RELATIONSHIPS BETWEEN LAND USE AND TRAVEL BEHAVIOR IN THE PUGET SOUND REGION

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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.

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 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 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 positively correlated with transit usage and walking for both work and shopping trips. Employment density, population density, and land-use mix were negatively correlated with trip distance. 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

Gary Pivo, Ph.D.
Associate Professor of
Urban Design and Planning
University of Washington

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SUMMARY

This report is based on the technical report and Ph.D. dissertation by Lawrence Frank (1994a, 1994b). It examines the relationship between land-use patterns and travel behavior for work and shopping at the census tract scale in the Central Puget Sound region of Washington State. It's part of a larger research agenda on land-use and travel behavior being pursued at the University of Washington with support from the Washington State Department of Transportation (Pivo and Moudon 1992).

Our overall finding is that certain land-use patterns, including greater employment density, population density, land-use mix and job-housing balance, are associated with less auto use. This occurs even when other factors that affect travel behavior are controlled, such as household demographics, car ownership, and transit level of service. Our findings reinforce previous results in the scientific literature but are derived from data on the Central Puget Sound, giving them more validity for Washington State than previous studies.

One way that land-use can lessen auto use is by reducing the proportion of trips that are made by single occupant vehicles (SOVs). This effect occurs after density thresholds of 50-75 employees per gross acre or 9-13 persons per gross acre (about 9 to 12 dwelling units per net acre) are crossed. These thresholds are 6.5 to 10 times the average employment density and 2 to 3 times the average population density presently found in Central Puget Sound census tracts.[1] To reach these thresholds, it would be necessary to develop urban and suburban centers similar to those proposed by the City of Seattle in *Toward A Sustainable Seattle* and already adopted by the Puget Sound

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[1] Most census tracts in the region are not average. Suburban tracts tend to have densities that are lower than the regional average and urban tracts tend to have densities that are higher. Therefore, it will require greater change in the suburbs and less change in the central cities to cross the thresholds required to lessen the proportion of trips made by SOVs.

Regional Council in *Vision 2020* and the King County Council in its *Countywide Planning Policies.*

Downtown Bellevue and Pioneer Square in Seattle are examples of tracts with employment densities of 50 employees per gross acre. They have similar gross densities but very different built forms. Downtown Bellevue combines high-rise office towers fronting on plazas with one and two story retail and surface parking. Pioneer Square is predominantly four and five story buildings covering all of their parcel and containing offices over retail.

Examples of census tracts with population densities of 11 persons per gross acre are Seattle's Northgate area, Benson Center in Kent, and northern Everett along Broadway. These areas vary in character and include housing types ranging from detached single family homes on 3,600 to 9,000 square foot lots to multi-family housing in garden apartments and low-rise apartment blocks.

It is not necessary for centers to contain both jobs and housing to reduce auto use. Combinations of dense housing, shopping, and dense employment are associated with the greatest reduction in auto use; however, reduced auto use can also be expected in relatively pure but dense employment areas, in areas that combine dense population with less dense employment or shopping, and in areas that combine dense employment with less dense housing or shopping.

Another way that land-use can reduce SOV use is by shortening trip distances. Shorter distances are found in tracts with greater land-use mixing, job-housing balance, population density, and employment density. A mix/balance approach could reduce trip distances without increasing densities, and could reduce miles traveled comparable to that generated by a density/centers approach. Examples of balanced census tracts include Seattle's Fremont area, Renton's Talbot Hill area southeast of the I-405 and Valley Freeway intersection, and parts of the City of Kirkland. Highly mixed tracts include Federal Way's Steel Lake area, parts of Bellevue, and Seattle's Northgate and its environs.

CONCLUSIONS AND RECOMMENDATIONS

Greater density, land-use mixing, and jobs/housing balance are associated with less auto use for work and shopping trips. In particular:

- greater density is associated with reduced trip distance and a lower proportion of trips made by single occupant vehicles (SOVs);

- greater land-use mixing is associated with reduced trip distance and travel time; and

- greater jobs/housing balance is associated with reduced trip distance and travel time.

This study confirms the finding of previous researchers that the relationship between density and mode split is nonlinear. At the lower end of the density spectrum, a given change in density is associated with less change in SOV use than the same density change at the higher end of the spectrum. Significant movement from SOVs to other modes does not occur until certain density thresholds are reached. For work trips, the thresholds are 50 to 75 employees per gross acre or 9 to 13 residents per gross acre (about 12 dwellings per net acre). For shopping trips, they are 75 employees per gross acre and 18 residents per gross acre (about 20 dwellings per net acre).[2]

Several factors other than land-use affect individual travel behavior. They include age, possession of a driver's license, access to a car, working at home, transit level of service, and household type. Controlling for these other factors does not significantly diminish the effect of land-use.

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[2] The formula used to convert gross population density to net residential density was (gross population density / 2.56) / 0.35. 2.56 was used as the average household size and 0.35 was used as the net area available for housing within centers after 25 percent of the area is used for public purposes, 20 percent for critical areas and open space, and 20 percent for employment.

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INTRODUCTION

This project examined the relationship between land-use patterns and travel behavior for work and shopping in the Central Puget Sound region of Washington State. The region contains King, Pierce, and Snohomish counties, the largest cities in the state, and just over half the population.

In this report, we use the term "land-use pattern" to mean various measures of the density and mix of residential and commercial activities. It is measured at the census tract scale, using variables such as employment density or mix of residential, commercial and industrial uses. We use the term "travel behavior" to refer to the mode, distance, and temporal length of trips taken to and from individual census tracts.

Auto use can be lessened by reducing the number and proportion of trips made by single occupant vehicles (SOVs), shortening trips, and reducing travel time. Several land-use characteristics at various scales are thought to affect these elements of travel, but the ones examined in this project include elements measured at the census tract scale including population density, employment density, land-use mix, and jobs/housing balance. Other land-use characteristics thought to affect travel that are measured at other scales, such as the arrangement of development on building sites, the regional pattern of suburban shopping centers, and parking supply were not tested in this study because of time and data limitations.

REVIEW OF PREVIOUS WORK

Various lines of previous work were examined for this project, including research on land and energy use, land-use and air quality, and land-use and transportation. They all generally point to the conclusion that greater land-use density, mix, and jobs/housing balance reduce auto use.

Studies on how land-use affects energy use focus on how density, nucleation (i.e., the amount of a region's development inside urban centers and downtowns), and urban containment (i.e., the absence of low density development on the urban fringe) reduce energy consumption. Since autos are a major energy user, the findings also suggest these patterns reduce auto use.

In a comparative analysis of 32 urban areas around the world, Newman and Kenworthy (1989) found that gas consumption per capita decreased dramatically as density increased. For example, annual fuel consumption was nearly 600 gallons in Houston, with a density of less than 10 persons per acre, compared to 25 gallons in Hong Kong with a density of 120 persons per acre. They also concluded that gas 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 variations.

Other studies have also found that energy can be saved through densification (Owens 1978, Rickaby 1987). In a comparative analysis of six settlement patterns, Rickaby (1987) observed that concentrating growth in existing urban areas had the greatest impact on reducing fuel consumption. He also showed that concentrating growth in dispersed-nucleated villages reduces fuel consumption, and the closer the nucleated villages were to an urban center, the greater were the fuel savings.

In the 1970s, considerable research was done on the impacts of land-use on air pollution. It found that the most important land-use determinants of air pollution are city

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size and the scale of manufacturing concentrations. Further comparative research found that lower pollution levels are associated more with densely concentrated urban areas. Brian Berry (1974) concluded that, "the core oriented city, with a 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."

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, and presumably more dispersed, metropolitan areas commute farther than residents of smaller communities (Bellomo et al. 1970). A more direct study of dispersion supported these results, finding that as residences move away from the central business district (CBD), their average trip lengths increase (Zahavi 1976).

The impact of dispersed development on auto use is currently under dispute. Some researchers have suggested that dispersion of employment throughout an urban area reduces auto use because it is associated with reduced travel times (Gordon and Richardson 1991). Others feel, however, that the decreased travel time is caused by faster speeds from more car use and less congestion and that dispersed employment causes greater auto use because it causes a decline in transit's market share and greater separation between trip origins and destinations (Pisarski 1987, Levine 1991, Daniels 1980).

Jobs/housing balance refers to the distribution of employment in relation to the distribution of households in an urban area (Guiliano 1991). Some empirical work suggests that policies designed to increase jobs/housing balance may be ineffective (White 1989). On the other hand, research in Toronto concluded that rising residential population in the city center offset the increased commuting to the center that was anticipated because of increased office development. The 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 three hour morning rush period" (Nowlan and Stewart 1991).

