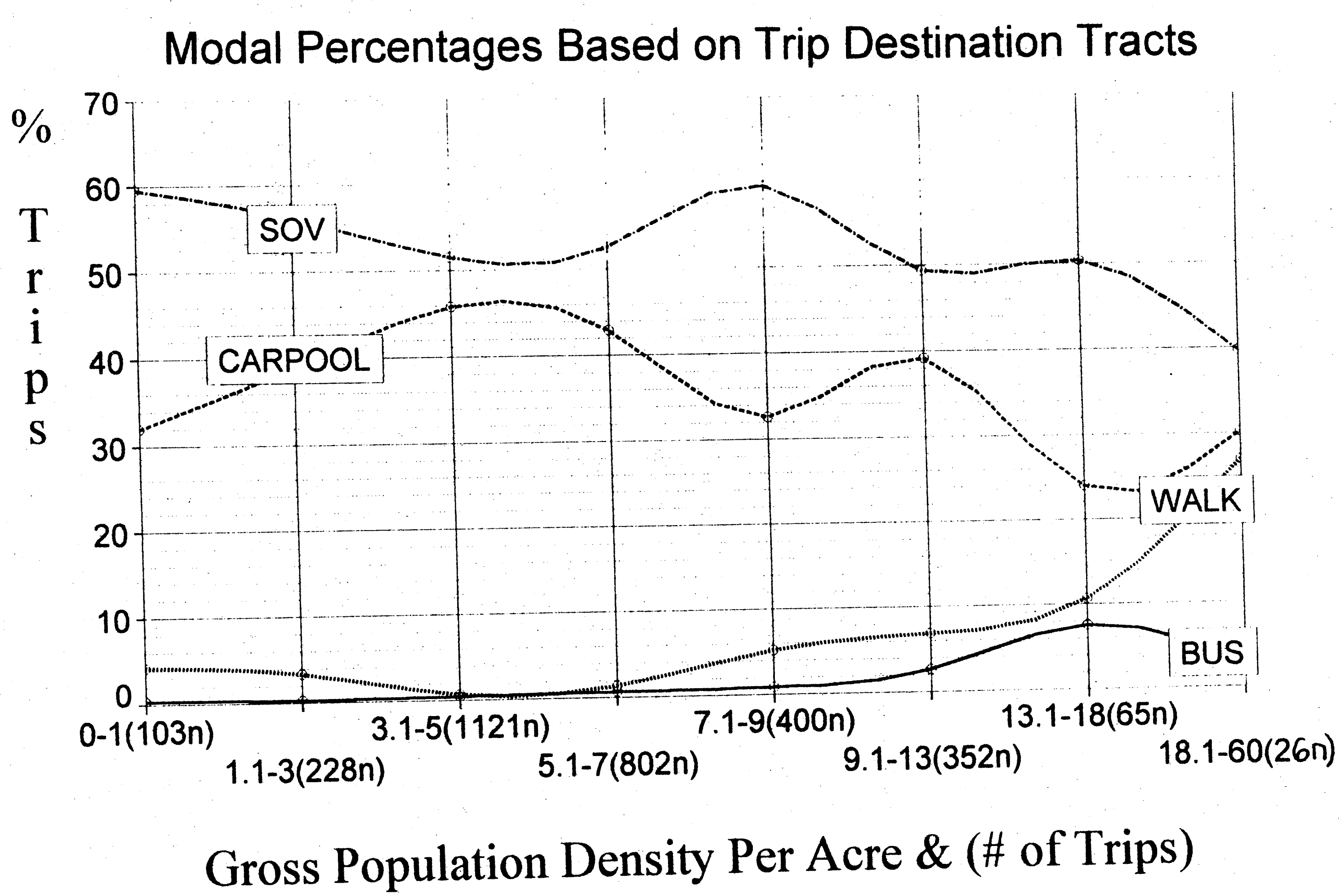
Adj. R-Sq.	0.21
Sig. F	0
F-Value	42.34
Dgrs. of Frdm.	312

POPULATION DENSITY AT TRIP ORIGINS AND MODE CHOICE FOR SHOPPING TRIPS

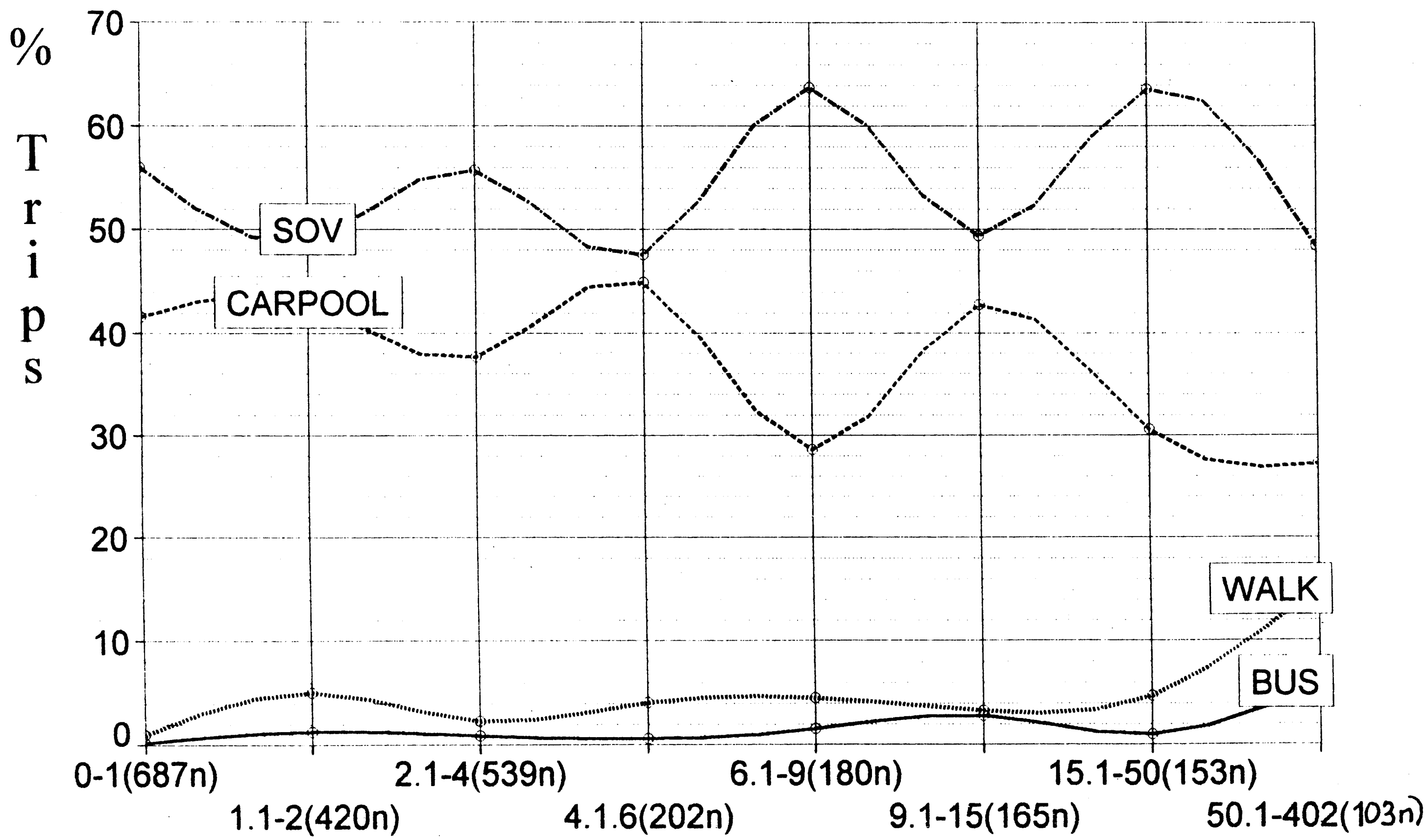



POPULATION DENSITY AT TRIP DESTINATIONS
AND MODE CHOICE FOR SHOPPING TRIPS
% Trips
60
50
40
30
20
10
0
SOV
CARPOOL
WALK
BUS
0-1(246n)
1.1-3(684n)
3.1-5(549n)
5.1-7(708n)
7.1-9(603n)
9.1-13(314n)
13.1-18(53n)
18.1-60(50n)
Gross Population Density Per Acre & (# of trips)

AVERAGE POPULATION DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR SHOPPING TRIPS

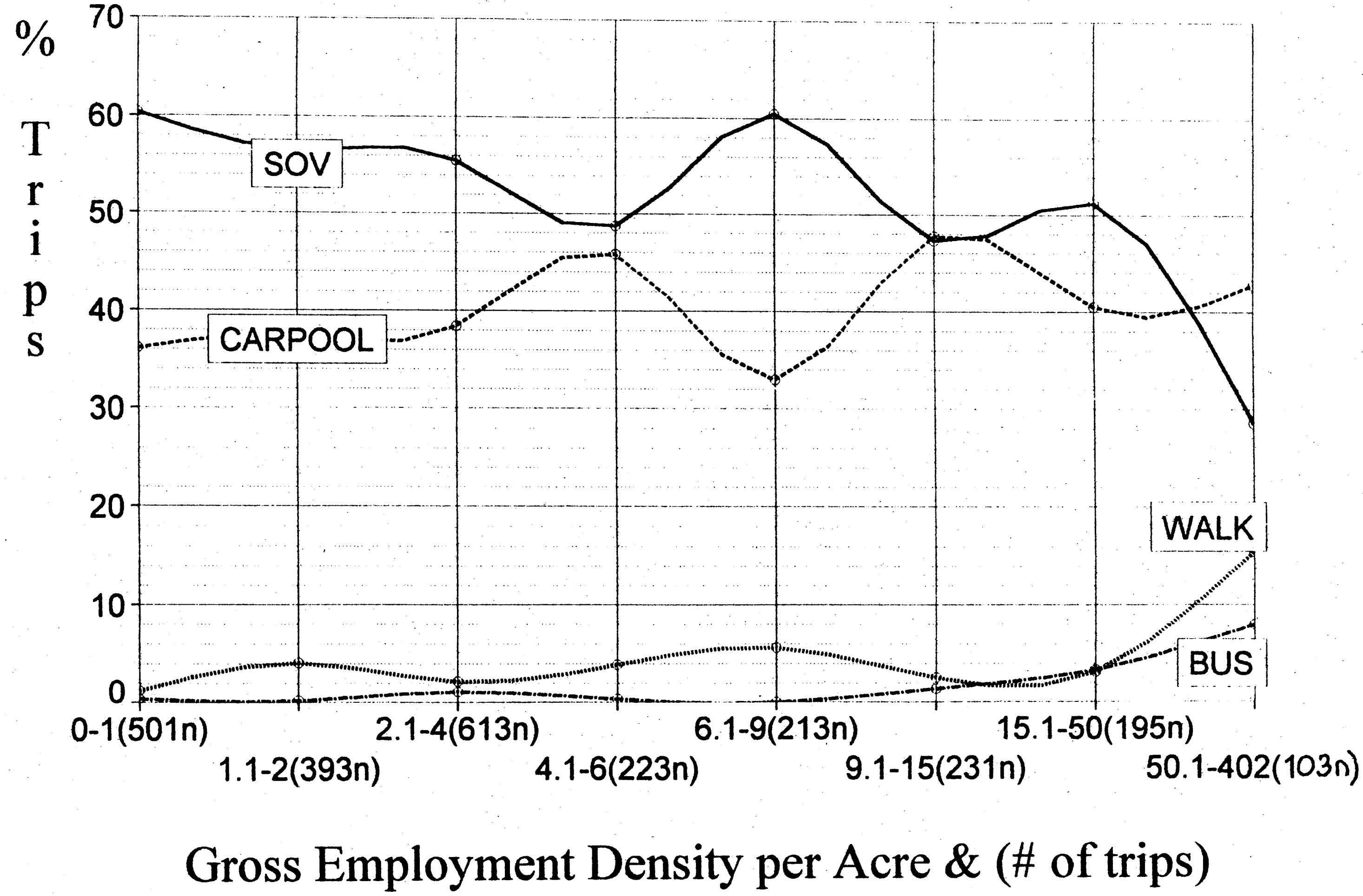


EMPLOYMENT DENSITY AT TRIP ORIGINS AND MODE CHOICE FOR SHOPPING TRIPS

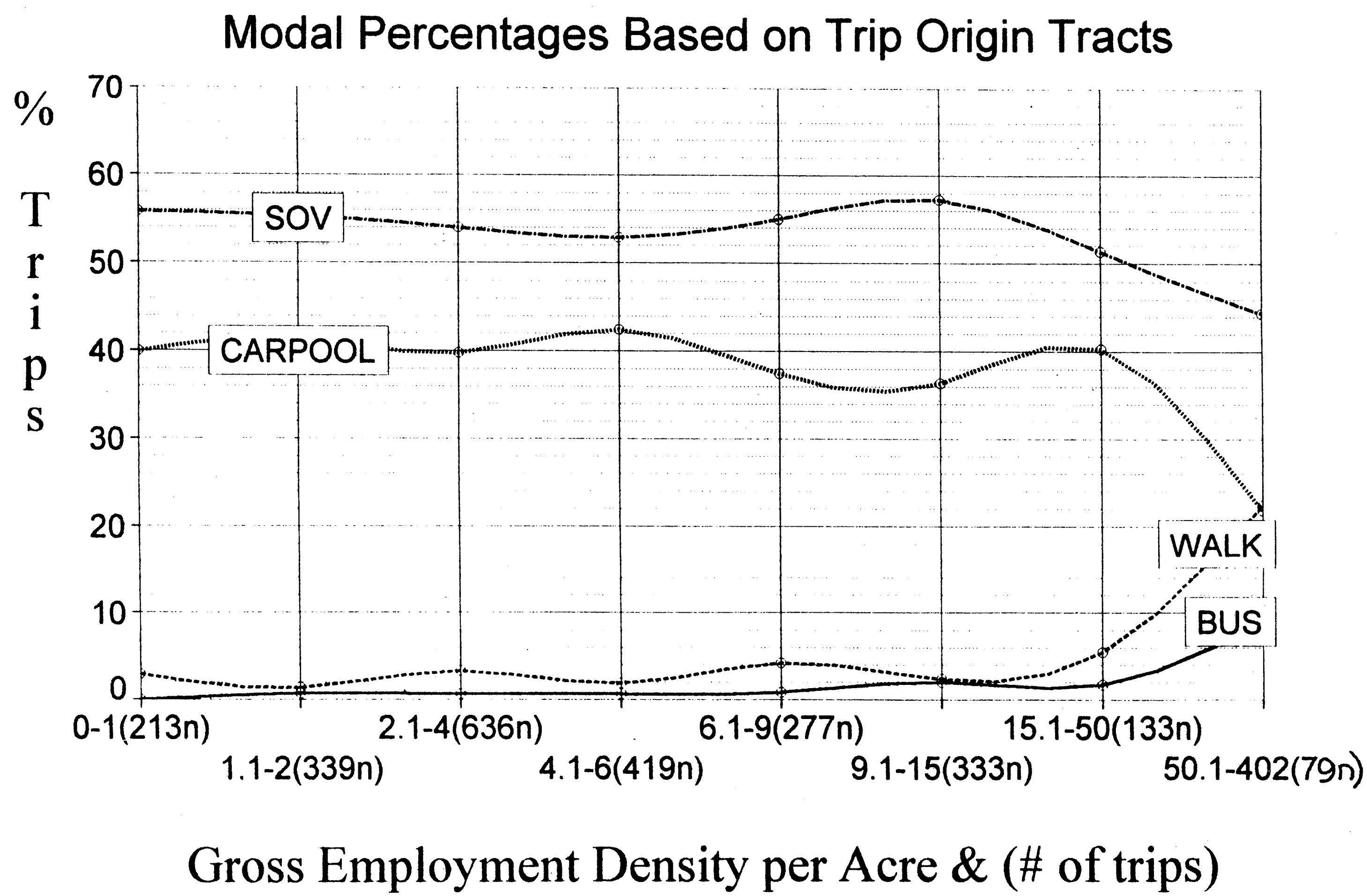


Gross Employment Density per Acre & (# of trips)

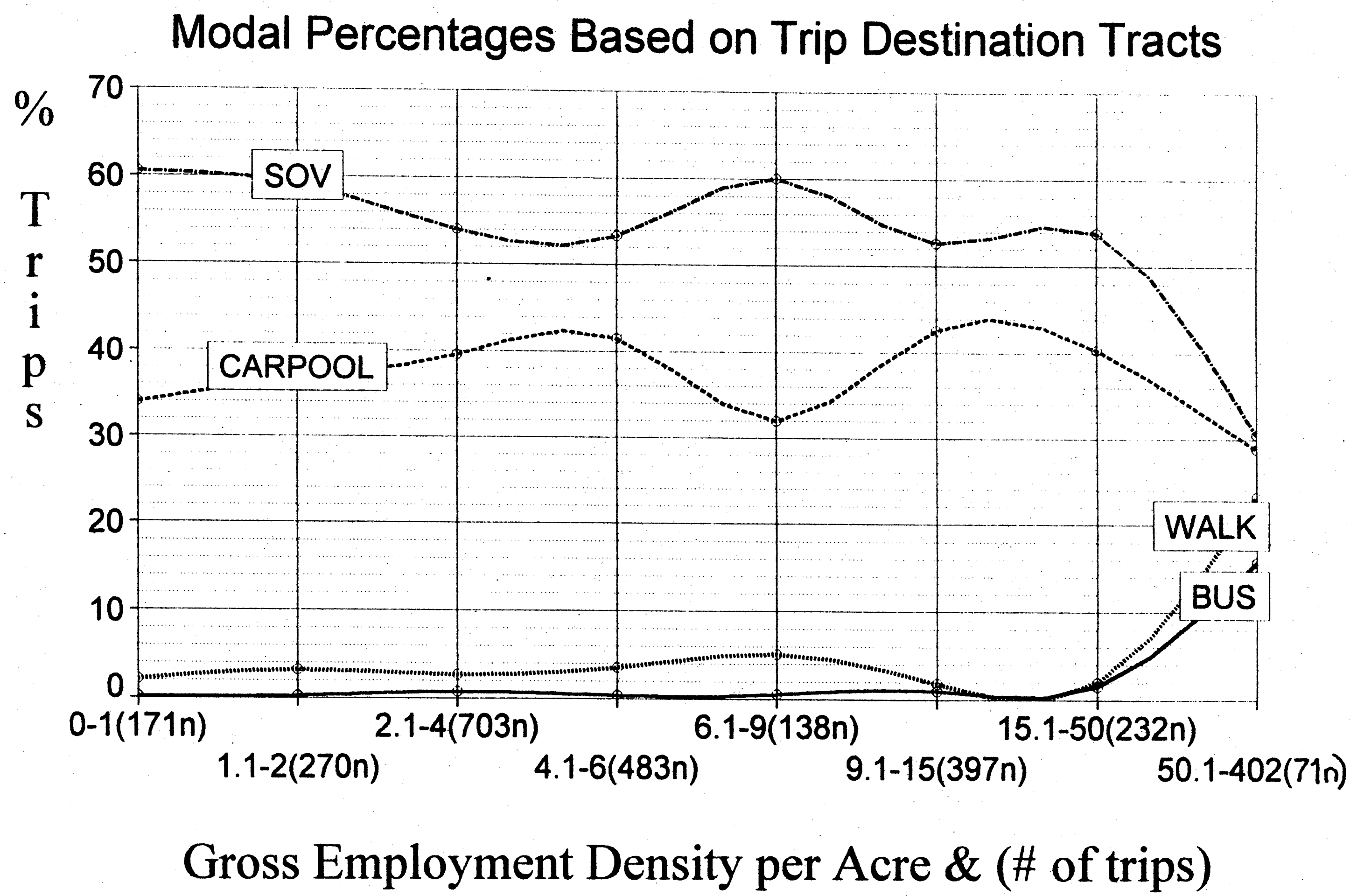
EMPLOYMENT DENSITY AT TRIP DESTINATIONS AND MODE CHOICE FOR SHOPPING TRIPS



AVERAGE EMPLOYMENT DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR SHOPPING TRIPS



AVERAGE EMPLOYMENT DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR SHOPPING TRIPS



APPENDIX D

ALL TRIPS:
CORRELATIONS (INCLUDES TRAVEL TIME, TRIP DISTANCE, AND TRIP GENERATION), MULTIVARIATE REGRESSION MODELS, AND DENSITY THRESHOLD

VARIABLES CORRELATED WITH TRAVEL TIME

ALL TRIPS

VARIABLE	corr. coeff. (r)	weighted trips (n)	signif. (p)
average employment density at trip origins and destinations	0.1335	15169	0
employer density at trip destinations	0.1172	18724	0

VARIABLES CORRELATED WITH TRIP DISTANCE

ALL TRIPS

VARIABLE	corr. coeff. (r)	weighted trips (n)	signif. (p)
average population density at trip origins and destinations	-0.1185	24218	0
level of service for transit: distance to nearest bus stop	0.1282	28508	0

VARIABLES CORRELATED WITH % SOV TRIPS

ALL TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
less than one vehicle available per driver	-0.18	570	0
employed outside the home	0.31	571	0
has a drivers license	0.3	571	0
population density at trip origins	-0.16	492	0
average employment density at trip origins and destinations	-0.17	356	0
employer density at trip origins	-0.16	360	0
average population and employment density at trip origins and destinations	-0.2	356	0

%SOVALO.XLS

Multi-Variate Regression Model
% SOV Trips at Origins
ALL TRIPS

variables in model

Variable Name	Sig. T	Beta	B
average population density at origins and destinations	0	-0.15	-0.52
average employment density at origins and destinations	0.04	-0.15	-0.12
has a drivers license	0	0.26	0.214
employed outside home	0	0.26	0.72
CONSTANT	0.12	n/a	-19.93

summary statistics

Adj. R-Sq.	0.19
Sig. F	0
F-Value	22.65
Degrs. Frdm.	355

VARIABLES CORRELATED WITH % SOV

ALL TRIPS - DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
population density at trip destinations	-0.15	492	0
less than one vehicle available per driver	-0.19	573	0
households with two or more adults over 65	-0.18	574	0
age	-0.17	574	0
employed outside the home	0.32	574	0
has a drivers license	0.27	574	0
average employment density at trip origins and destinations	-0.14	360	0.01
average population and employment density at trip origins and destinations	-0.16	360	0

%SOVALD.XLS

Multi-Variate Regression Model

% SOV Trips at Destinations

ALL TRIPS

variables in model

Variable Name	Sig. T	Beta	B
population density at trip destinations	0.03	-0.11	-0.31
average employment density at origins and destinations	0.01	-0.15	-0.13
has a drivers license	0	0.22	0.65
employed outside home	0	0.22	0.19
household with 2 or more adults over 65	0.02	-0.12	-0.14
CONSTANT	0.47	n/a	-9.91

summary statistics

Adj. R-Sq.	0.19
Sig. F	0
F-Value	15.3
Degrs. Frdm.	359

VARIABLES CORRELATED WITH % CARPOOL

ALL TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
less than one vehicle available per driver	0.16	570	0
households with more than 2 adults over 65	0.18	571	0
household size	0.14	571	0
gender is male	-0.17	571	0
age	0.18	356	0
employed outside the home	-0.32	360	0
average employment density at trip origins and destinations	-0.13	356	0
average population and employment density at trip origins and destinations	-0.2	356	0
travel time for carpooling	0.26	544	0

%CPLALO.XLS

Multi-Variate Regression Model

% Carpool Trips at Origins

ALL TRIPS

variables in model

Variable Name	Sig. T	Beta	B
employed outside the home	0	-0.31	-0.27
median household value of destination tracts	0.02	-0.09	-4.73
CONSTANT	0	n/a	59.63

summary statistics

Adj. R-Sq.	0.11
Sig. F	0
F-Value	33.68
Degrs. Frdm.	537

VARIABLES CORRELATED WITH % CARPOOL

ALL TRIPS - DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
less than one vehicle available per driver	0.16	573	0
households with more than 2 adults over 65	0.23	574	0
age	0.21	574	0
gender is male	-0.17	571	0
employed outside the home	-0.36	360	0
median household value	-0.16	549	0
average employment density at trip origins and destinations	-0.15	360	0
average population and employment density at trip origins and destinations	-0.15	360	0
travel time for carpooling	0.26	547	0

%CPLALD.XLS

Multi-Variate Regression Model

% Carpool Trips at Destinations

ALL TRIPS

variables in model

Variable Name	Sig. T	Beta	B
employed outside the home	0	-0.31	-0.23
median household value of origin tracts	0.02	-0.19	0
less than one vehicle available per driver	0.08	0.1	0.14
mixing of uses at trip destinations	0.04	-0.12	-11.51
CONSTANT	0	n/a	72.42

summary statistics

Adj. R-Sq.	0.14
Sig. F	0
F-Value	13.45
Degrs. Frdm.	298

VARIABLES CORRELATED WITH % TRANSIT

ALL TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average population density at trip origins and destinations	0.18	491	0
average employment density at trip origins and destinations	0.61	356	0
average population and employment density at trip origins and destinations	0.64	356	0
average mixing of uses at trip origins and destinations	0.16	298	0
household size	-0.18	571	0
number of vehicles available	-0.23	571	0
has a drivers license	-0.55	571	0

%BUSALO.XLS

Multi-Variate Regression Model
% Transit Trips at Origins
ALL TRIPS

variables in model

Variable Name	Sig. T	Beta	B
population density at destinations	0	0.21	0.2
average employment density at origins and destinations	0	0.56	0.09
has a drivers license	0	-0.2	-0.12
mean household income	0.02	- 0.09	0
CONSTANT	0	n/a	12.39

summary statistics

Adj. R-Sq.	0.48
Sig. F	0
F-Value	82.64
Degrs. Frdm.	354

VARIABLES CORRELATED WITH % TRANSIT

ALL TRIPS - DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average population density at trip origins and destinations	0.12	492	0
average employment density at trip origins and destinations	0.6	360	0
average mixing of uses at trip origins and destinations	0.14	298	0.02
level of service for transt: distance to nearest bus stop	-0.12	572	0
number of vehices available	-0.22	574	0
household income	-0.11	572	0
has a driver's licence	-0.55	574	0
households with one adult between 35-64	0.26	574	0
household size	-0.17	574	0
average distance for walking trips	-0.2	239	0

%BUSALD.XLS

Multi-Variate Regression Model

% Transit Trips at Destinations

ALL TRIPS

variables in model

Variable Name	Sig. T	Beta	B
average employment density at origins and destinations	0	0.61	0.11
has a drivers license	0	-0.21	-0.12
mean household income	0.01	-0.11	0
CONSTANT	0	n/a	14.38

summary statistics

Adj. R-Sq.	0.41
Sig. F	0
F-Value	83.89
Degrs. Frdm.	358

VARIABLES CORRELATED WITH % WALK TRIPS

ALL TRIPS - ORIGINS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average population density at trip origins and destinations	0.45	492	0
average employment density at trip origins and destinations	0.4	356	0
mixing of uses at trip origins	0.21	299	0
households with one adult between 35-64	0.18	571	0
employer density at trip origins	0.46	360	0
number of vehicles available	-0.15	571	0
level of service for transit: distance to nearest bus stop	-0.16	569	0
average distance for walking trips	-0.16	239	0

%WLKALO.XLS

Multi-Variate Regression Model

% Walking Trips at Origins

ALL TRIPS

variables in model

Variable Name	Sig. T	Beta	B
population density at origins	0	0.39	0.33
average employment density at origins and destinations	0	0.26	0.07
households with one adult between 35-64	0.05	0.09	0.04
CONSTANT	0.34	N/A	-0.4

summary statistics

Adj. R-Sq.	0.29
Sig. F	0
F-Value	50.9
Degrs. Frdm.	355

VARIABLES CORRELATED WITH % WALK TRIPS

ALL TRIPS - DESTINATIONS

VARIABLE	corr. coeff. (r)	tracts (n)	sig. (p)
average population density at trip origins and destinations	0.45	492	0
average employment density at trip origins and destinations	0.37	360	0
mixing of uses at trip destinations	0.2	299	0
households with two adults less than 35	0.2	574	0
household size	-0.14	574	0
number of vehicles available	-0.14	574	0
level of service for transit: distance to nearest bus stop	-0.16	572	0
trip maker is a student	0.12	574	0.01
average distance for walking trips	-0.2	239	0