Empirical research on how mixed use affects travel behavior is rare. One effort found that motorized travel could be reduced by introducing services, such as banks and restaurants, 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).

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 San Francisco Bay Area discovered that land-use mix was partially responsible for a reduction in vehicle miles traveled (Handy 1991, Holtzclaw 1990).

Researchers have found population and employment density to be the aspects of land-use that are most highly correlated with travel behavior (Pushkarev and Zupan 1982, Cervero 1987, Spillar 1989, Johnston 1994). Pushkarev and Zupan (1982) found that as density increased, both per capita and total transit ridership increased. Additional work to test their findings has led to debates over the levels of density needed to support various forms of transit (Pickrell 1985, Spillar 1989). The primary criticism is that Pushkarev and Zupan's density thresholds were too low. This may have been due to the fact that the New York metropolitan area was a case in their analysis. New York City has densities that are extraordinarily high at the employment trip end and that could skew the mode choice of commuters living in lower density parts of the region.

Declining densities have been associated with decreased transit use because dispersed origins and destinations cannot be effectively served with conventional transit service (Kain 1988). This relationship is based on the theory that 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 itself is a causal factor of travel behavior or a proxy for other characteristics that are present at different levels of development intensity. This is because non-SOV travel has been found to be much lower in outlying areas with densities equal to central areas. For example, suburban Klahanie Ridge (located east of Seattle) has an average of 6.8 dwelling units per acre (Moudon and Weisman 1990), which is comparable to that of the urban 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, the causal factor affecting mode split may be transit level of service rather than density. Thus, density itself may not be the primary factor affecting travel behavior. Density may simply be associated with other factors, like level of transit service, which are the real causes of travel behavior.

To summarize, previous studies have found relationships to exist between various aspects of land-use and travel behavior. Their general results are that:

1. less density and more dispersion decrease trip times while simultaneously increasing air pollution, gasoline consumption, trip lengths and the proportion of trips made by private vehicles;

2. greater jobs/housing balance reduces vehicle miles traveled; and

3. greater land-use mixing reduces trip generation and vehicle miles traveled.

4. Dispersion can be associated with reduced travel time and increased travel speeds.

PROCEDURES

CONCEPTUAL FRAMEWORK AND EXPERIMENTAL DESIGN

Figure 1 shows the relationship between travel behavior and the factors that affect it. Urban form factors, such as density, and non-urban-form factors, such as household income can affect travel behavior. In this study, we treated land-use factors as the independent variables, travel behavior factors as the dependent variables, and non-land-use factors, as the control variables. Our goal was to isolate the effects of land-use on travel behavior while controlling for the effects of those non-land-use factors that also affect travel.

We used a correlational research design to test for relationships (Babbie 1989). Our analysis was cross-sectional (i.e., looked at one point in time) and therefore did not examine whether changes in travel behavior actually followed changes in land-use. While this design can show associations between land-use and travel, it cannot prove that changes in land-use actually caused changes in travel behavior.
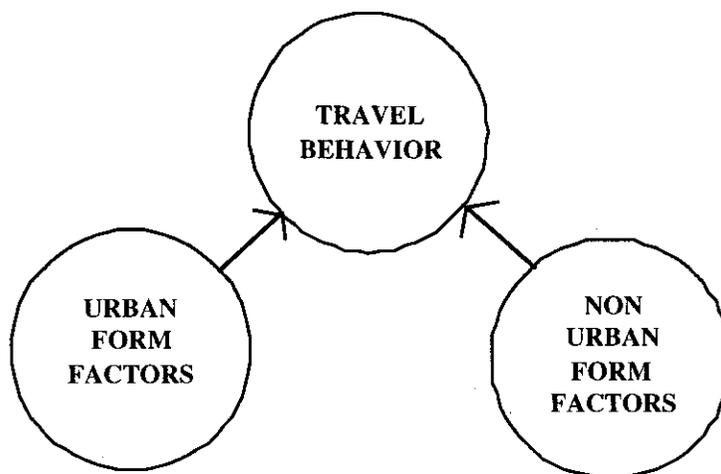
Figure 1. Conceptual Model

UNITS OF ANALYSIS

Travel behavior was examined using two different units of analysis. The individual trip was used to measure trip length and travel time, and the census tract was used to measure modal split.

Land-use factors were measured at the census tract scale. We examined travel behavior in relation to the land-use pattern of tracts where trips began and ended. Our use of the census tract as the land-use unit of analysis was convenient because land-use data were available to us at this scale from secondary sources. However, it is an imprecise measure of the actual land-use where trips began and ended because census tracts can include large areas (see Appendix A). For the purposes of this study, a trip may have been coded as beginning in a high density tract, when in fact it began in the low density portion of a high density tract. As a consequence, the correlations reported here are probably lower than they would have been if smaller geographic areas were used to measure land-use (such as traffic analysis zones).

VARIABLES

Table 1 lists the variables used in this report. Several different sources were combined to build the data base.

Our largest data source was the Puget Sound Transportation Panel (PSTP) survey, conducted by the Puget Sound Regional Council (PSRC). It provided data on the purpose, mode, distance, and travel time for about 30,000 trips taken by 1,500 households in King, Pierce, and Snohomish Counties over a two-day period in 1989, although most of the trips were taken within King County. The survey also provided data on the individuals making each trip (e.g., whether they had a driver's license), their households (e.g., income), and the transit level of service at trip ends.

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Table 1. Variables in the Study

DEPENDENT VARIABLES

Trip Level

TRIPDIST   Trip distance in miles.
TRIPTIME   Trip time in minutes.

Tract Level

PCTSOVO   Percentage of trips beginning in the tract made by SOV.
PCTSOVD   Percentage of trips ending in the tract made by SOV.
PCTPOOLO   Percentage of trips beginning in the tract made by carpool.
PCTPOOLD   Percentage of trips ending in the tract made by carpool.
PCTWALKO   Percentage of trips beginning in the tract made by walking.
PCTWALKD   Percentage of trips ending in the tract made by walking.
PCTBUSO   Percentage of trips beginning in the tract made by bus.
PCTBUSD   Percentage of trips ending in the tract made by bus.

INDEPENDENT VARIABLES

POPDENO   Average gross population density per acre in the census tract where the trip began.
POPDEND   Average gross population density per acre in the census tract where the trip ended.
POPDENA   Average of the average gross population densities in the census tracts where the trip began and ended.
EMPDENO   Average gross employment density per acre in the census tract where the trip began.
EMPDEND   Average gross employment density per acre in the census tract where the trip ended.
EMPDENA   Average of the average gross employment densities in the census tracts where the trip began and ended.
MIXENTO   Measure of land-use mixing in the census tract where the trip began.
MIXENTD   Measure of land-use mixing in the census tract where the trip ended.
MIXENTA   Average of the land-use mixing in the census tracts where the trip began and ended.
JHRATIOO   Jobs/housing ratio in the census tract where the trip began.
JHRATIOD   Jobs/housing ratio in the census tract where the trip ended.

Table 1. Variables in the Study (Continued)

CONTROL VARIABLES

Tripmaker Characteristics

NUMVEH	Number of vehicles in tripmaker's household.
VEHAVAIL	Number of vehicles per driver in tripmaker's household.
HHSIZE	Number persons in tripmaker's household.
INCOME	Income of tripmaker's household.
AGE	Age of tripmaker.
SEX	Gender of tripmaker.
EMPLOY	Whether tripmaker is employed inside or outside the home.
OCC	Tripmaker's occupation.
WKFREQ	Number of days per week tripmaker works.
CARREQD	Whether a car is required at work.
HHTYPE	Type of household of tripmaker.
STUDENT	Whether or not the tripmaker is a student.
LICENSE	Whether or not the tripmaker has a driver's license.
BUSPASS	Whether or not the tripmaker has a bus pass.

Transit and Roadway Level of Service

BUSDISTO	Distance to nearest bus stop from trip origin.
TRAFCONG	Level of traffic congestion during trip.

The PTSP survey intentionally over-sampled transit and carpool households. We employed a weighting system developed by Pendyala, Goulias, and Kitamura (1989) to produce a sample more representative of all households in the region. Trips were analyzed without reference to whether they were part of a trip chain because each trip in the database was coded independently.

U. S. Census Bureau data from the 1990 Census of Population and Housing were used to provide the number of persons and households living in each census tract. These data were divided by tract area measures provided by PSRC to compute gross tract population densities. They were also used together with employment data to compute the jobs/housing ratio for each tract.