%WLKALD.XLS

Multi-Variate Regression Model

% Walking Trips at Destinations

ALL TRIPS

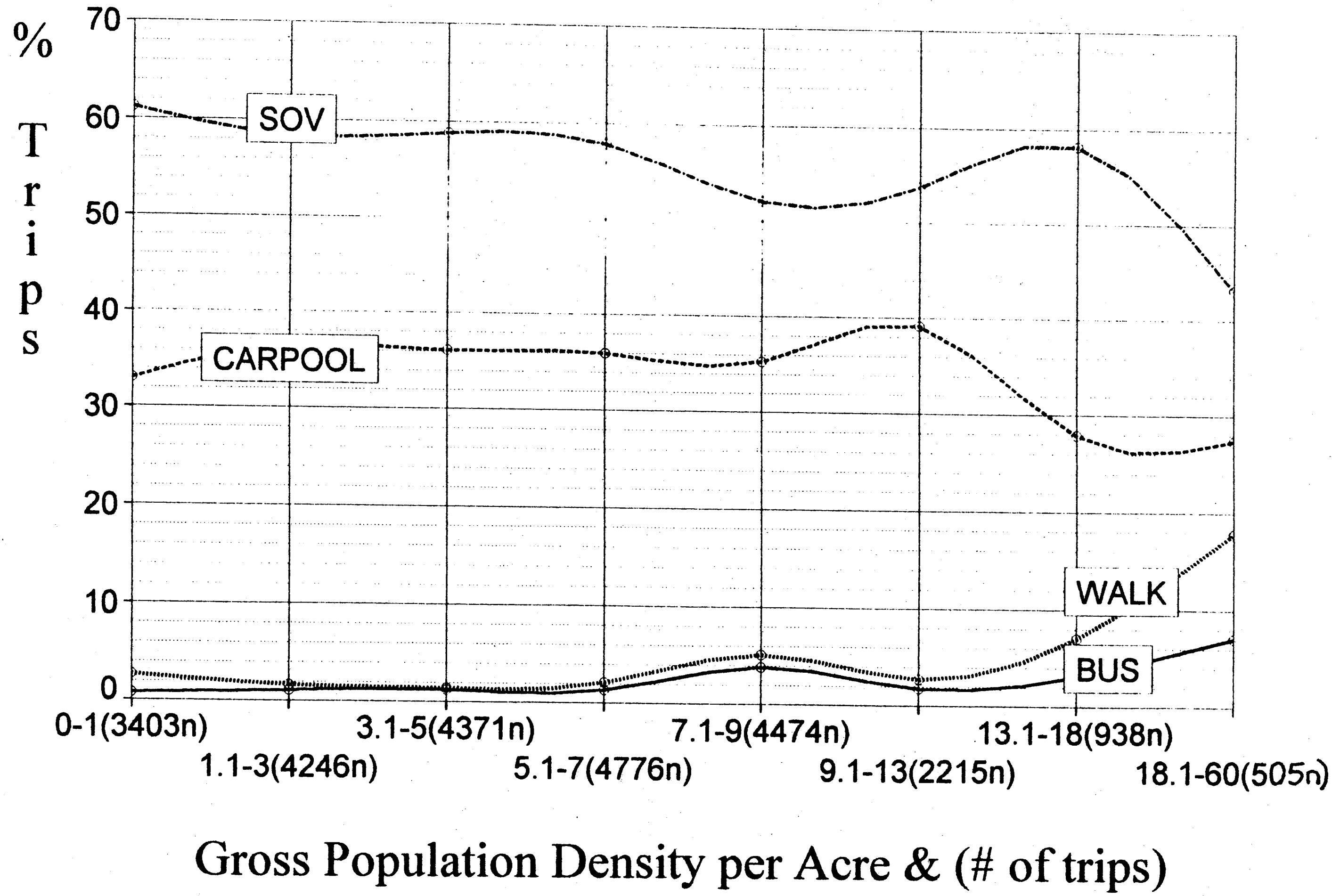
variables in model

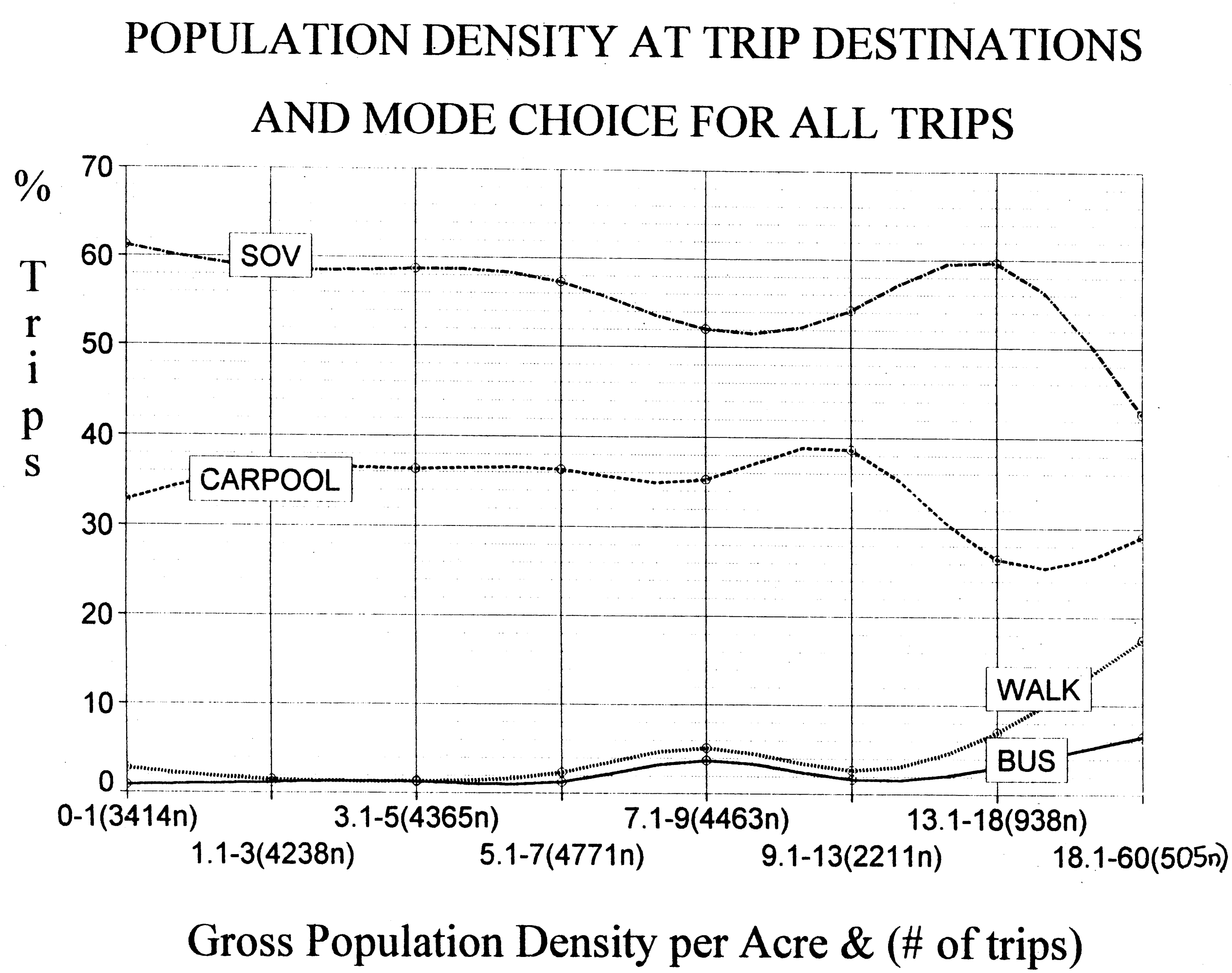
Variable Name	Sig. T	Beta	B
population density at destinations	0	0.36	0.32
average employment density at origins and destinations	0	0.22	0.06
households with two or more adults under 35	0.01	0.14	0.07
CONSTANT	0.28	n/a	-0.42

summary statistics

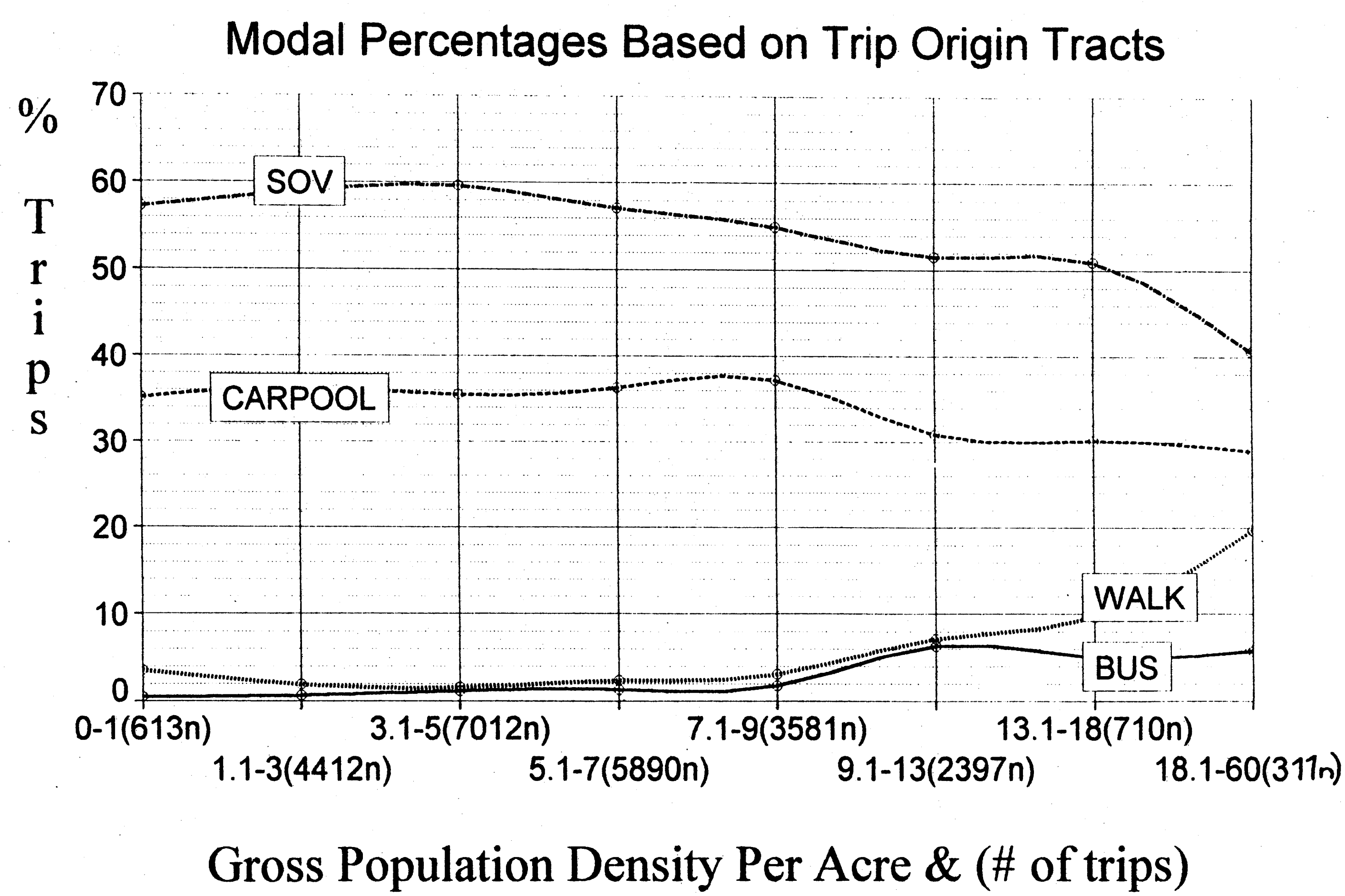
Adj. R-Sq.	0.28
Sig. F	0
F-Value	48.42
Degrs. Frdm.	359

POPULATION DENSITY AT TRIP ORIGINS AND MODE CHOICE FOR ALL TRIPS

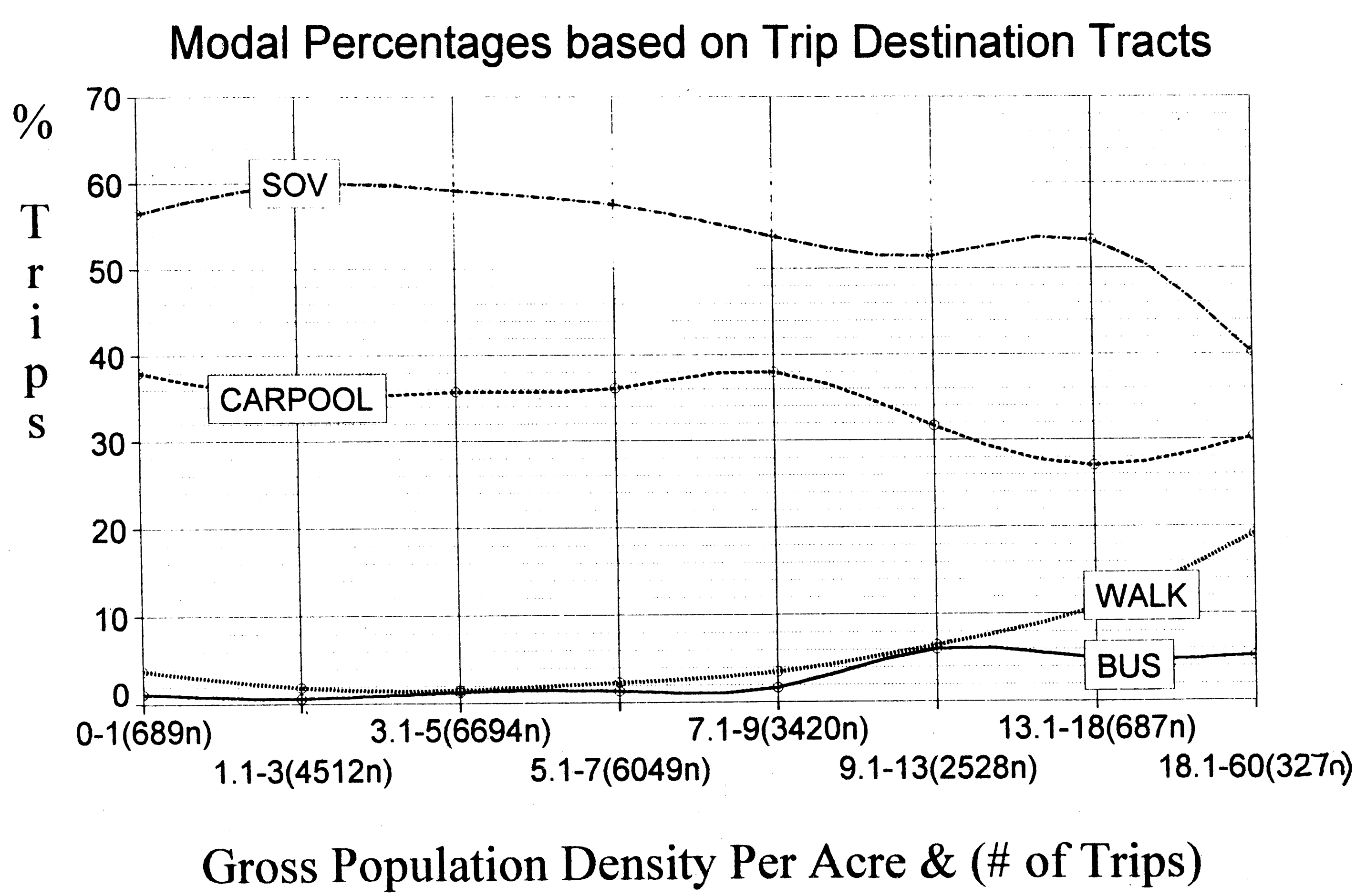



POPULATION DENSITY AT TRIP DESTINATIONS
AND MODE CHOICE FOR ALL TRIPS
% Trips
70
60
50
40
30
20
10
0
SOV
CARPOOL
WALK
BUS
0-1(3414n)
1.1-3(4238n)
3.1-5(4365n)
5.1-7(4771n)
7.1-9(4463n)
9.1-13(2211n)
13.1-18(938n)
18.1-60(505n)
Gross Population Density per Acre & (# of trips)