The Washington State Employment Security Department (ESD) ES-202 files provided data on the numbers of jobs within each census tract in the study area. These

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files only included employees covered by the Washington Employment Security Act, which is about 85 percent of all employees. An inflation factor was used to produce an estimated figure for total employment in each tract. The adjusted figures were used to compute the employment density and jobs/housing ratio for each census tract.

The King County Building and Land Development (BALD) file was provided by the King County Assessor's Office. This is an enormous database containing information on approximately 500,000 parcels in King County. The BALD file was used to develop a measure of land-use mix for each census tract.[3] Similar data were not available for Pierce and Snohomish counties, therefore, our analyses of land-use mix are solely based on King County data.

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[3] Land use mixing was measured using an entropy index with a scale ranging from 0 to 0.845 with 0.845 representing the highest level of mixing. The index is based on the following equation: level of land use mix (entropy value) = {[single family x $\log_{10}$(single family)] + [multifamily x $\log_{10}$ (multifamily)] + [retail and services x $\log_{10}$ (retail and services)] + [office x $\log_{10}$ (offices)] + [entertainment x $\log_{10}$ (entertainment)] + [institutional x $\log_{10}$ (institutional)] + [industrial/manufacturing x $\log_{10}$ (industrial/ manufacturing]}.

DISCUSSION

A DESCRIPTION OF LAND-USE AND TRAVEL IN THE REGION

- *Most shopping and work trips begin and end in relatively low density areas without land-use mixing and a jobs/housing balance.*

The land-use characteristics at trips ends and travel characteristics of trips in the Central Puget Sound region are summarized in Tables 2 and 3. The land-use results describe the land-use characteristics at the origin and destination of individual work and shopping trips. The travel results are based on trip and census tract units of analysis.

The median work trip was about 6 miles long and took about 18 minutes. In the median census tract, approximately 81 percent of the trips began in an SOV and about 89 percent ended in an SOV. The median work trip began and ended in a tract with 4 to 5 persons per gross acre, began in a tract with 2 employees per acre, and ended in a tract with 7 employees per acre. The typical trip also began and ended in a tract without a jobs/housing balance.

The typical shopping trip was about 2.7 miles and ten minutes long. Typical shopping trips began and ended in tracts with about 5 persons and 2 to 3 employees per acre. Fifty-seven percent of the shopping trips beginning or ending in the median census tract were made by SOV and 33 percent were made by carpool.

The maps in Appendix A show the location of census tracts with different levels of population density, employment density, mix and balance. Overall, employment and population densities decrease with increasing distance from central city cores. This is not true for mix and balance which do not appear to follow a particular geographic pattern. [4]

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[4] The mean mix score is on a relative scale of 0 to 0.845. This makes it impossible to interpret the descriptive statistics in absolute terms.

Table 2. Land-use Characteristics at Trip Ends in the Puget Sound Region, 1989

ELEMENT	MEAN[5]	MEDIAN[6]	STD. DEV.[7]	MIN.[8]	MAX.[9]	N[10]
POPDENO						
work trips	5.46	4.93	4.72	0.006	58.26	4258
shop trips	5.87	5.37	5.07	0.006	58.26	3186
POPDEND						
work trips	5.74	4.39	6.30	0.006	58.26	4209
shop trips	5.70	5.36	4.66	0.006	58.26	3207
POPDENA						
work trips	5.56	4.76	4.48	0.006	58.26	4085
shop trips	5.74	5.14	4.24	0.006	58.26	3145
EMPDENO						
work trips	14.02	1.77	58.88	0.002	401.43	3100
shop trips	11.70	2.25	44.37	0.002	401.43	2450
EMPDEND						
work trips	37.46	6.59	92.61	0.002	401.43	3374
shop trips	12.30	2.84	48.38	0.002	401.43	2471
EMPDENA						
shop trips	12.60	2.50	41.90	0.002	401.43	2055
MIXENTO						
work trips	0.46	0.46	0.18	0.002	0.79	2108
shop trips	0.50	0.52	0.17	0.002	0.79	1502
MIXENTD						
work trips	0.53	0.53	0.15	0.006	0.79	2491
shop trips	0.55	0.57	0.14	0.006	0.79	1476
MIXENTA						
work trips	0.49	0.50	0.12	0.048	0.79	1924
shop trips	0.52	0.54	0.12	0.076	0.79	1375
JHRATIO						
work trips	2.00		0.28	0.000	1.00	3408

[5] The mean is also called the average. It is the sum of the values of all observations divided by the number of observations and provides a measure of central tendency in the data.

[6] The median is the value above and below which one-half of the observations fall. It is a good measure of central tendency when there are extreme values that could skew the mean.

[7] The standard deviation (STD.DEV.) measures the dispersion in the data. The larger the number, the greater the variation among the cases.

[8] The minimum (MIN.) is the smallest value in the distribution and is used together with the maximum (MAX.) to indicate the range of values in the data. This provides another measure of the degree of dispersion in the data.

[9] See footnote 8.

[10] N is the number of cases available for analysis. For example, we had 4,258 cases of work trips with data for POPDENO in the data base.

Table 3. Travel Characteristics for Trips, Persons, and Census Tracts in the Puget Sound Region, 1989

VARIABLE	MEAN	MEDIAN	STD. DEV.	MIN.	MAX.	*N*
Trip Level						
TRIPDIST						
work trips	8.92	5.90	8.92	0.3	68.17	4739
shop trips	4.47	2.70	4.93	0.3	40.90	3669
TRAVTIME						
work trips	21.49	18.00	15.58	1.0	120.00	4711
shop trips	14.34	10.00	11.24	1.0	105.00	3689
Tract Level						
PCTSOVO						
work trips	74.76	80.86	26.66	0.0	100.00	509
shop trips	58.61	57.63	30.39	0.0	100.00	497
PCTSOVD						
work trips	80.10	89.08	25.95	0.0	100.00	446
shop trips	58.94	57.76	33.07	0.0	100.00	393
PCTPOOLO						
work trips	14.33	4.48	21.51	0.0	100.00	509
shop trips	34.98	33.33	29.85	0.0	100.00	497
PCTPOOLD						
work trips	13.06	0.00	21.93	0.0	100.00	446
shop trips	33.63	31.82	31.72	0.0	100.00	393
PCTWALKO						
work trips	3.69	0.00	12.52	0.0	100.00	509
shop trips	3.16	0.00	10.03	0.0	100.00	407
PCTWALKD						
work trips	3.37	0.00	12.44	0.0	16.67	446
shop trips	4.17	0.00	14.53	0.0	100.00	393
PCTBUSO						
work trips	5.16	0.00	13.34	0.0	100.00	509
shop trips	1.23	0.00	6.35	0.0	100.00	497
PCTBUSD						
work trips	1.68	0.00	5.48	0.0	51.81	446
shop trips	1.45	0.00	8.45	0.0	100.00	393

BUS USE TO WORK

- *Greater employment density, population density, and land-use mix are associated with more work trips by bus.*

The strongest relationship found in the entire study was between the percentage of workers who take the bus to work and the average employment density at the origin and destination of work trips (r=.59, n=274).[11] More workers take the bus to work when they begin *and* end their trips in areas with high employment density.

Previous research has focused on density at the work trip destination. However, our work indicates that the average of the density at both trip ends is a stronger predictor of mode split. This suggests that living, shopping *as well as* working in denser environments is better than only working in dense environments when it comes to reducing SOV use.

Greater bus use was also associated with more land-use mixing at work trip destinations and with greater population density at both trip ends, however the relationships were weaker than for employment density (r=.15, n=223 and r=.19, n=382, respectively).

A non-land-use factor related to bus use was the proportion of workers who share a vehicle with others in their household (r=.14, n=446). More workers took the bus when they did not always have a car at their disposal. This reinforces the idea that many bus patrons are "transit-dependents" who take the bus because they have no other choice.

A linear regression model using average employment density at trip origins and destinations explained 42 percent of the variation in PCTBUS (see Table 4). The model predicts that a tenfold increase in the employment density of a census tract with average employment density (i.e., from 10 to 100 employees per acre) would increase bus use for

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[11] The r value is the Pearson correlation coefficient and indicates the degree of association between two variables. Perfect association is represented by the value 1, and absence of association is represented by the value 0. The n value is the number of cases used to compute the r value.

work trips from 2 percent to 11 percent. This kind of increase would be associated with the creation of a major employment center. As we will discuss under **Thresholds,** below, while a linear model would predict that small density increases in typical tracts would result in some increased bus use, this would probably not occur until certain minimum density thresholds are crossed. This caveat also applies to all of the regression models presented in this report.