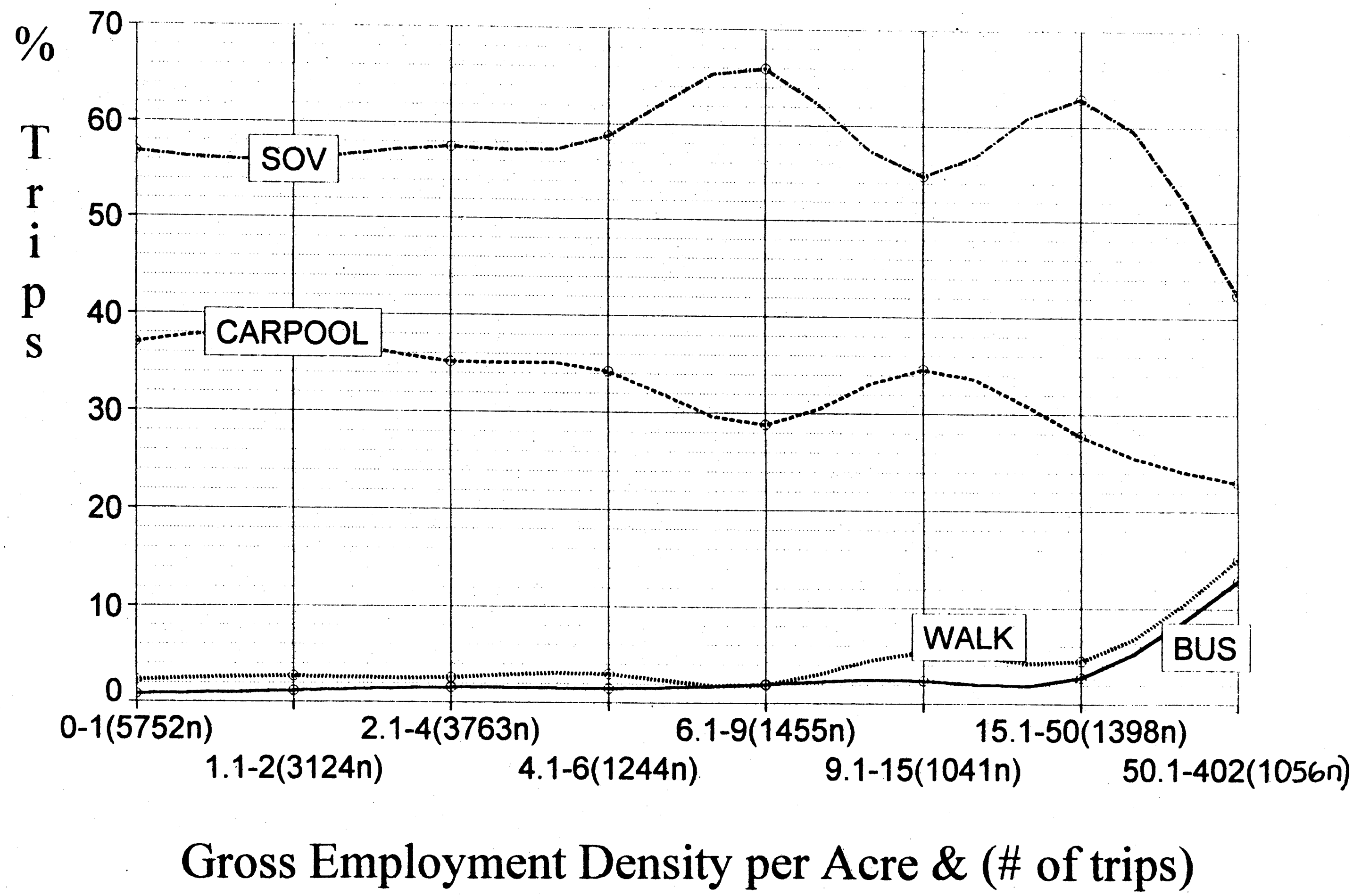
AVERAGE POPULATION DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR ALL TRIPS



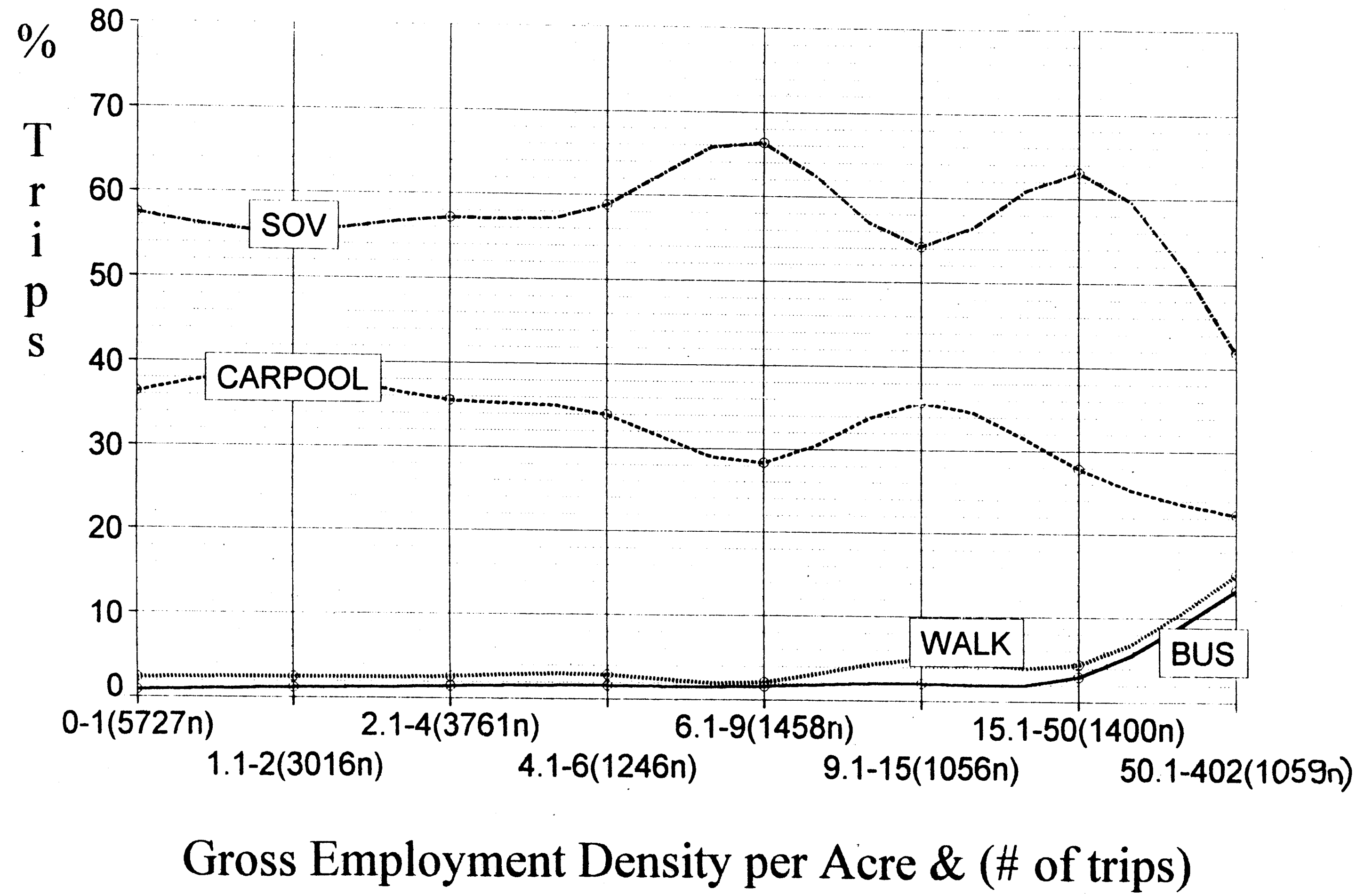
AVERAGE POPULATION DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR ALL TRIPS



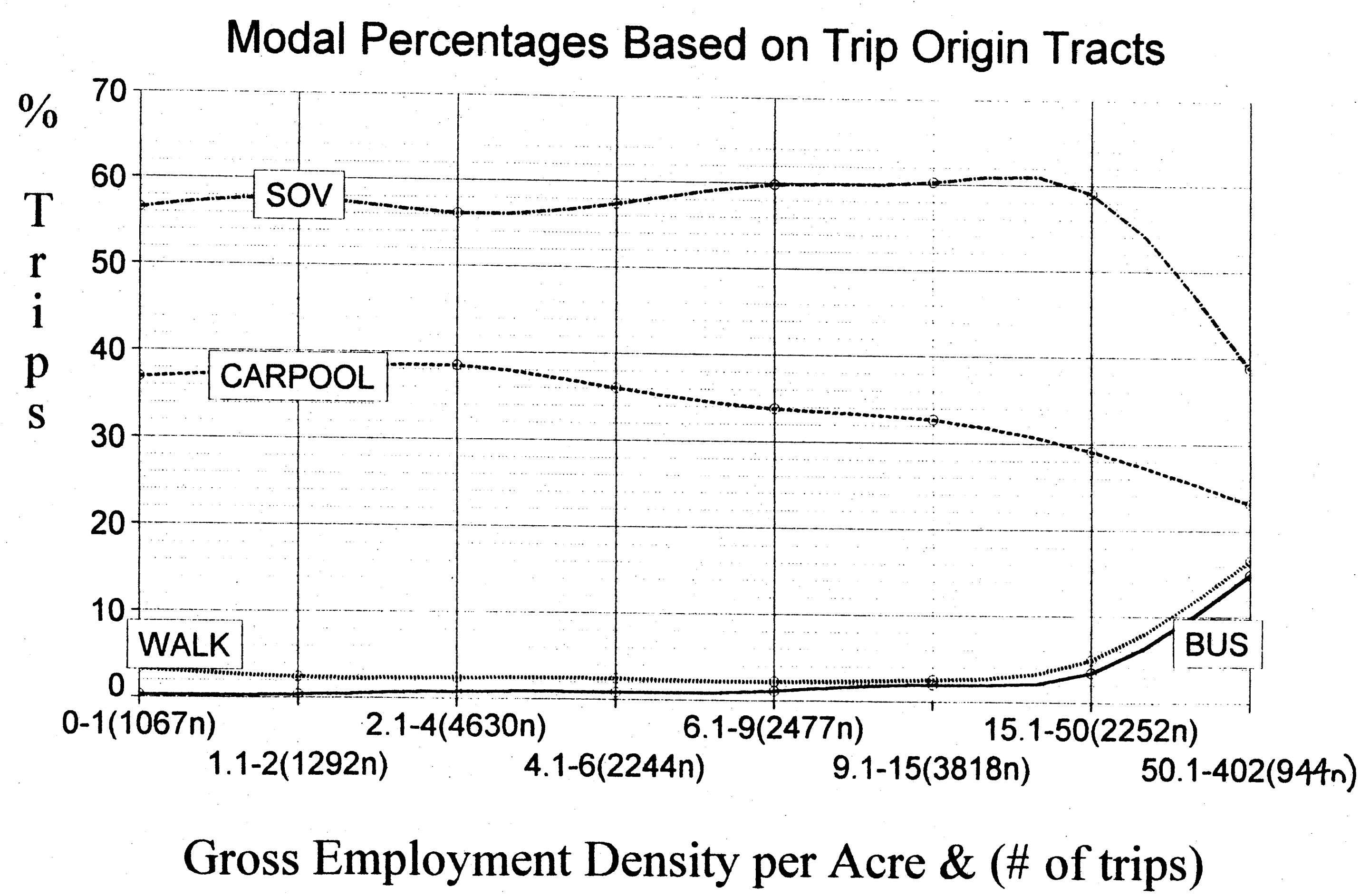
EMPLOYMENT DENSITY AT TRIP ORIGINS AND MODE CHOICE FOR ALL TRIPS



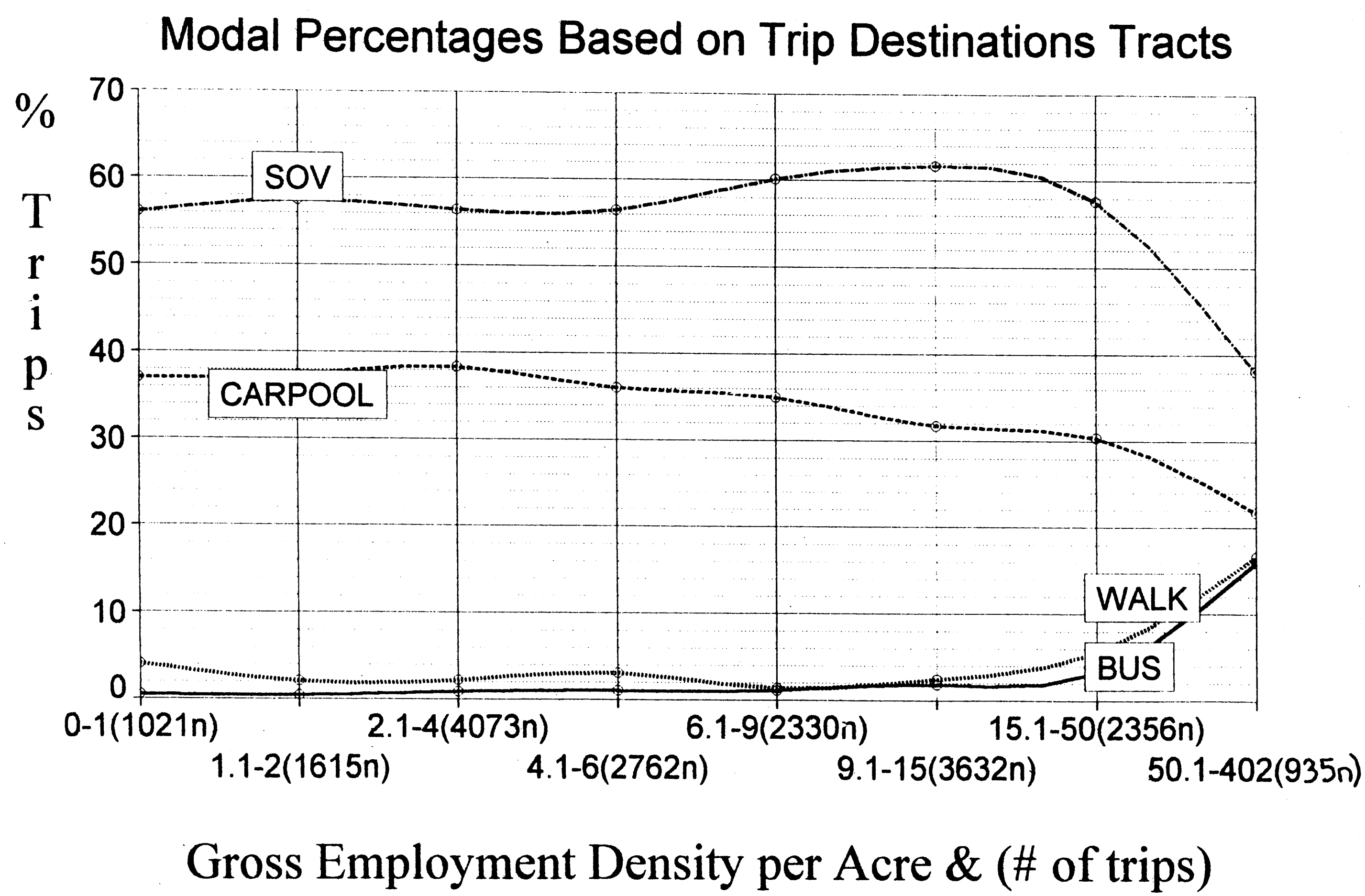
EMPLOYMENT DENSITY AT TRIP DESTINATIONS AND MODE CHOICE FOR ALL TRIPS



AVERAGE EMPLOYMENT DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR ALL TRIPS

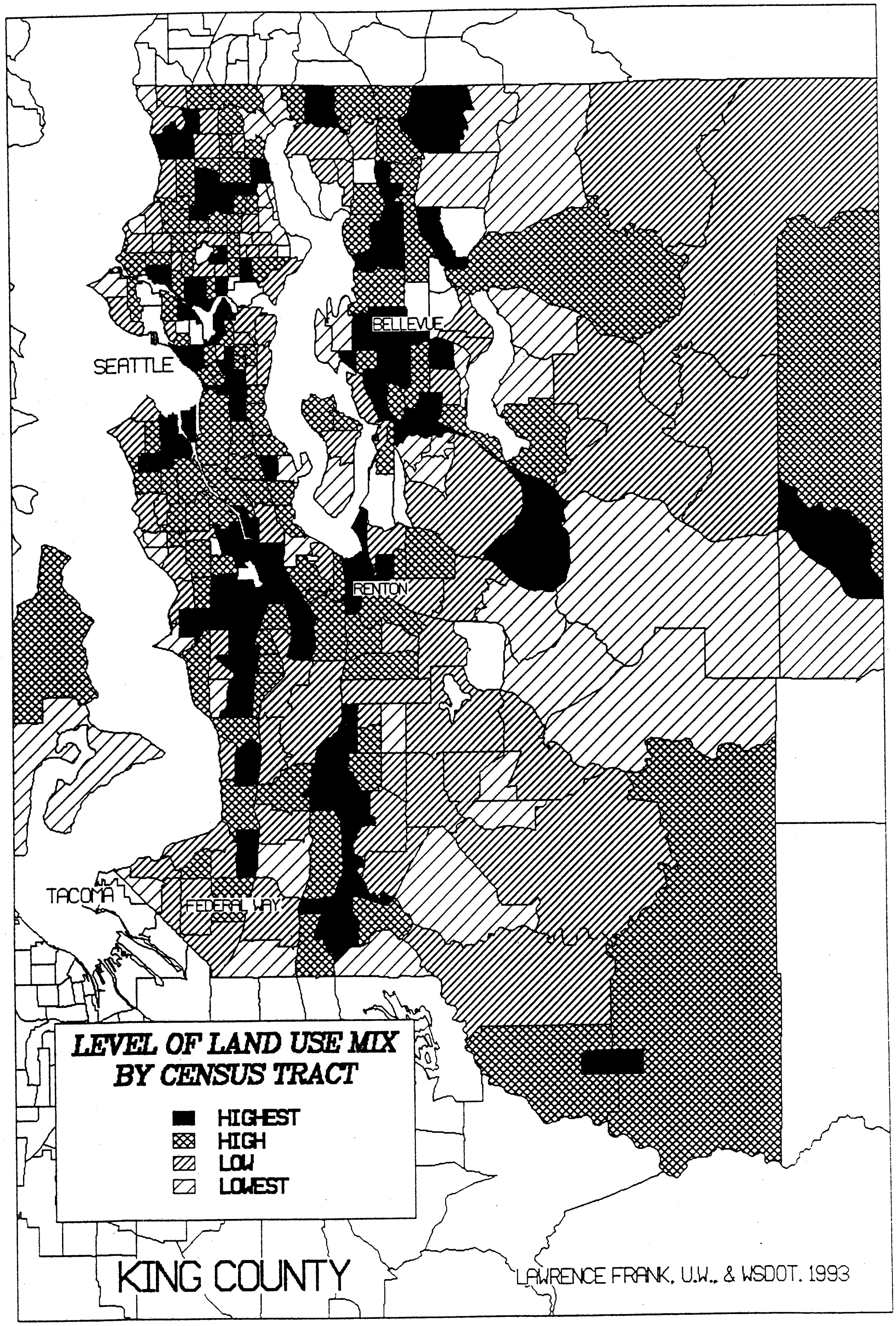


AVERAGE EMPLOYMENT DENSITY OF TRIP ORIGINS AND DESTINATIONS AND MODE CHOICE FOR ALL TRIPS

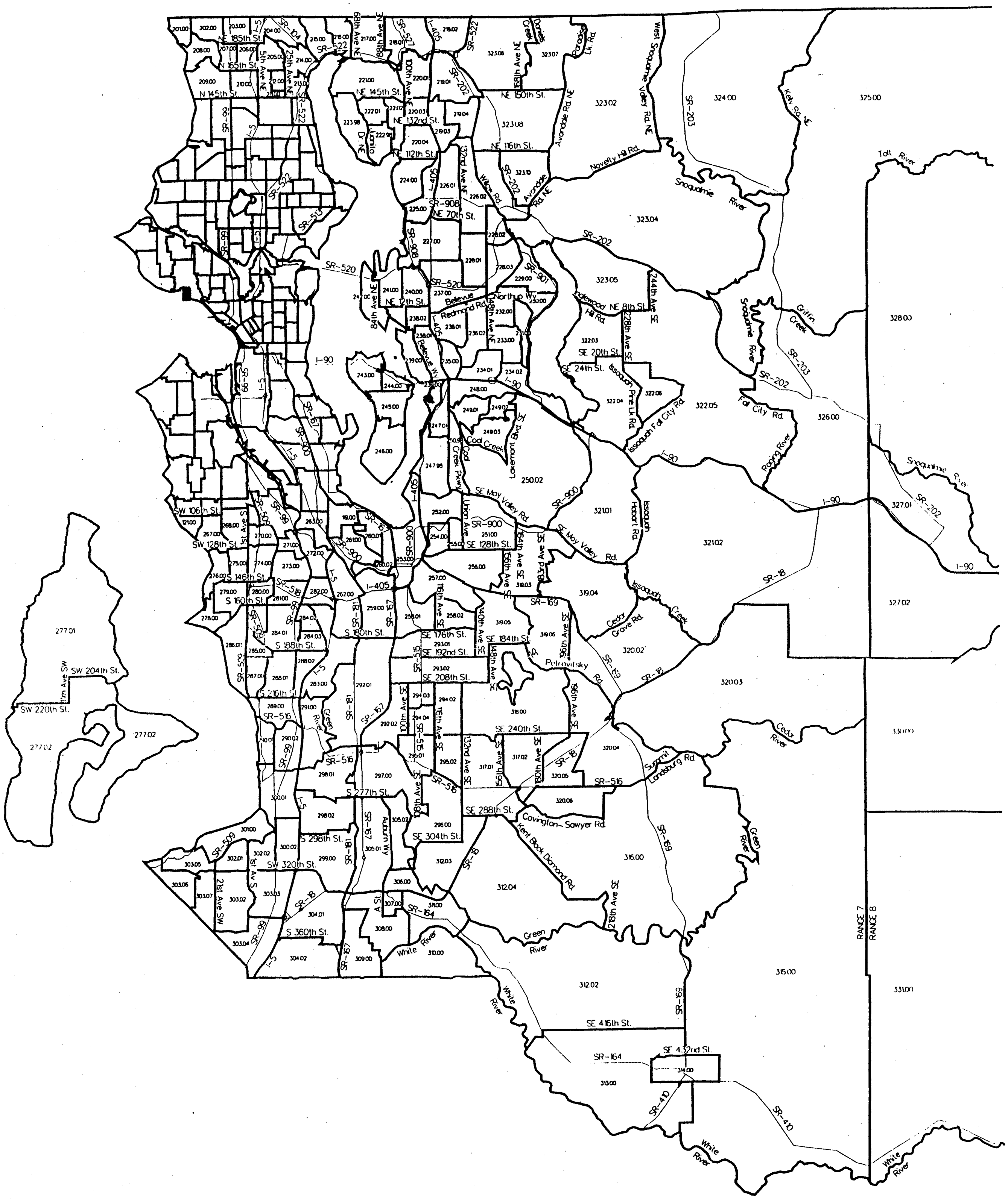


APPENDIX E

CENSUS TRACT MAPS OF URBAN FORM VARIABLES



LEVEL OF LAND USE MIX
BY CENSUS TRACT
HIGHEST
HIGH
LOW
LOWEST
SEATTLE
BELLEVUE
RENTON
TACOMA
FEDERAL WAY
KING COUNTY
LAWRENCE FRANK, U.W., & WSDOT. 1993