BUS USE TO SHOP

- *Greater employment density, population density, and mixing of uses are associated with more shopping by bus.*

Employment density at trip origins and destinations was almost as strongly related to bus use for shopping (r=.44, n=252) as it was to bus use for work. There also was a repeat of the relationship between bus use and average population density at trip origins and destinations (r=.16, n=345). In general, shoppers who begin and end their shopping trips in dense census tracts are more likely to take the bus.

Having the option to drive and household demographics were other factors associated with shopping by bus. Bus use for shopping fell where more shoppers had a driver's license and where shoppers owned more cars (r= -.27, n=393 and -.21, n=393, respectively). Bus use for shopping increased where more shoppers were from single, young adult households (i.e., households with one adult under 35) (r=.22, n=393).

The best regression model explained 43 percent of the variation in bus use (see Table 5) and predicts that all else being equal, a tenfold increase in the average employment density at trip origins and destinations of an average tract would increase bus use for shopping from 1.74 percent to 6.12 percent of all shopping trips.

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Table 4. **Predictors of the Percentage of Work Trips to Destination Census Tracts by Bus in King, Pierce, and Snohomish Counties, 1989.**

	Coefficient[12]	Beta[13]	Sig.[14]
	Dependent Variable: Percentage of all work trips made to census tracts by bus.		
EMPDENA	0.10	0.65	0.00
Constant[15]	0.79	N/A	0.01

Summary Statistics:
    R Squared = 0.42[16]
    F = 135.42
    Prob(F) = 0.00[17]

Variable Definitions:

EMPDENA	= avg. of the gross employment density at the origin and destination of all trips ending in the tract

[12] The coefficient indicates the change in the dependent variable caused by a one unit change in the independent variable. The actual magnitude of the coefficient depends on the units in which the variables are measured.

[13] Beta is the coefficient in standardized units so it can be compared to other coefficients in the model, if any. Variables with higher betas contribute more than other variables to explaining the variation in the dependent variable.

[14] Sig. is the probability that the coefficient will be zero in the population. Low values indicate the coefficient is not the result of chance but is likely to really exist in the whole population.

[15] Constant is the theoretical value of the dependent variable when the independent variable(s) are zero and the point at which the regression line crosses the vertical (y) axis.

[16] R Squared or the coefficient of determination measures how well the model fits the data and can be interpreted as the percentage of change in the dependent variable that can be explained by the model. Note that an R Squared of 0 does not necessarily mean there is no relationship between the dependent and independent variables. Instead, it indicates there is no *linear* relationship. Many of the R-Squares in this study are low because we fit a linear model to relationships, which are generally nonlinear (as shown by Figures 2 - 5, below).

[17] The F value and Prob(F) measure the probability that R-squared is zero in the population. A low value for Prob(F) indicates the R-squared is probably not zero.

Table 5. Predictors of the Percentage of Shopping Trips to Destination Census Tracts by Bus in King, Pierce, and Snohomish Counties, 1989.

	Dependent Variable: Percentage of all work trips made to census tracts by bus.		
	Coefficient	Beta	Sig.
EMPDENA	0.05	0.32	0.00
POPDENA	0.16	0.19	0.00
POOLDIST	0.61	0.51	0.00
Constant	-2.62	N/A	0.00
Summary Statistics:			
R Squared = 0.43			
F = 41.92			
Prob(F) = 0.00			
Variable Definitions:			
EMPDENA	= avg. of the gross employment density at the origin and destination of all trips ending in the tract		
POPDENA	= avg. of the gross population density at the origin and destination of all trips ending in the tract		
POOLDIST	= average distance for carpool trips made to the tract		

The model also predicts that increasing population density at the origin and destination of shopping trips would increase bus use for shopping. Increasing the population density to 40 persons per acre[18] in a tract of average population density (typical of a dense urban center) would increase bus use from 1.74 percent to about 7 percent of all shopping trips.

If both employment and population densities were simultaneously increased to 100 employees and 40 persons per acre, respectively, bus use for shopping would grow to over 11 percent of all shopping trips.

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[18] This is equal to about 45 dwelling units per net acre, typical of low-rise and garden apartments.

WALKING TO WORK

- *Greater employment density, population density, and land-use mix are associated with more walking to work.*

Walking to work was more strongly correlated with land-use factors than non-land-use factors. The strongest correlation was with employment density at trip origins (r=.43, n=324), indicating that more work trips are made by walking in tracts with high employment density. A relatively strong correlation also was found between walking to work and the average population density at trip origins and destinations (r=.34, n=443). Tracts with higher population density that drew employees from tracts with high population density had more workers walk to work. Land-use mixing at trip origins was a third land-use factor associated with walking (r=.21, n=267). Mixing increases walking to work by allowing people to live and shop within walking distance of their workplace.

A regression model was built using all three land-use factors to predict the proportion of work trips made by walking. It explained 31 percent of the variation in walking to work. According to the model, increasing the population density in a typical tract to 40 persons per acre, through the development of a suburban residential center, would increase the share of work trips by walking from a current level of about 3 percent to about 27 percent. This of course assumes that the center will also have employment in it or nearby, which is currently the case with dense residential areas like Seattle's Capitol Hill situated next to downtown Seattle.

The model further predicts that increasing employment density to 100 employees per acre in a tract that currently has average employment density, by creating a major employment center, would increase walking to work from about 3 percent to about 18 percent of all work trips.

Increasing the average mixing of uses at trip origins and destinations by 0.1 (on a scale of 0-0.845) would increase the percentage of walk trips to work by about 2 percent.

Table 6. **Predictors of the Percentage of Work Trips from Origin Census Tracts by Walking in King, Pierce, and Snohomish Counties, 1989.**

	Dependent Variable: Percentage of all work trips made from census tracts by walking.		
	Coefficient	Beta	Sig.
POPDENA	0.70	0.29	0.00
EMPDEN0	0.17	0.38	0.00
MIXA	20.41	0.15	0.01
Constant	-12.87	N/A	0.00

Summary Statistics:
>   R Squared = 0.31
>   F = 33.14
>   Prob(F) = 0.00

Variable Definitions:

POPDENA	= avg. of the population density at the origin and destination of all trips
EMPDENO	= employment density in the tract where trips began
MIXA	= degree of land-use mixing in the tracts where trips began and ended

Table 7. **Predictors of the Percentage of Shopping Trips from Origin Census Tracts by Walking in King, Pierce, and Snohomish Counties, 1989**

	Dependent Variable: Percentage of all work trips made from census tracts by walking.		
	Coefficient	Beta	Sig.
POPDENO	0.89	0.26	0.00
EMPDEND	0.11	0.19	0.00
<1VEHIC	0.12	0.15	0.00
MEANAGE	-0.18	-0.13	0.01
LICENSE	-0.45	-0.40	0.00
Constant	47.68	N/A	0.00

Summary Statistics:
>   R Squared = 0.35
>   F = 28.85
>   Prob(F) = 0.00

Variable Definitions:

POPDENO	= population density at trip origins
EMPDEND	= gross employment density at the destination of all trips beginning in the tract
<1VEHIC	= percent of shoppers with less than one vehicle available for their own use
MEANAGE	= average age of shoppers in the tract
LICENSE	= percent of shoppers in the tract that have a driver's license

WALKING TO SHOP

- *Greater population and employment density are associated with more walking to shop.*

The average population density at trip origins and destinations and employment density at trip destinations were associated with higher proportions of walking to shop (r=.31, n=345 and r=.24, n=256, respectively). Dense residential areas increase walking to shop by supporting retail services within walking distance of housing. Dense employment areas can support retail within walking distances of workplaces. In fact, this tendency to have shopping nearby is one of the more attractive and unique qualities of dense urban environments.

Several non-land-use factors were associated with pedestrian shopping. The strongest was the proportion of shoppers with driver's licenses, which was inversely related to walking to shop (r=-.43, n=393). Conversely, increased pedestrian shopping was found in areas with more shoppers from households with less than one vehicle per driver (r=.22, n=393), more students (r=.16, n=393), and more single young-adult households (one adult less than 35 years old) (r=.22, n=393).

A regression model combining these factors explained 35 percent of the variation in pedestrian shopping. The proportion of shoppers with a driver's license made the largest contribution to the model, however land-use factors also played a significant part.

All else being equal, the model predicts that increasing the average population density at trip origins and destinations to 40 persons per acre would increase walking to shop to about 25 percent of all shopping trips.

The model further predicts that increasing the employment density to 100 workers per acre in a tract with average density would increase shopping trips by walking from about 6 percent to about 16 percent of all shopping trips.

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SOV USE TO WORK

- *Greater employment density and land-use mix are associated with fewer SOV work trips.*

Among the land-use variables, the percentage of work trips by SOV was most strongly related to average employment density where trips began and ended (r= -.26, n=274). As the density increased, SOV trips decreased. Greater land-use mixing also reduced SOV use, but the relationship was weaker (r= -13, n=273).