King County

1990 Census Tracts

Puget Sound Regional Council

October 1992

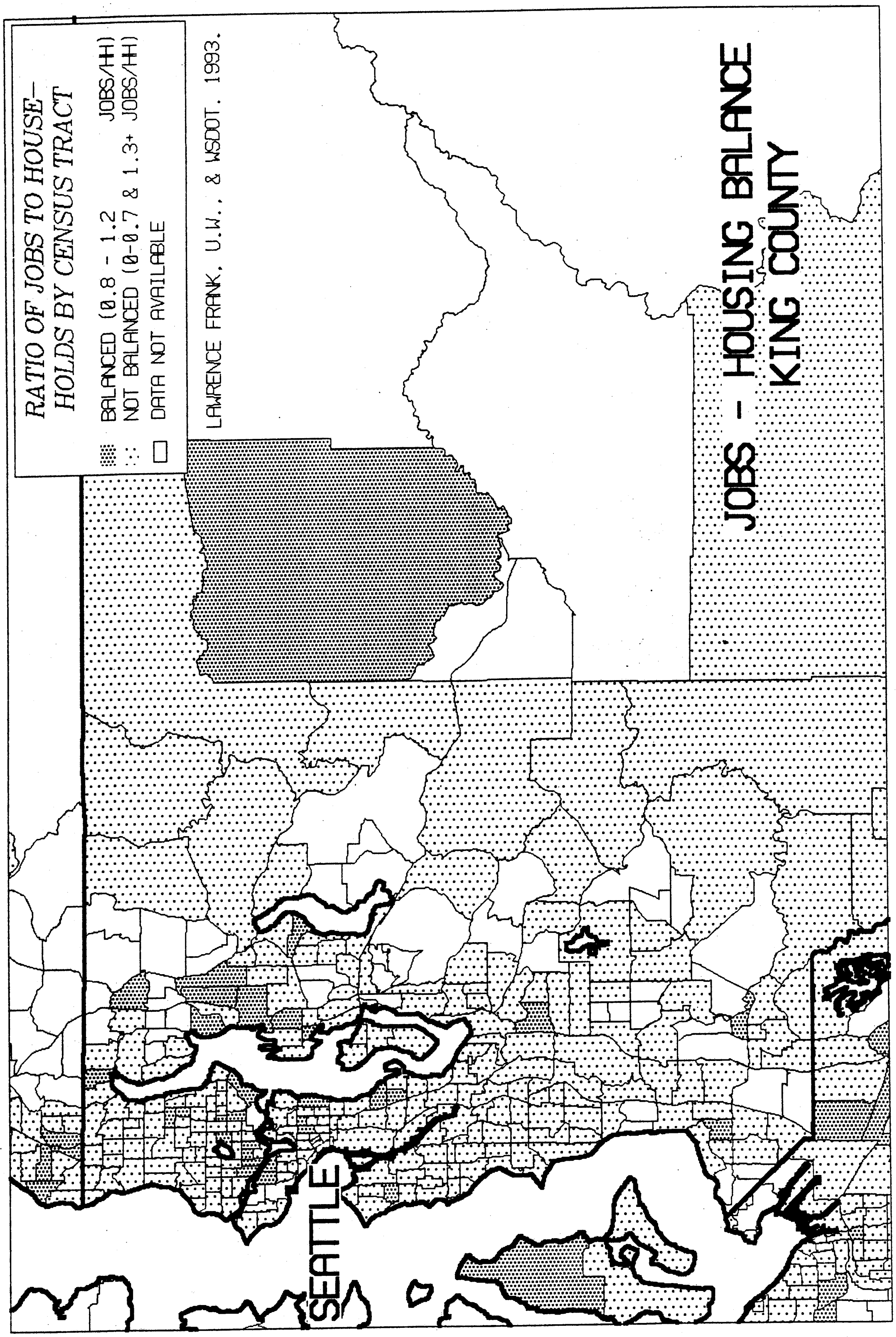
miles

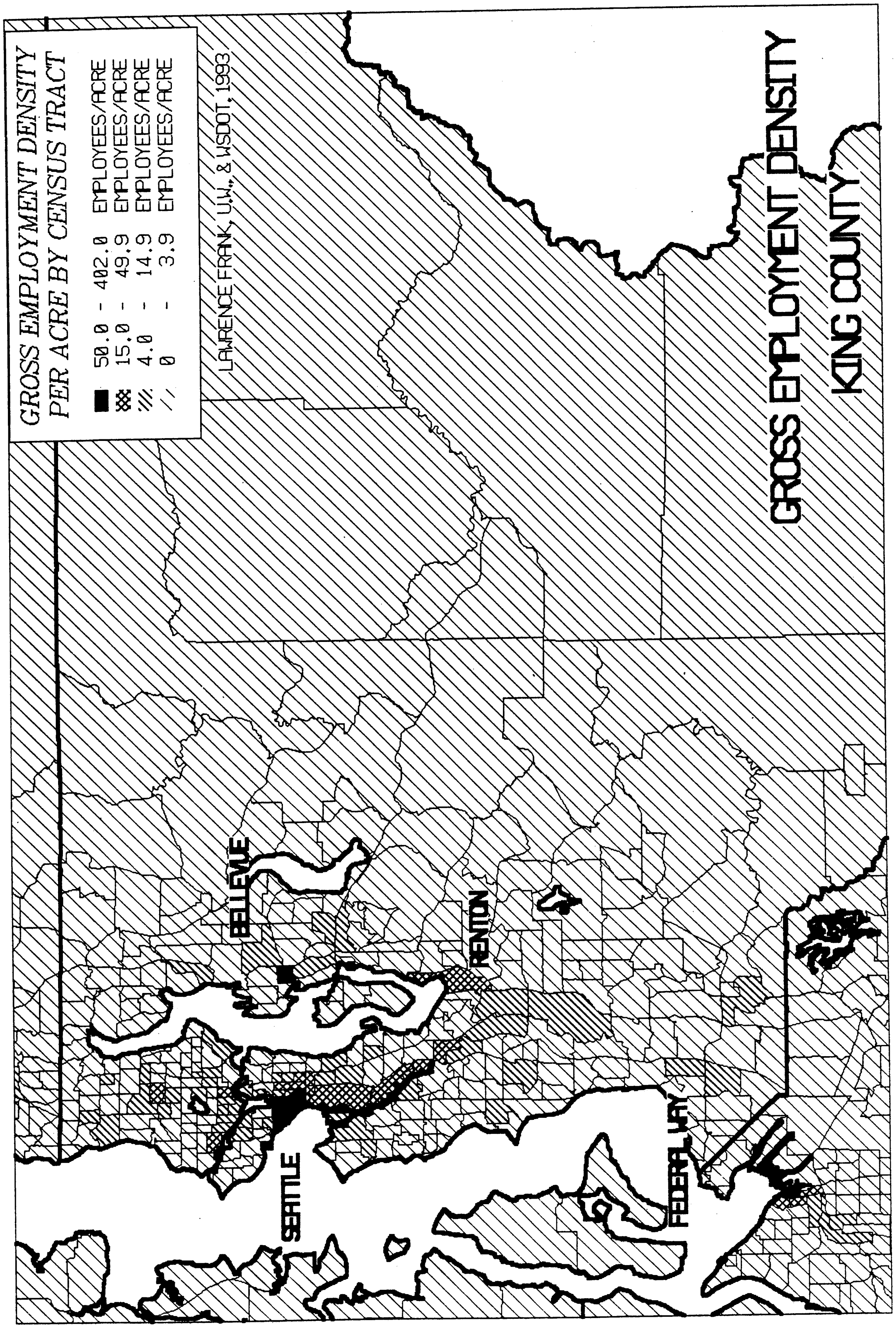
0 1 2 3 4 5

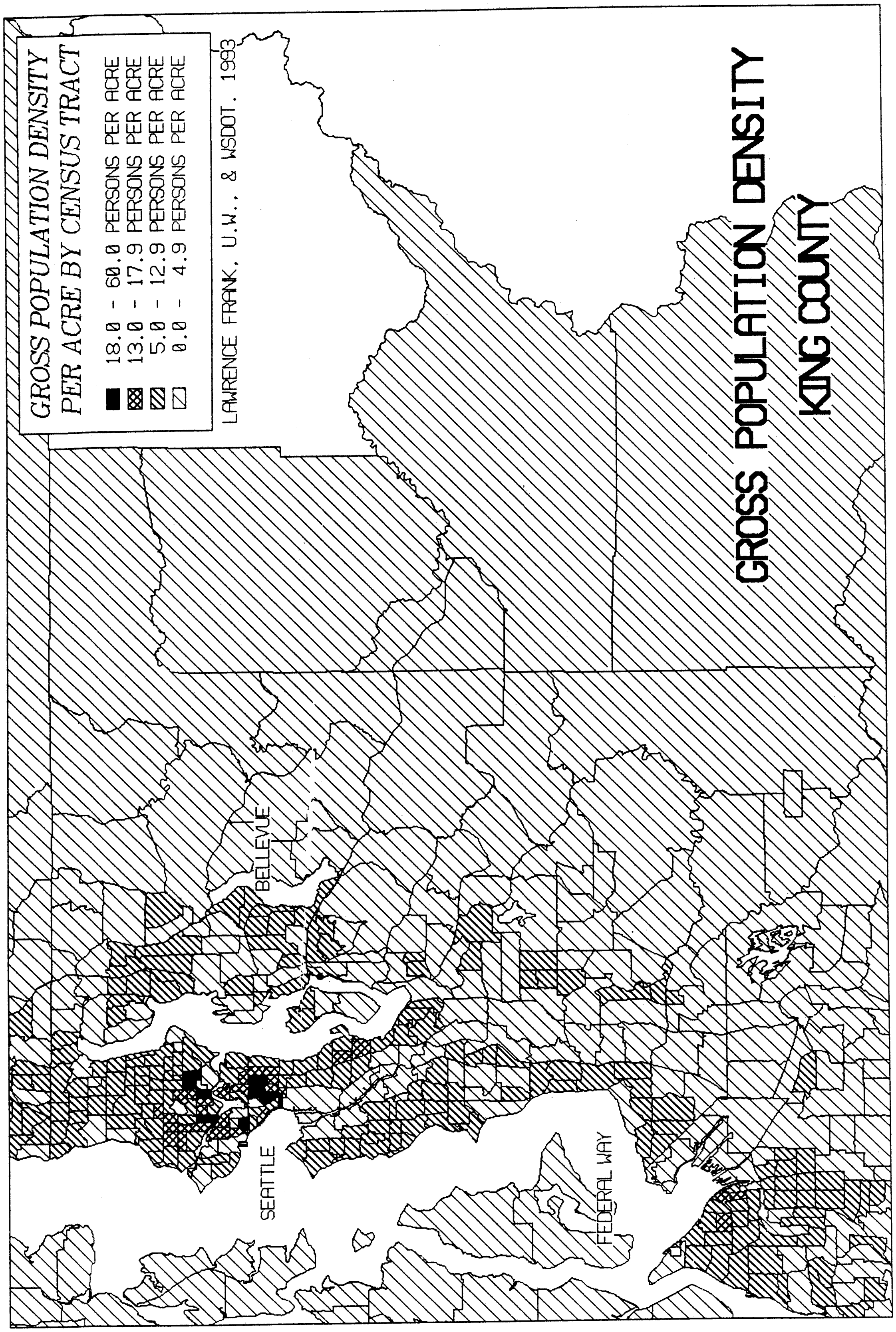
N

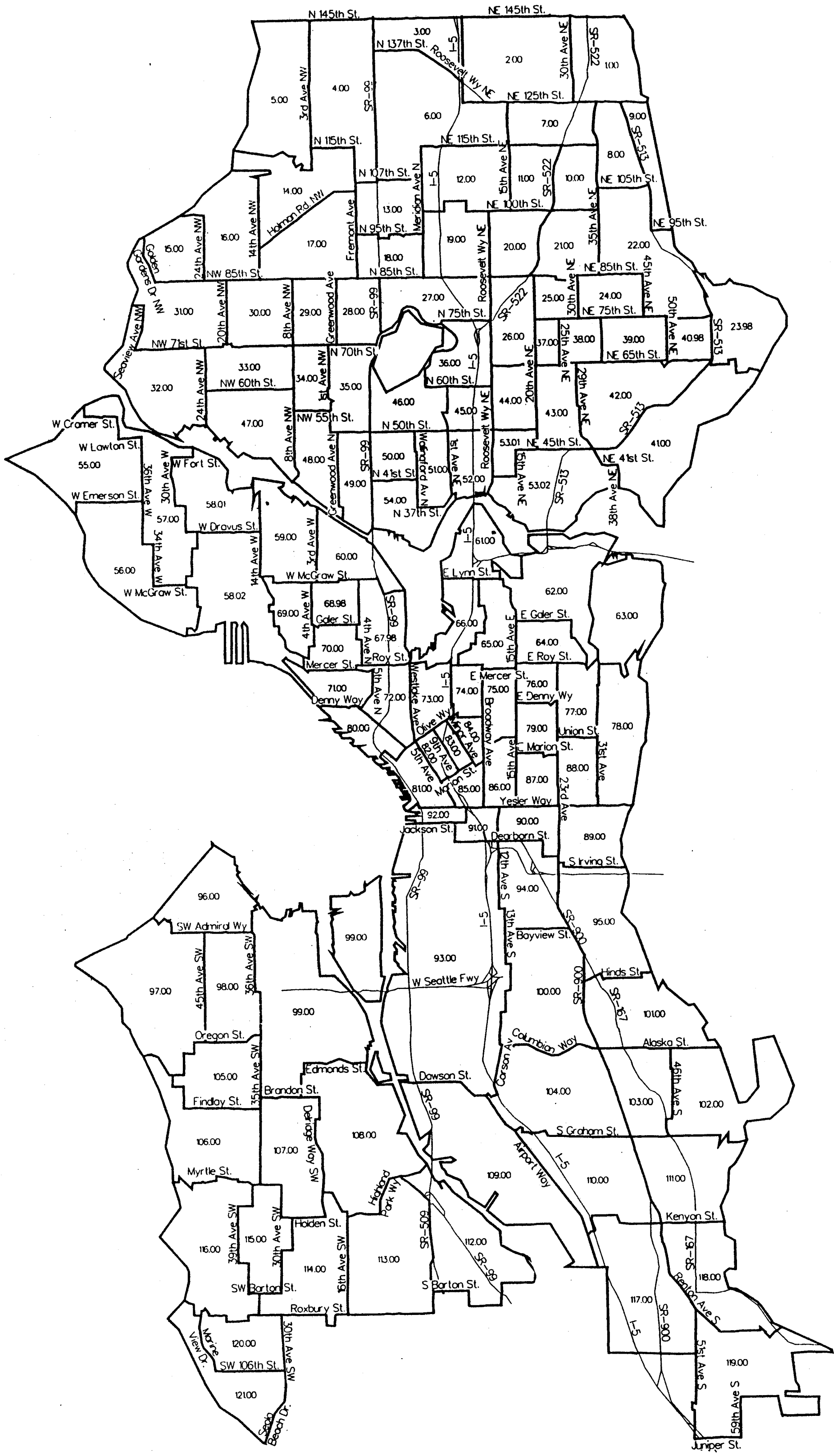
* Refer to Seattle Census Tract map for City of Seattle information.

- Census Tract 329 in N.E. corner not shown.
- Tracts 325 and 328 extend to R. 10 E.
- Tracts 330 and 331 extend to eastern county boundary.


RATIO OF JOBS TO HOUSE-HOLDS BY CENSUS TRACT
BALANCED (0.8 - 1.2 JOBS/HH)
NOT BALANCED (0-0.7 & 1.3+ JOBS/HH)
DATA NOT AVAILABLE
LAWRENCE FRANK, U.W., & WSDOT. 1993.
JOBS - HOUSING BALANCE
KING COUNTY
SEATTLE


GROSS EMPLOYMENT DENSITY
PER ACRE BY CENSUS TRACT
50.0 - 402.0 EMPLOYEES/ACRE
15.0 - 49.9 EMPLOYEES/ACRE
4.0 - 14.9 EMPLOYEES/ACRE
0 - 3.9 EMPLOYEES/ACRE
LAWRENCE FRANK, U.W., & WSDOT, 1993
GROSS EMPLOYMENT DENSITY
KING COUNTY
BELLEVUE
RENTON
SEATTLE
FEDERAL WAY


GROSS POPULATION DENSITY
PER ACRE BY CENSUS TRACT
18.0 - 60.0 PERSONS PER ACRE
13.0 - 17.9 PERSONS PER ACRE
5.0 - 12.9 PERSONS PER ACRE
0.0 - 4.9 PERSONS PER ACRE
LAWRENCE FRANK, U.W., & WSDOT. 1993
GROSS POPULATION DENSITY
KING COUNTY
BELLEVUE
SEATTLE
FEDERAL WAY



Seattle

1990 Census Tracts

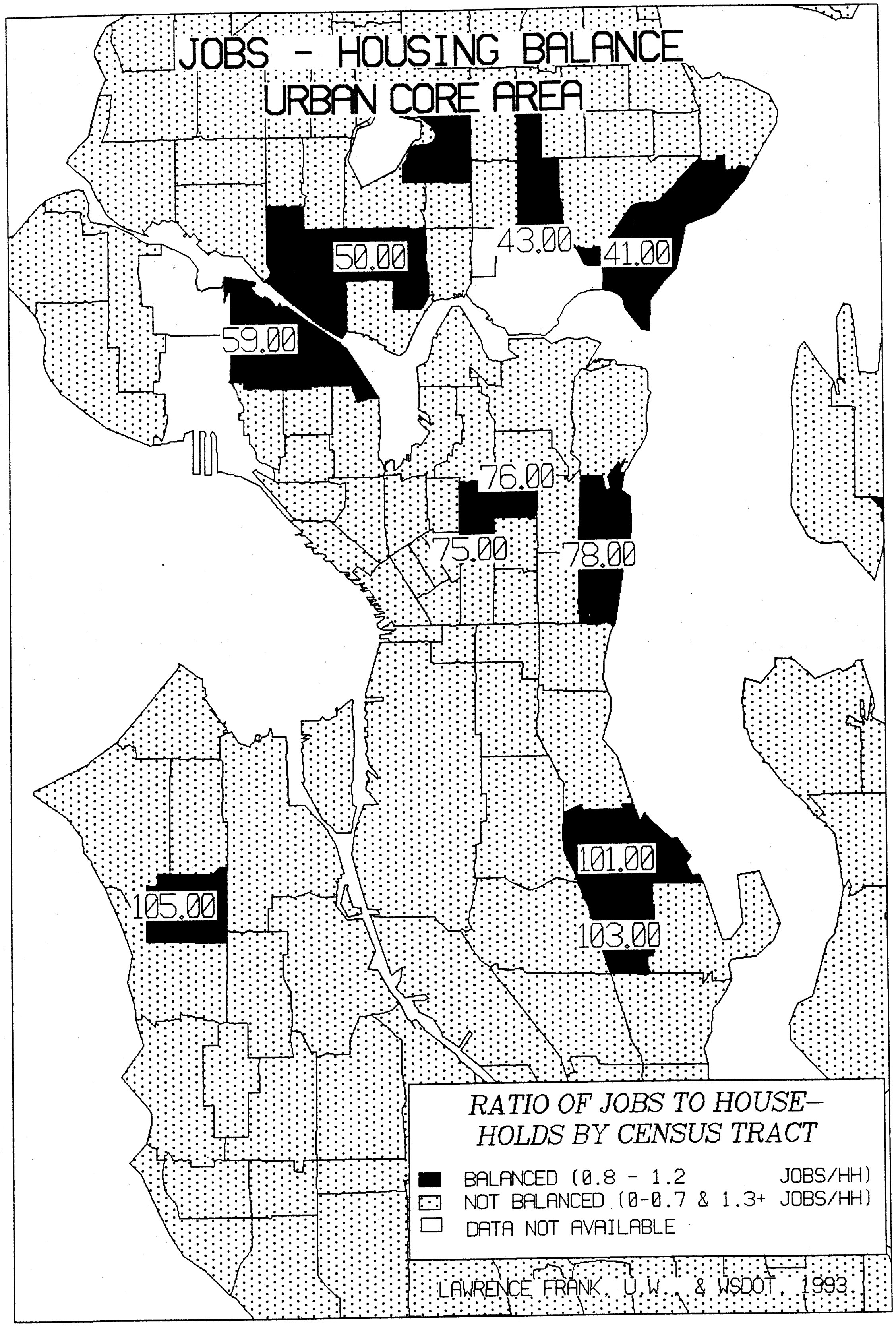
Puget Sound Regional Council

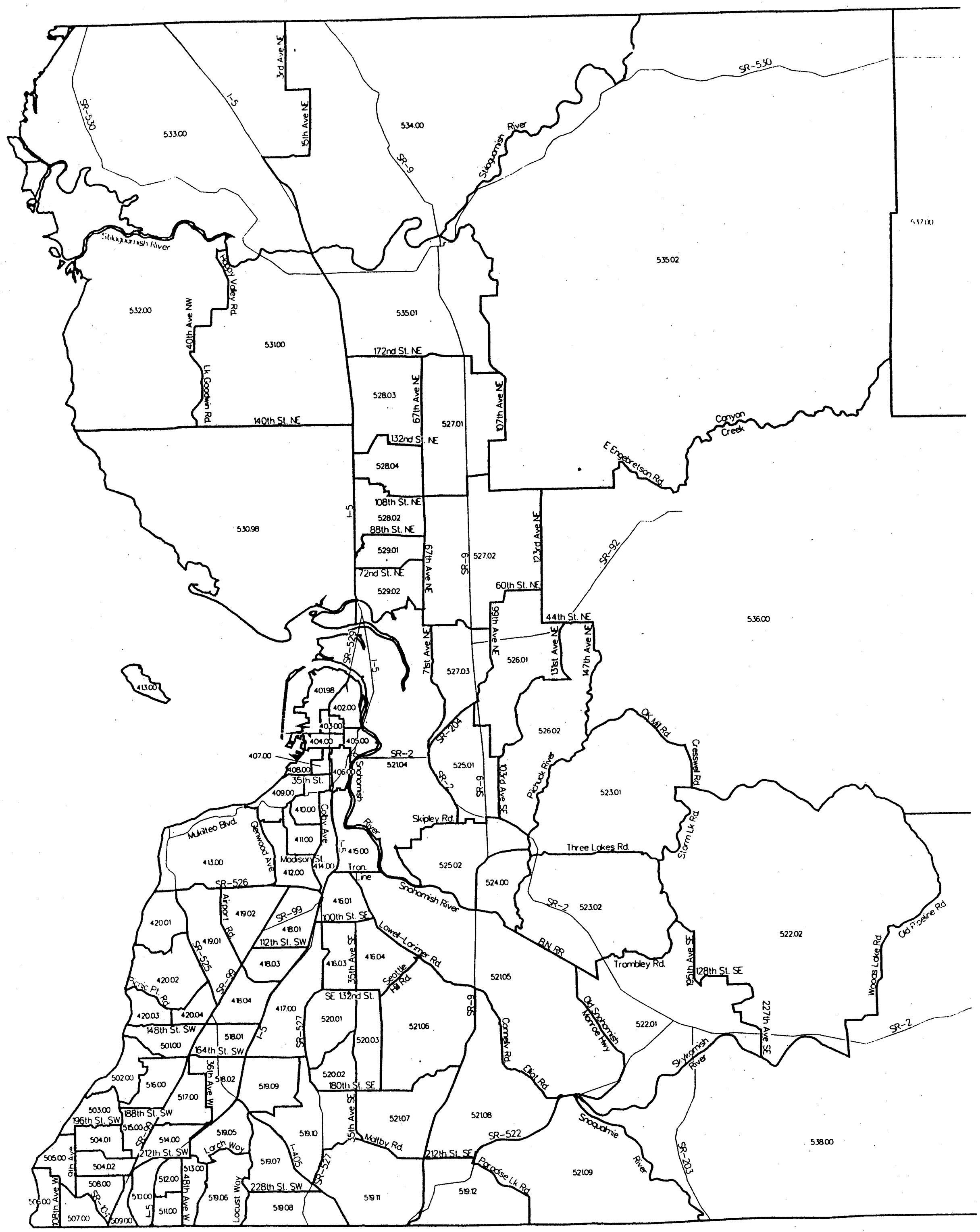
October 1992

miles

0 1 2 3 4 5

N


JOBS - HOUSING BALANCE
URBAN CORE AREA
50.00
43.00
41.00
59.00
76.00
75.00
78.00
101.00
105.00
103.00
RATIO OF JOBS TO HOUSE-HOLDS BY CENSUS TRACT
BALANCED (0.8 - 1.2 JOBS/HH)
NOT BALANCED (0-0.7 & 1.3+ JOBS/HH)
DATA NOT AVAILABLE
LAWRENCE FRANK, U.W., & WSDOT, 1993