Non-land-use factors also affected SOV use. SOVs increased where more commuters had a drivers license (r=.25, n=446) and where it took longer to get to work by bus (r=.22, n=77). SOV use declined where more commuters were senior citizens (r= -.16, n=446).

Table 8. Predictors of the Percentage of Work Trips to Destination Census Tracts by SOV in King, Pierce, and Snohomish Counties, 1989

	Dependent Variable: Percentage of all work trips made to census tracts by single occupant vehicles.		
	Coefficient	Beta	Sig.
EMPDENA	-0.28	-0.29	0.00
LICENSE	0.81	0.37	0.00
Constant	5.31	N/A	0.69

Summary Statistics:
     R Squared = 0.20
     F = 27.08
     Prob(F) = 0.00

Variable Definitions:

EMPDENA	= avg. of the gross employment density at the origin and destination of all trips ending in the tract.
LICENSE	= percent of workers in the tract that have a driver's license.

A regression model of SOV use to work is shown in Table 8. It includes the average of employment density at trip origins and destinations and the proportion of workers with a driver's license. As indicated by the beta weights, the proportion of workers with a driver's license was more important than employment density for predicting SOV use.

The model predicts that, all else being equal, increasing the average of employment density at trip origins and destinations in a tract with average employment density to 100 workers per acre would decrease the percentage of work trips made by SOV from 82 percent to 57 percent.

SOV USE TO SHOP

•   *Greater employment density is associated with fewer SOV shopping trips.*

The proportion of shopping trips by SOV was lower to tracts with higher employment density (r= -.15, n=256). SOV use increased where more shoppers had driver's licenses and worked outside their home (r=.22, n=393 and .23, n=393, respectively).

A multiple regression model that used destination employment density, driver's licenses, households with one adult between 35 and 64, and average household income could explain only 14 percent of the variation in the percentage of all shoppers arriving in census tracts by SOV. The proportion of shoppers with driver's licenses and the proportion from households with one adult between 35 and 64 had roughly twice the explanatory power of employment density. Nevertheless, the model predicts that increasing the employment density at trip destinations to 100 employees per acre would decrease the mode share of SOV for shopping trips by 19 percent.

CARPOOLING TO WORK

- *Greater land-use mix is associated with more carpooling to work.*

The proportion of workers who carpooled to work increased with greater land-use mixing at trip origins (r=.18, n=273).[19] However, the variable most strongly related to carpooling to work was the proportion of workers employed outside the home (r= -.26, n=446). Areas with less employment outside the home (i.e., more in-home work) had more carpooling. These tracts are probably lower density areas because working at home tends to increase in lower density areas (like rural districts). Carpooling is the most realistic option to driving alone in lower density areas. This could explain why less employment outside the home would be associated with more carpooling.

Table 9. Predictors of the Percentage of Shopping Trips to Destination Census Tracts by SOV in King, Pierce, and Snohomish Counties, 1989.

	Dependent Variable: Percentage of all work trips made to census tracts by single occupant vehicles.		
	Coefficient	Beta	Sig.
EMPDEND	-0.19	-0.18	0.00
LICENSE	0.45	0.23	0.00
HHTYPE1	0.40	0.21	0.00
INCOME	0.00	0.16	0.01
Constant	3.63	N/A	0.75

Summary Statistics:
  R Squared = 0.14
  F = 11.33
  Prob(F) = 0.00

Variable Definitions:

EMPDEND	= gross employment density at the destination of all trips ending in the tract.
LICENSE	= percent of shoppers in the tract that have a driver's license.
HHTYPE1	= percent of shoppers coming to the tract from households with one adult between 35 and 64 years of age.
INCOME	= mean household income of shoppers.

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[19] This finding was based on data for the 273 census tracts studied in King County because land use mix data were not available in the other study counties.

Two additional non-land-use factors were related to carpooling. Tracts with more workers coming from households with one adult over 65 had greater proportions of carpooling to work (r=.18, n=446). Tracts with more workers with driver's licenses had less carpooling to work (r= -.15, n=446).

CARPOOLING TO SHOP

- *Greater land-use mixing is associated with more of carpooling to shop.*

Carpooling to shop increased in census tracts with more land-use mixing (r=.16, n=204). Carpooling declined where more shoppers were from households with one adult between 35 and 65 (r= -.21, n=393).

THRESHOLDS

Up to this point, our analysis has used linear models to predict mode split. However, relationships between mode split and land-use tend to be nonlinear. Increasing the density of census tracts, for example, does not begin to change mode split until after certain density thresholds are crossed. Then, change can occur relatively rapidly.

An analysis was conducted to find these thresholds. Our results are shown in Figures 2 through 5.

For work trips, SOV use did not decline and alternative modes did not increase significantly until an employment density of 50 to 75 employees per gross acre was reached.[20]   After that point, little or no change occurred until reaching 125 to 175 employees per acre. The population density threshold was 9 to 13 persons per acre. The mid point of this range, 11 persons per gross acre, is equivalent to a net dwelling unit

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[20] King County has adopted a standard of 50 employees per gross acre in its Countywide Growth Management Policies.

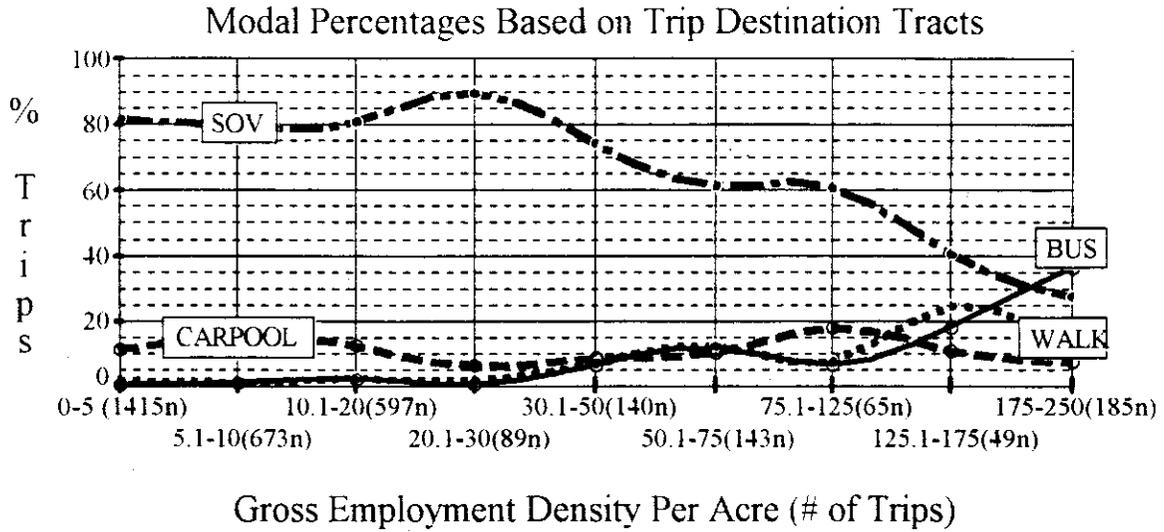## Modal Percentages Based on Trip Destination Tracts

Figure 2. Average Employment Density at Trip Origins and Destinations and Mode Split for Work Trips

Modal Percentages Based on Trip Origin Tracts
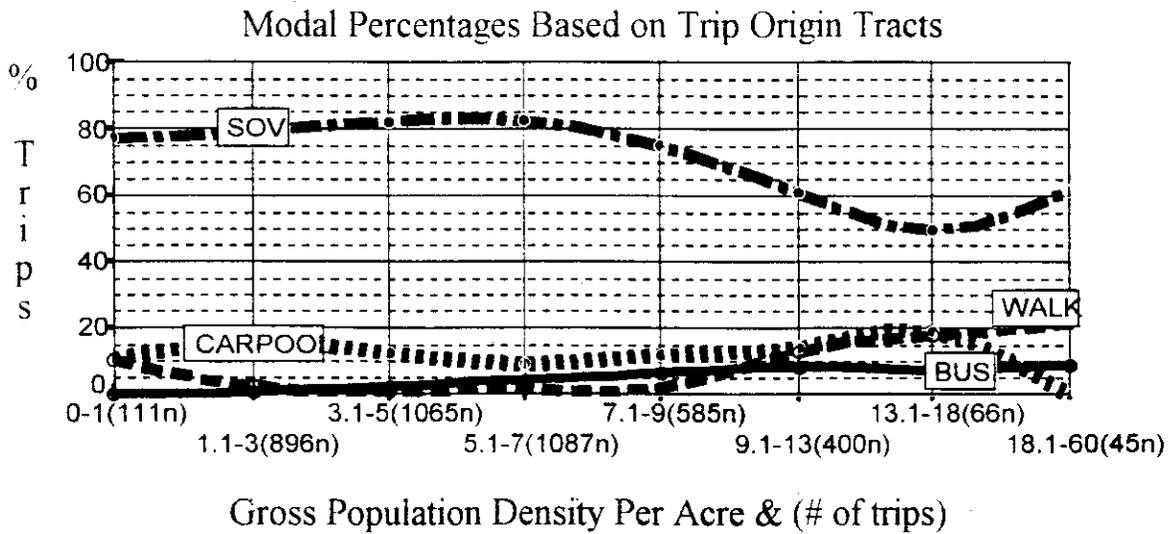
Figure 3. Average Population Density at Trip Origins and Destinations and Mode Split for Work Trips

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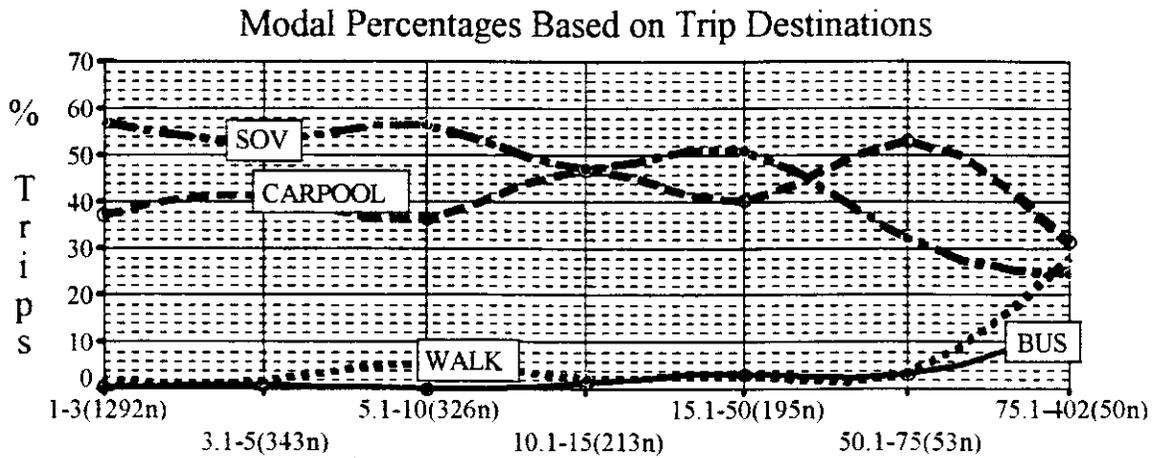
Modal Percentages Based on Trip Destinations

Figure 4. Employment Density at Trip Destinations and Mode Split for Shopping Trips
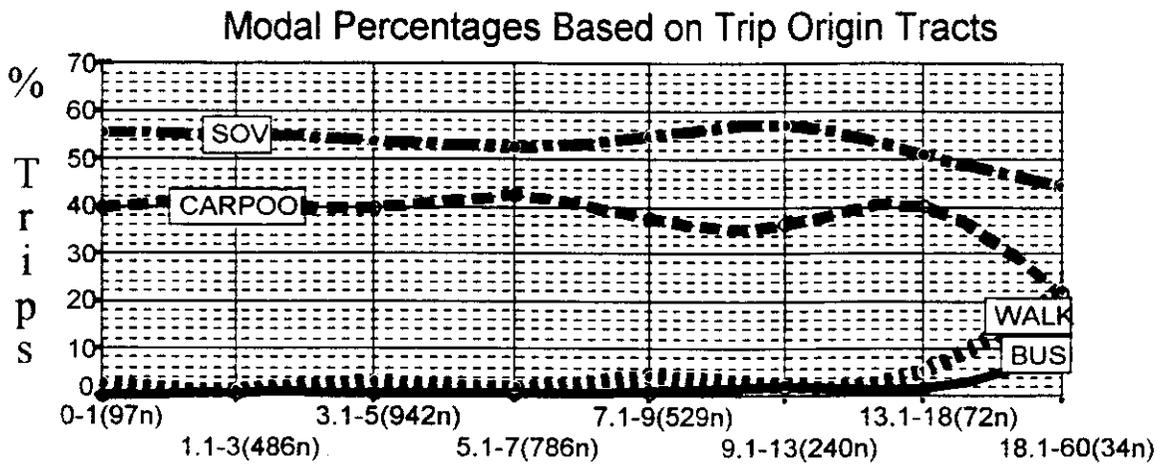
Modal Percentages Based on Trip Origin Tracts

Figure 5. Average Population Density at Trip Origins and Destinations and Mode Split for Shopping Trips

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density of 12 units per net acre.[21] This is higher than the 7 dwelling units per net acre which is often cited as the density necessary to support significant transit use (Pushkarev and Zupan 1977).[22] As noted under **REVIEW OF PREVIOUS WORK**, the 7-unit threshold has been criticized before for being too low in cities without very large and dense cores like New York City.

The thresholds for shopping were higher than those for work trips. For shopping, the most dramatic threshold was after employment passed 75 employees per gross acre and population passed 18 persons per gross acre (or 20 dwelling units per net acre).

WORK TRIP DISTANCE

- *Greater population density, employment density, land-use mix, and jobs/housing balance are associated with shorter work trips.*

Population density, employment density, and land-use mix at trip origins were all negatively correlated with trip distance (r=-.17, n=4205; -.13, n=3071; and -19, n=2098 respectively). This could be caused by workers living in dense, mixed tracts and working close to home, and by workers taking short trips to and from other personal and professional activities in their workplace vicinity. Further study distinguishing between home and non-home-based trips is needed.

Work trip distance also was related to jobs/housing balance. The average distance of work trips ending in balanced tracts (with a jobs-to-households ratio of 0.8–1.2) was 29 percent shorter than the distance of trips ending in unbalanced tracts (6.9 miles compared to 9.6 miles). We believe this is more the result of shorter distances between

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[21] This computation assumes there would be 2.56 persons per dwelling unit, 35 percent of a given tract would be used for housing, 25 percent for streets and other infrastructure purposes, 20 percent for critical areas and open space, and 20 percent for commercial uses. Thus, the conversion formula was (11/2.56)/.35.

[22] It also is lower than the households per acre criteria adopted by King County in the Urban Centers Criteria of its Countywide Growth Management Policies. That criteria is given as 15 households per gross acre, which we estimate to be equivalent to 30 to 60 dwellings per net acre, assuming that 25 percent of the gross center area would be used for residential uses and the remainder would be used for commercial uses, open space, critical areas, and infrastructure.

homes and workplaces and less the result of more short trips to and from the workplace during the workday. This is because balanced tracts were not the dense, mixed tracts where one would expect to find more short trips to and from workplace during the workday.

SHOPPING TRIP DISTANCE

- *Greater population density is associated with shorter shopping trips.*

We found that as population density increased, shopping trip distance decreased (r=-.16, n=3145). This is unsurprising, given that retail stores are typically spaced more frequently in denser areas, which reduces the distance people must travel for a given shopping need.

WORK AND SHOPPING TRIP TRAVEL TIME

- *Greater land-use mix and job-housing balance are associated with decreased work trip travel time.*

- *Greater employment density is associated with increased work and shopping trip travel time.*

Work trips originating in more mixed census tracts took less time (r=-0.16, n=2107). This is probably because mixed areas allow people to live closer to work and generate more short distance trips during the work day.

Work trips ending in higher density census tracts took more time (r=.19, n=3370). This could be caused by slower travel speeds or longer travel distance. However, given the finding from the previous section that higher employment density decreased travel distance, it is probably the result of slower travel speeds secondary to congestion around higher density employment areas and more trips made by slower traveling buses.

Work trip travel time also was related to jobs/housing balance. Balance reduced travel time. The average time required for work trips to balanced tracts was 24 percent less than the average time required for work trips to unbalanced tracts (17.3 minutes compared to 22.9 minutes). People working in balanced tracts probably live closer to

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work than people working in unbalanced tracts. It is possible that more short trips during the work day account for the lower travel time, but this is probably not the case because balanced tracts were not necessarily dense or mixed places and are therefore unlikely to generate more short trips during the workday.

Shopping trip travel time also was related to land-use. In particular, shopping trip travel time increased with average employment density at trip origins and destinations (r=0.12, n=2448). As with work trips, this is probably from traffic congestion and more bus use in and around dense areas.

The number of household vehicles is a non-land-use factor that was positively correlated with shopping trip travel time (r=.13, n=2448).