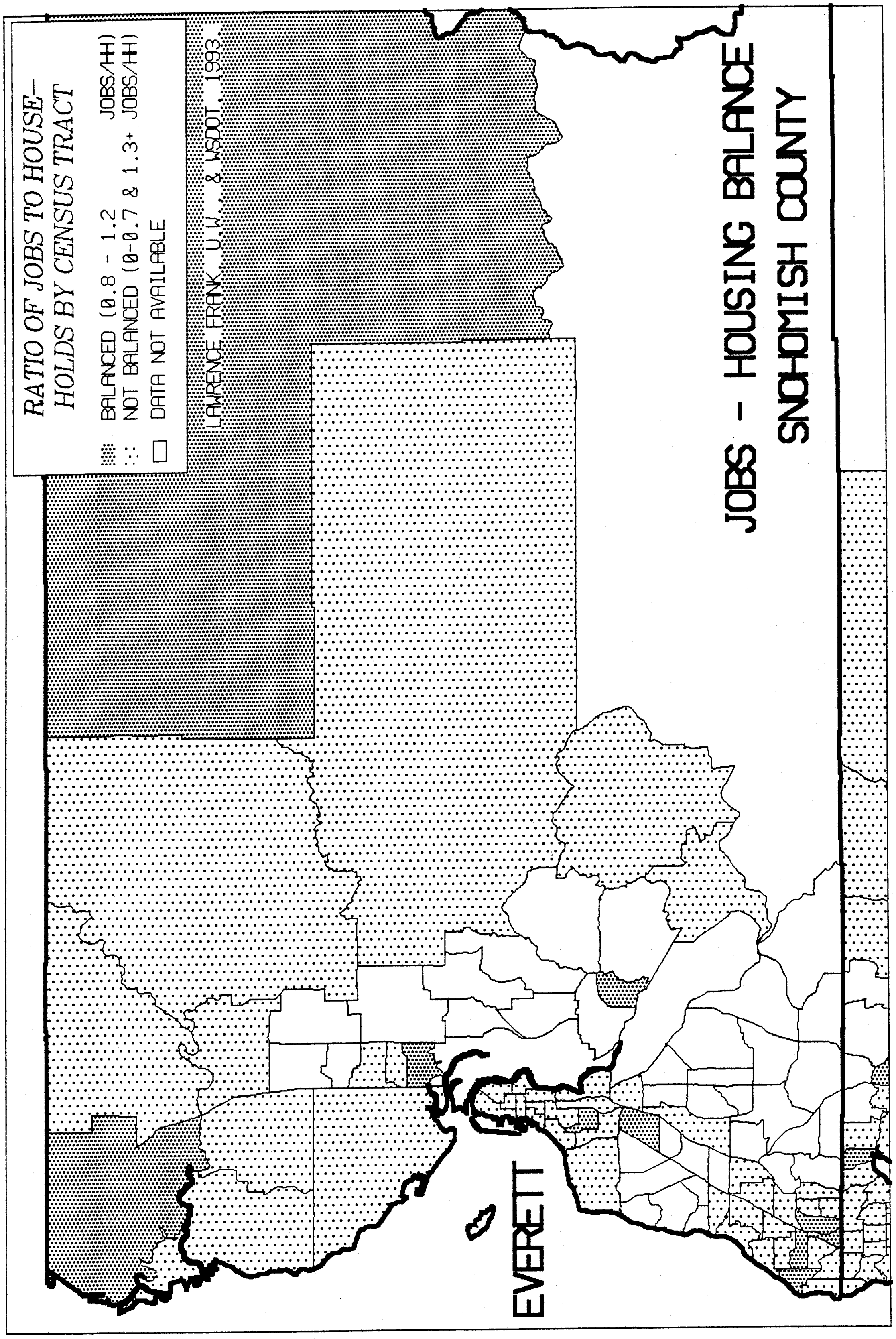


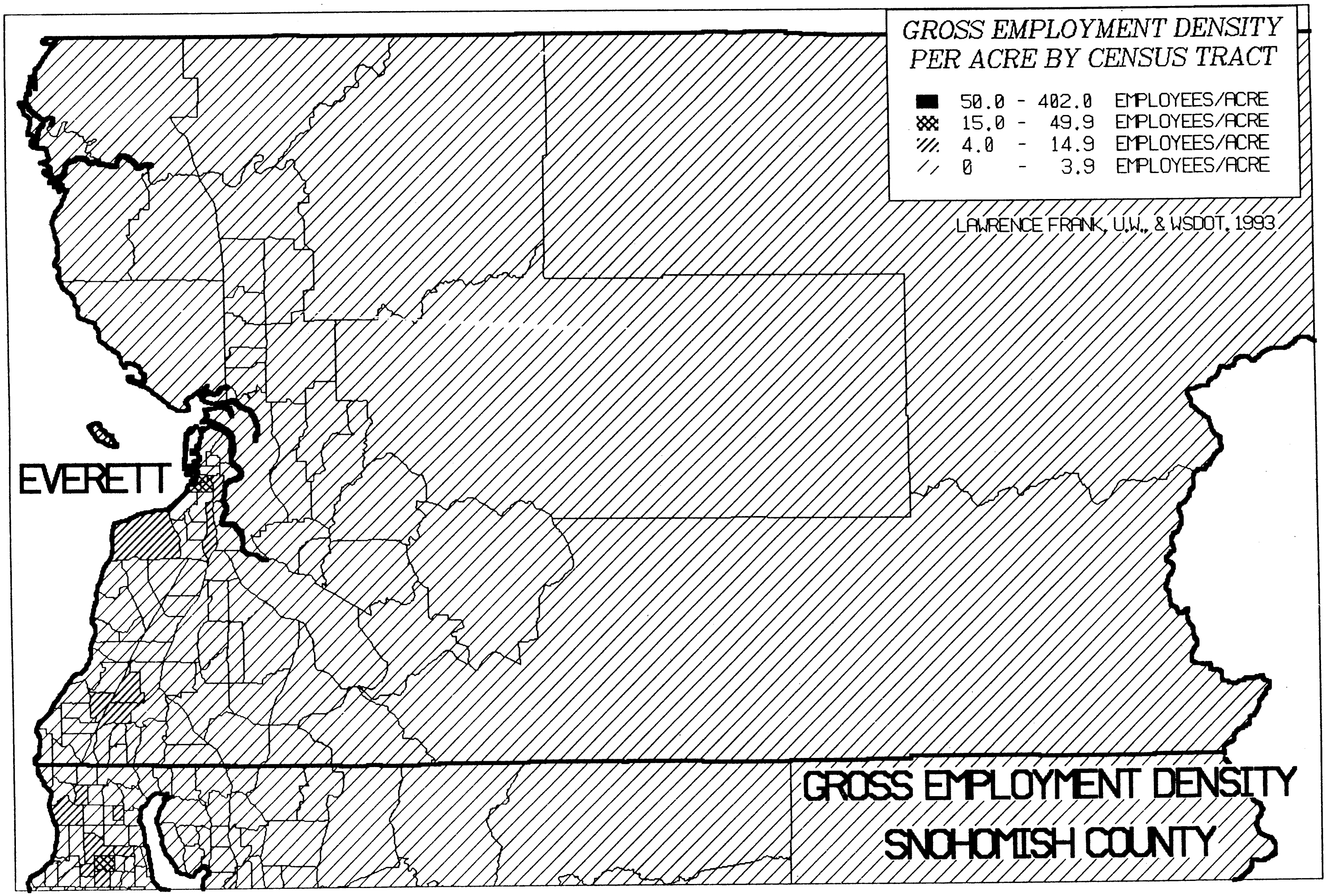
Snohomish County

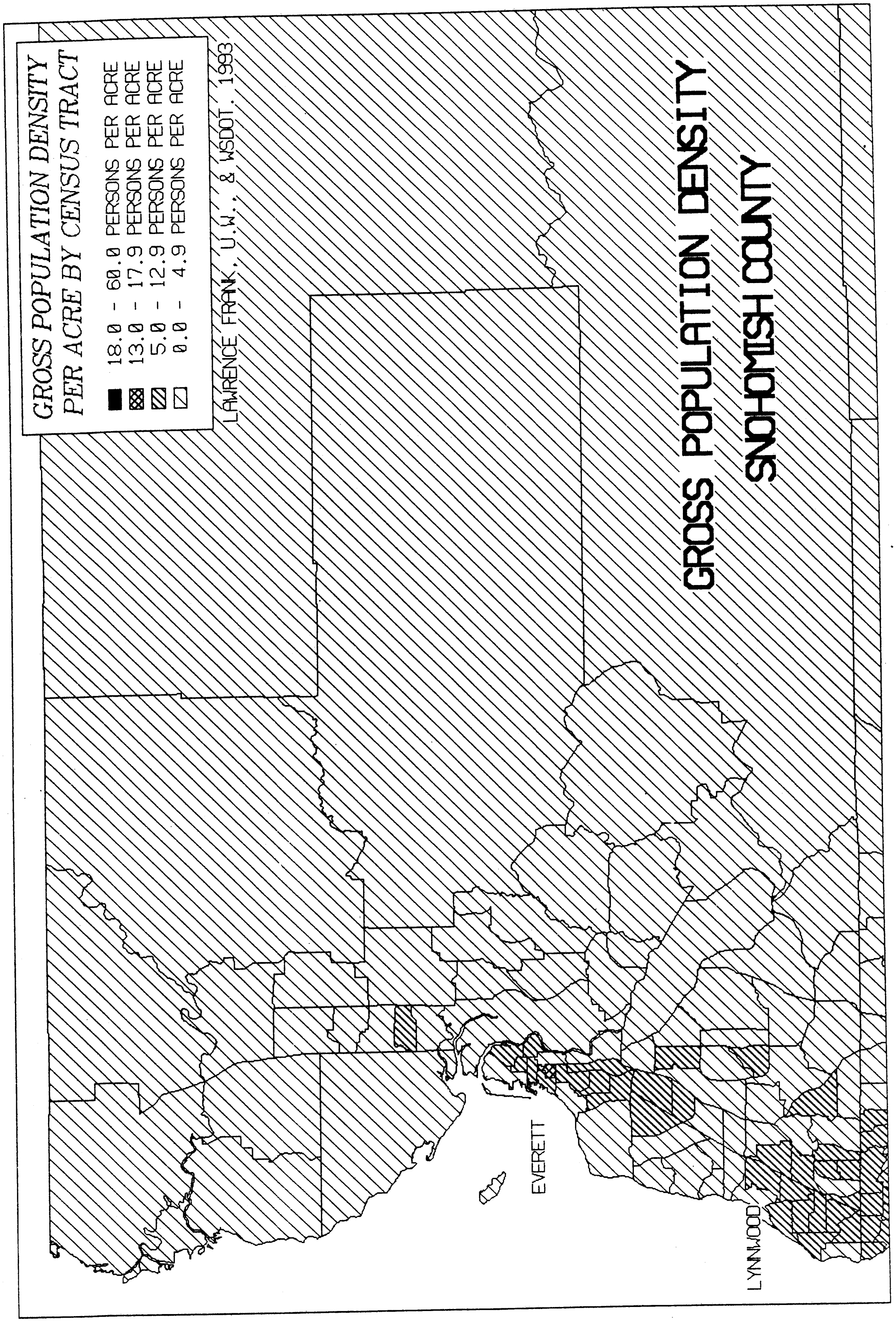
1990 Census Tracts

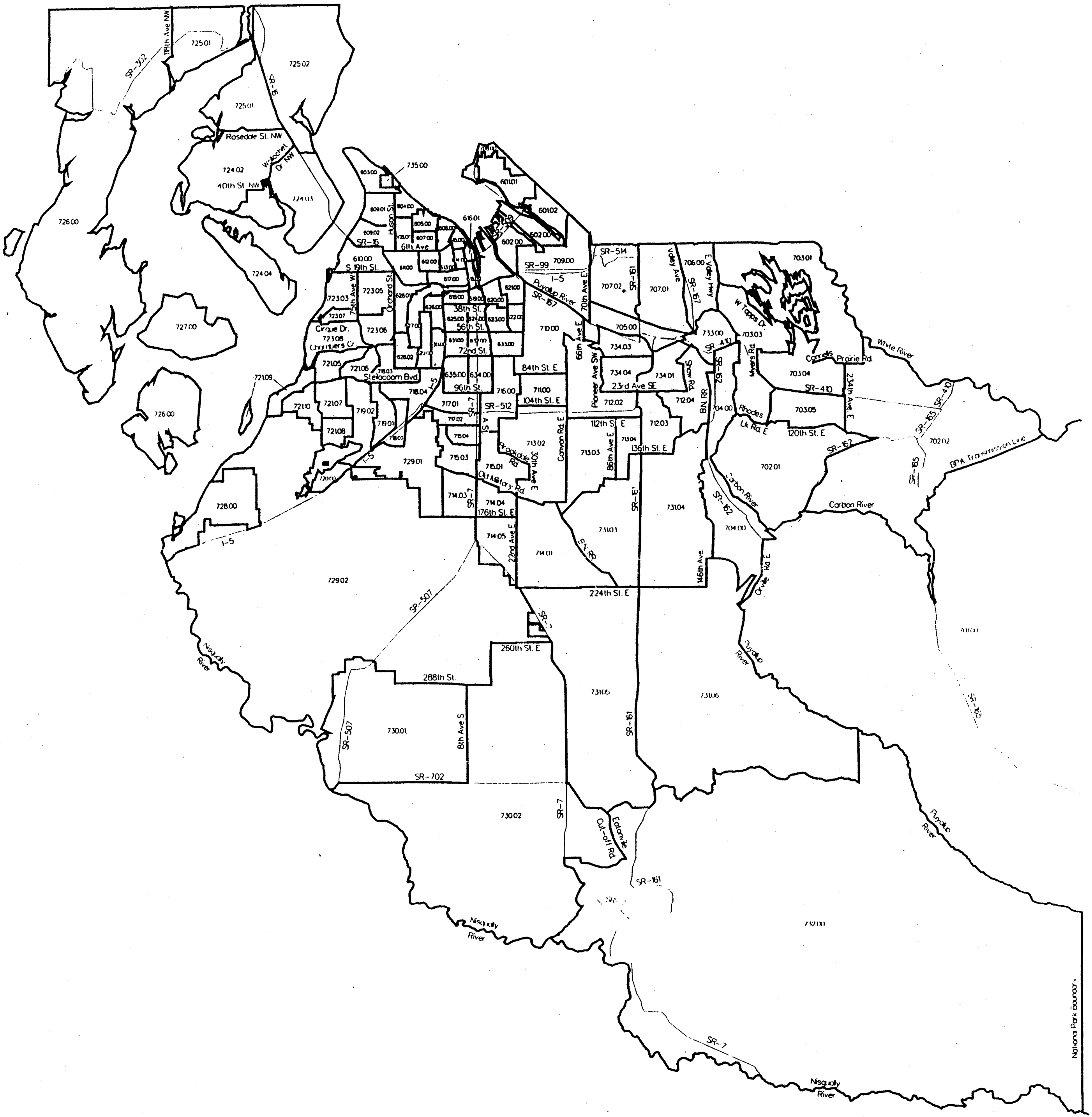
Puget Sound Regional Council
October 1992

miles
0 1 2 3 4 5 N


RATIO OF JOBS TO HOUSE-
HOLDS BY CENSUS TRACT
BALANCED (0.8 - 1.2 JOBS/HH)
NOT BALANCED (0-0.7 & 1.3+ JOBS/HH)
DATA NOT AVAILABLE
LAWRENCE FRANK, U.W., & WSDOT, 1993
JOBS - HOUSING BALANCE
SNOHOMISH COUNTY
EVERETT