COMBINATIONS OF USES

- *It is not necessary for centers to contain both jobs and housing to reduce auto use.*

The regression models indicate that employment density and housing density can operate independently from one another to promote less driving alone. However, the evidence indicating that mix and balance reduce auto use suggests that the combination of dense housing and dense employment will be greater than the sum of its parts.

The regression models imply various combinations of land-uses that may reduce auto use for work and shopping. Less SOV use for work may result from downtowns that are almost pure employment areas and less SOV use for shopping may occur in dense employment areas with shopping for workers during the work day. More bus use to work appears in centers that combine dense employment with shopping and housing, while greater bus use for shopping is found in areas with either dense employment and shopping or dense population and shopping. Increased walking to work could result when dense employment is mixed with less dense housing and shopping, or when dense housing is combined with less dense employment. Finally, walking to shop may occur when shopping is located near dense employment or dense housing.

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The combination of dense housing, shopping, and dense employment is probably associated with the greatest reductions in auto use. Less auto use can also be produced from relatively pure but dense employment areas, in areas that combine dense housing with less dense employment or shopping, and in areas that combine dense employment with less dense housing or shopping.

SUMMARY OF FINDINGS

1. Density, mix and jobs/housing balance are all related to travel behavior. In general:

    *   as density goes up, travel time increases while trip distance and the proportion of trips made by SOV decline;

    *   as land-use mixing increases, trip distance, travel time, and the proportion of trips made by SOV decline;

    *   as jobs and housing become balanced, trip distance and travel time go down.

    The increased travel time is probably caused by slower speeds rather than greater trip distance. *Therefore, SOV use is generally reduced by greater density, land-use mixing, and jobs/housing balance.*

2. Employment density and jobs/housing balance had the strongest relationship with travel behavior.

3. The travel characteristics most strongly related to land-use were the proportion of trips by bus and the proportion of trips by walking.

4. Work travel behavior is more strongly related to land-use than shopping travel behavior.

5. The relationship between land-use and mode split is nonlinear. Substantial changes in land-use will yield small changes in travel behavior at the lower end of the land-use variable spectrum (e.g., in low density areas), but will yield much greater results once certain thresholds are reached. These thresholds for density are 50-75 employees and 9-13 persons per gross acre for work trips, and 75 employees and 18 persons per gross acre for shopping trips.

6. It is not necessary for centers to contain jobs and housing in order to reduce auto use. Dense employment by itself will reduce the proportion of work trips made by SOV, and dense employment with shopping reduces SOV use for shopping purposes. Bus use to work is promoted by centers that combine dense employment with shopping and housing, while bus use for shopping is promoted by either dense employment with shopping or dense population with shopping. Walking to work increases where there is dense employment mixed with housing and shopping, or where there is dense housing combined with employment.

Walking to shop increases where shopping is combined with dense employment or dense housing.

7. Controlling for non-land-use variables, like household income, did not diminish the relationships between land-use and travel behavior. The control variables most often related to travel behavior were household type, age, possession of a driver's license, vehicle availability, transit level-of-service, and working at home.

8. More analysis is needed to produce nonlinear models that will be more accurate than linear models for predicting the effect of land-use changes on travel behavior.

9. Our results are consistent with findings from previous research summarized in the introduction. In particular, our work confirms the findings of earlier research by showing that:

    •   density reduces trip distance and the proportion of trips made by SOV;

    •   density increases travel time and the proportion of trips made by alternatives to driving alone;

    •   land-use mixing reduces trip distance and travel time; and

    •   the relationship between land-use and mode split is nonlinear.

10. Our results go beyond the findings of previous research by showing that jobs/housing balance reduces trip distance and travel time.

11. The above findings only represent changes in travel behavior that are associated with variations in urban form. They do not reflect changes that may occur from changes in transit service. Recent research indicates that changing land-use in conjunction with improved transit service generates a synergistic impact on mode split (Middlesex, Somerset, Mercer Regional Council 1993).

12. The propensity to carpool was not found to be highly correlated with the land-use characteristics tested in this study. This suggests that the choice to carpool is a function of other factors.

APPLICATION/IMPLEMENTATION

At the most general level, these results show that market trends and public policies that increase density, mixing or jobs/housing balance at the census tract level will reduce auto use. State and local officials who want to reduce SOV use should understand that land-use density, mix, and balance can help them achieve their goal.

A great number of specific actions would increase density, mix, and balance. They include, to name just a few, changes in land-use policies that directly determine land-use patterns, as well as changes in transportation, infrastructure, and public finance policies that indirectly affect land-use. Up-zoning, density bonuses, minimum mix and density requirements, and balanced zoning in centers, coupled with down-zoning outside centers, would create a regulatory environment that reduces auto use. Concentrating infrastructure and transportation investments in centers and financing them with general revenues rather than impact fees would also attract more growth to centers. These are just some of the many measures that could promote land-use patterns that reduce auto use.

We found that using density to reduce SOV use would require very large increases in the population and employment density of typical census tracts. Assuming that the current level of transit service, parking supply, and accessibility continued, a 650 to 1,000 percent increase in the employment density or a 100 to 200 percent increase in population density in typical census tracts would be required to cause a significant reduction in the proportion of trips made by SOV (i.e., a change from around 80 percent to around 60 percent SOV). This is the kind of change proposed through the creation of regional centers in plans like the Puget Sound Regional Council's *Vision 2020,* King County's *Countywide Planning Policies,* or the City of Seattle's *Toward A Sustainable Seattle.* The changes would not need to occur in all tracts to have a large impact on total tripmaking in the region. Because dense tracts generate a

disproportionate share of all trips, changing the land-use in a minority of tracts could have a large total effect on regional travel. This study, therefore, supports the potential of new centers to reduce the proportion of trips made by SOV.

Our findings do differ from these plans in two ways. One is that the population density proposed for centers in the plans is typically greater than the thresholds found in this study. The second is that, contrary to how centers are often conceived of by planners, centers do not always need to have both dense population and employment to be effective. Various combination of dense housing, dense employment, and shopping can promote less SOV use.

This study also shows that land-use patterns can affect trip distance. Reducing trip distance is another way to reduce auto use. This can be done by increasing jobs/housing balance, land-use mix, population density, and employment density. These strategies have not been pursued by planners as aggressively as the creation of centers.

Improvements to the jobs/housing balance of tracts could be implemented without major density increases through infill and redevelopment. This would reduce the concerns of those worried about the effects of densification on neighborhood character. Jobs/housing balance could reduce SOV use through shorter trip distances by as much as 30 percent. While lowering SOV trip distances does improve the environment by reducing energy use, water pollution, noise pollution, and other impacts associated with vehicle miles of travel, it is not as effective for reducing air pollution as reducing the proportion of trips made by SOV because 80 percent of hydrocarbon emissions are due to cold starts and hot evaporative soaks (Cameron 1991). Shortening SOV trips is not as effective for reducing air pollution as eliminating them.

These findings should not be used by themselves to determine the direction of public policy. The costs and benefits of increased density and the other actions they imply must be weighed. Land-use change would not only reduce auto use, it could promote other objectives like affordable housing, air and water conservation, reduced

sprawl, conservation of resource lands, community development, and efficient infrastructure. However, land-use change could also generate costs such as discomfort for those who dislike density, financial costs to those who benefit from urban sprawl, and displacement of existing land uses. Policy-makers will ultimately need to strike a balance among all these competing interests.

SUBSEQUENT RESEARCH

The Clean Air Act Amendments of 1990, in conjunction with the Intermodal Surface Transportation Efficiency Act of 1991, stipulate that each region's transportation improvement program must meet air quality standards in order to receive federal funding for proposed projects.

Although this report confirms findings that increasing land use density, mixing land uses, and altering the jobs-housing balance can reduce dependency on single-occupant vehicle travel, little work has been done within the region to relate these findings to air quality. Therefore, as part of this project, additional research is underway to explore the relationships among land use, regional air quality, and household travel demand. Household travel characteristics that affect air quality include vehicle miles traveled, vehicle hours of travel, and trip generation rates. The results of this research, which will be performed in cooperation with the Washington State Department of Ecology, will be published in a subsequent report.