GROSS EMPLOYMENT DENSITY
PER ACRE BY CENSUS TRACT
50.0 - 402.0 EMPLOYEES/ACRE
15.0 - 49.9 EMPLOYEES/ACRE
4.0 - 14.9 EMPLOYEES/ACRE
0 - 3.9 EMPLOYEES/ACRE
LAWRENCE FRANK, U.W., & WSDOT, 1993
EVERETT
GROSS EMPLOYMENT DENSITY
SNOHOMISH COUNTY


GROSS POPULATION DENSITY
PER ACRE BY CENSUS TRACT
18.0 - 60.0 PERSONS PER ACRE
13.0 - 17.9 PERSONS PER ACRE
5.0 - 12.9 PERSONS PER ACRE
0.0 - 4.9 PERSONS PER ACRE
LAWRENCE FRANK, U.W., & WSDOT, 1993
GROSS POPULATION DENSITY
SNOHOMISH COUNTY
EVERETT
LYNNWOOD



Census Tract 701 extends to eastern county boundar

Pierce County

1990 Census Tracts

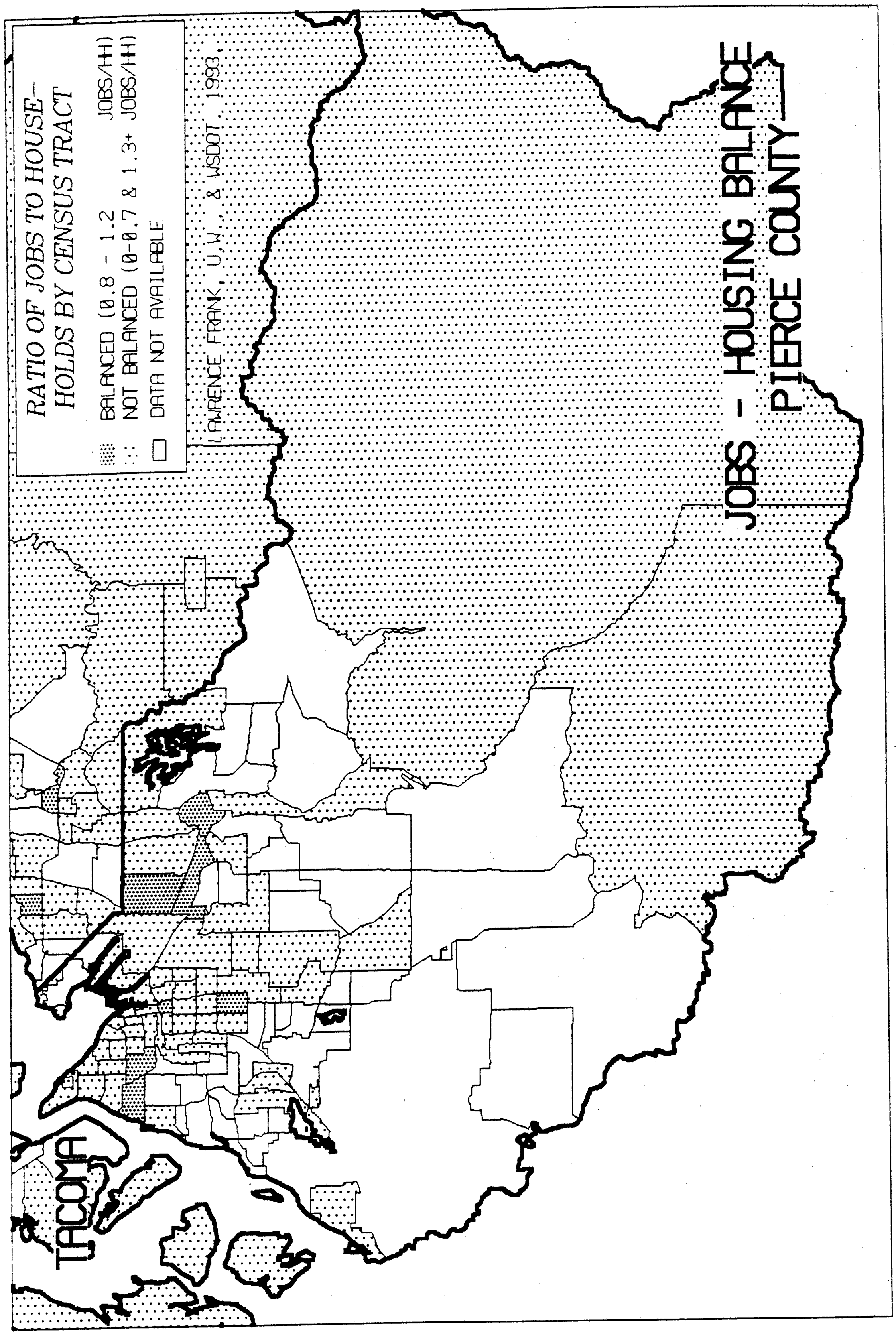
Puget Sound Regional Council

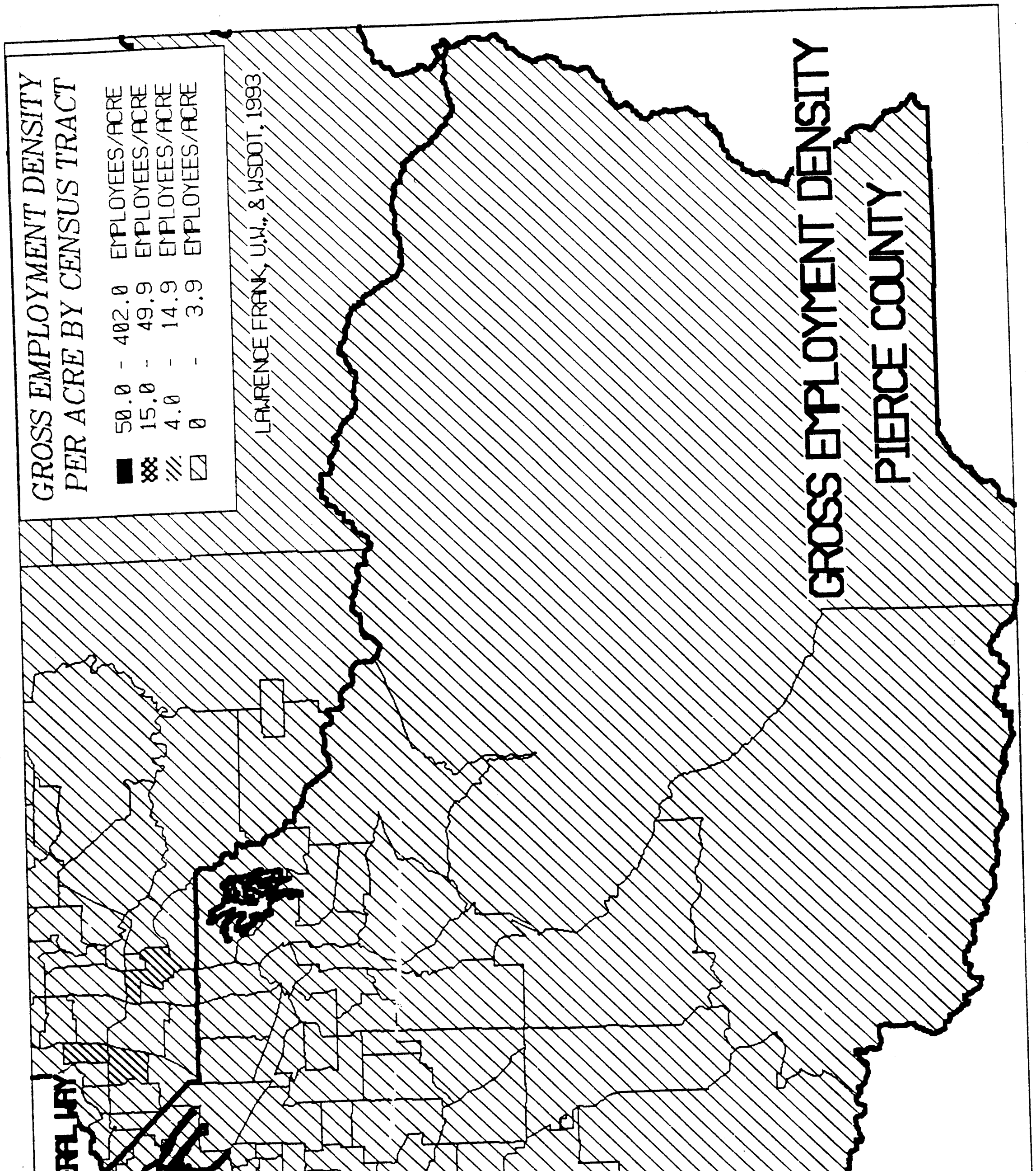
October 1992

miles

0 1 2 3 4 5 6

N


RATIO OF JOBS TO HOUSE-
HOLDS BY CENSUS TRACT
BALANCED (0.8 - 1.2 JOBS/HH)
NOT BALANCED (0-0.7 & 1.3+ JOBS/HH)
DATA NOT AVAILABLE
LAWRENCE FRANK, U.W., & WSDOT, 1993
JOBS - HOUSING BALANCE
PIERCE COUNTY
TACOMA


GROSS EMPLOYMENT DENSITY
PER ACRE BY CENSUS TRACT
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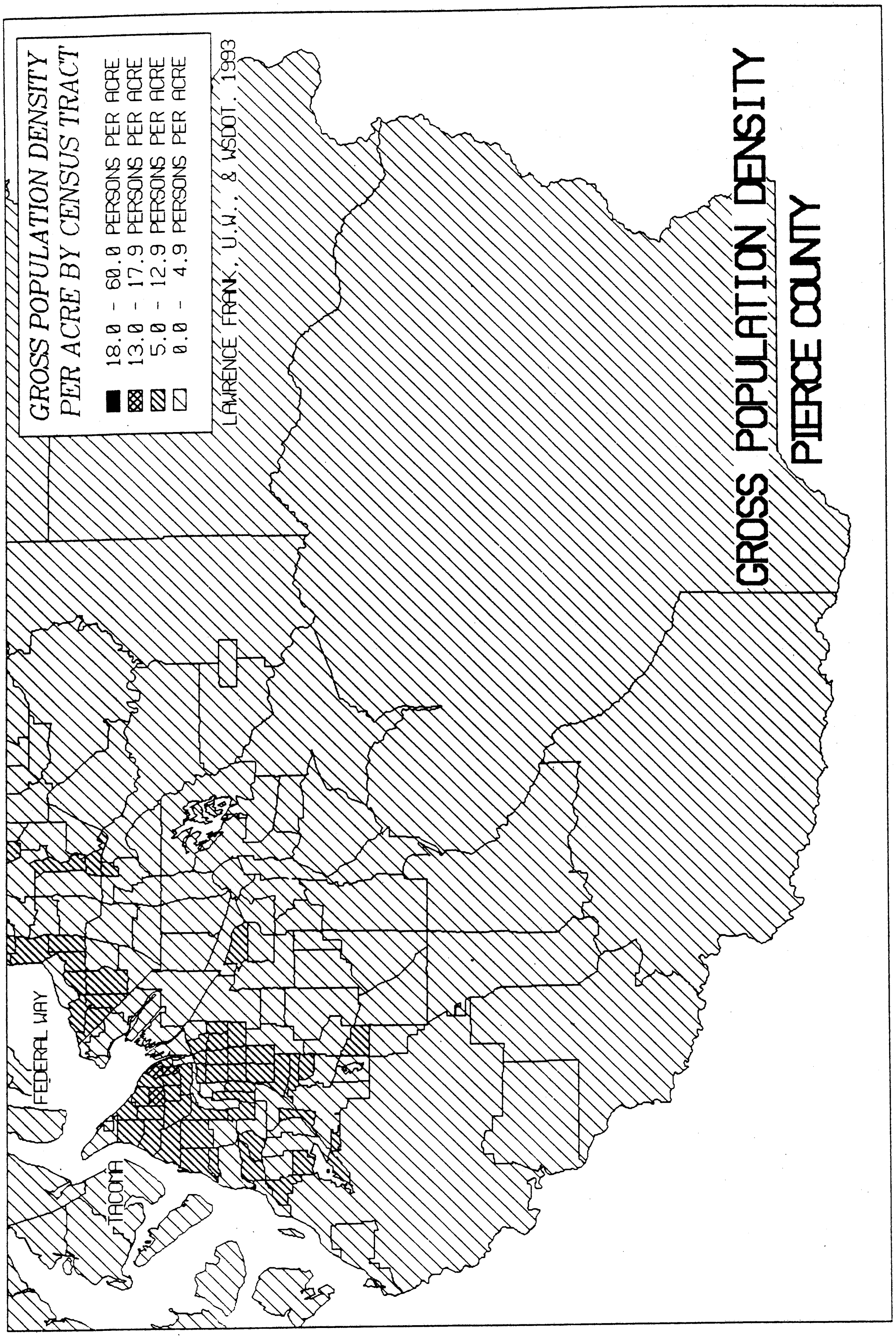
15.0 - 49.9 EMPLOYEES/ACRE
4.0 - 14.9 EMPLOYEES/ACRE
0 - 3.9 EMPLOYEES/ACRE
LAWRENCE FRANK, U.W., & WSDOT, 1993
GROSS EMPLOYMENT DENSITY
PIERCE COUNTY
TACOMA
FEDERAL WAY


GROSS POPULATION DENSITY
PER ACRE BY CENSUS TRACT
18.0 - 60.0 PERSONS PER ACRE
13.0 - 17.9 PERSONS PER ACRE
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0.0 - 4.9 PERSONS PER ACRE
LAWRENCE FRANK, U.W., & WSDOT, 1993
GROSS POPULATION DENSITY
PIERCE COUNTY
FEDERAL WAY
TACOMA