ACKNOWLEDGMENT

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APPENDIX A

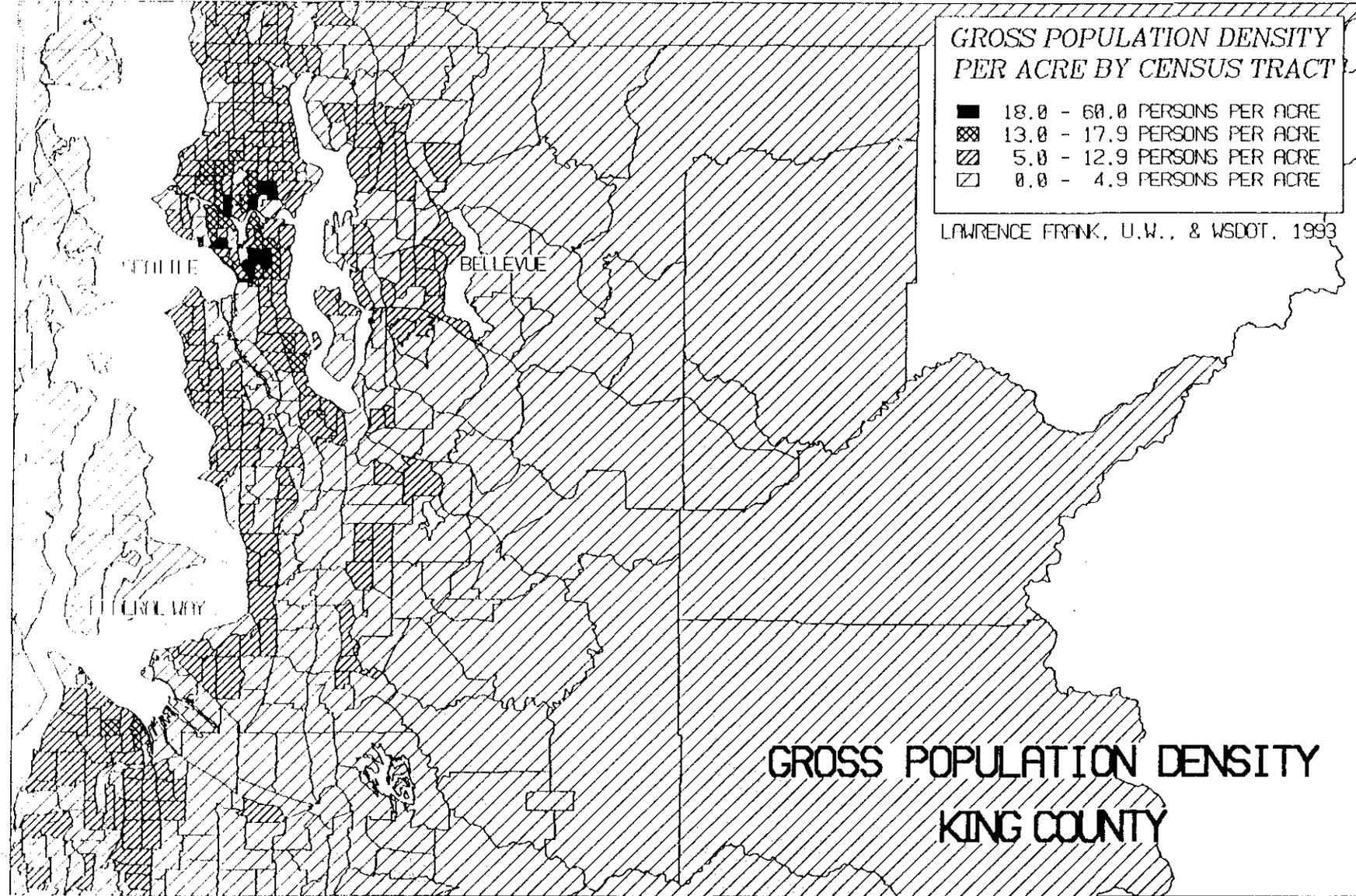# LOCATION OF CENSUS TRACTS WITH DIFFERENT LEVELS OF POPULATION DENSITY, EMPLOYMENT DENSITY, MIX AND BALANCE

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

SEATTLE

BELLEVUE

FEDERAL WAY

GROSS POPULATION DENSITY
KING COUNTY

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

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SEATTLE

BELLEVUE

RENTON

FEDERAL WAY

GROSS EMPLOYMENT DENSITY
KING COUNTY

LEVEL OF LAND USE MIX
BY CENSUS TRACT

- ■ HIGHEST
- ▨ HIGH
- ▨ LOW
- ▨ LOWEST

KING COUNTY

SEATTLE
BELLEVUE
RENTON
TACOMA
FEDERAL WAY

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

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SEATTLE

JOBS - HOUSING BALANCE
KING COUNTY

A-4

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

GROSS POPULATION DENSITY
SNOHOMISH COUNTY

GROSS POPULATION DENSITY
PER ACRE BY CENSUS TRACT

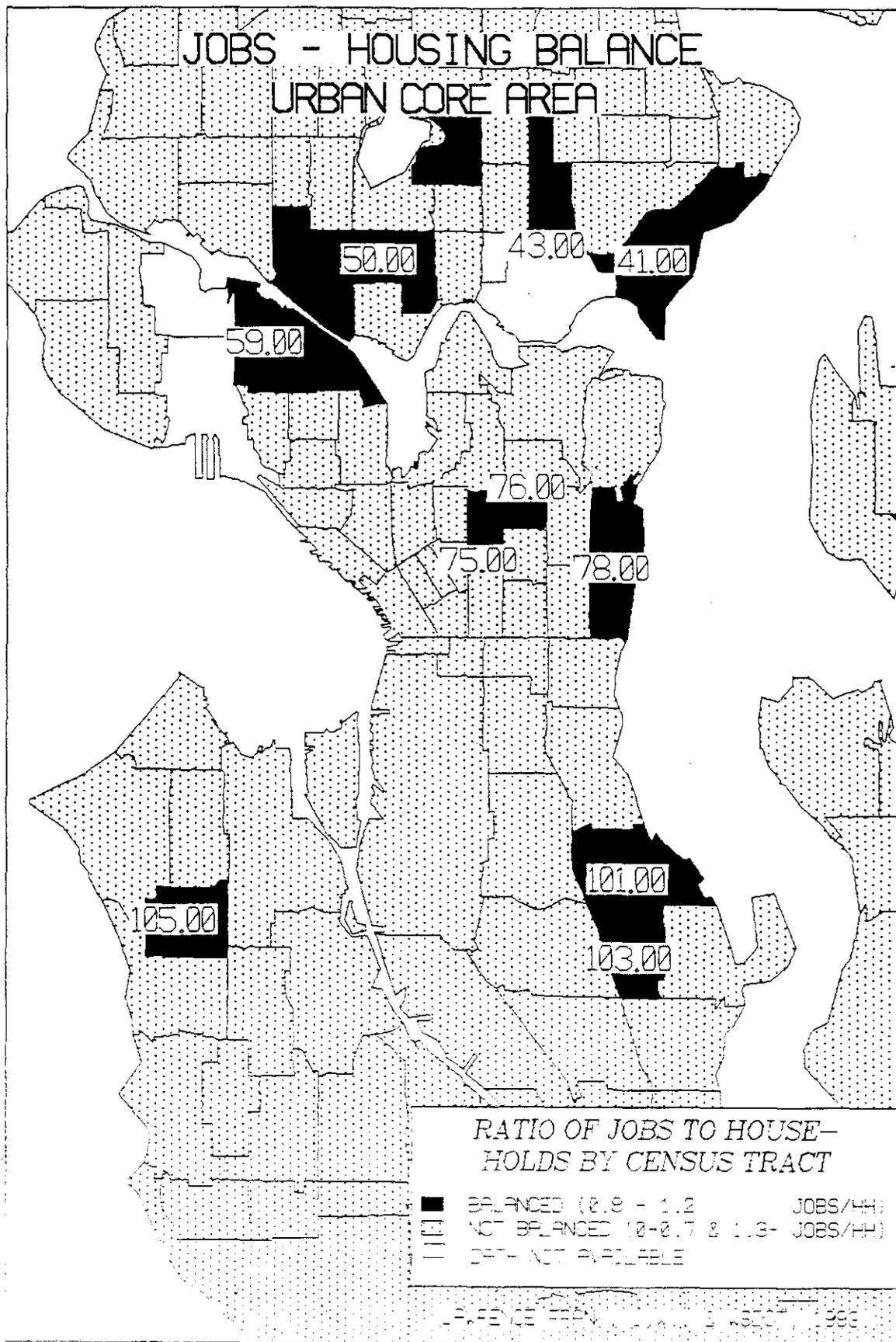|	
■	18.0 - 60.0 PERSONS PER ACRE
▨	13.0 - 17.9 PERSONS PER ACRE
▨	5.0 - 12.9 PERSONS PER ACRE
▨	0.0 - 4.9 PERSONS PER ACRE

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A-6

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

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EVERETT

GROSS EMPLOYMENT DENSITY

SNOHOMISH COUNTY

JOBS – HOUSING BALANCE SNOHOMISH COUNTY

EVERETT

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
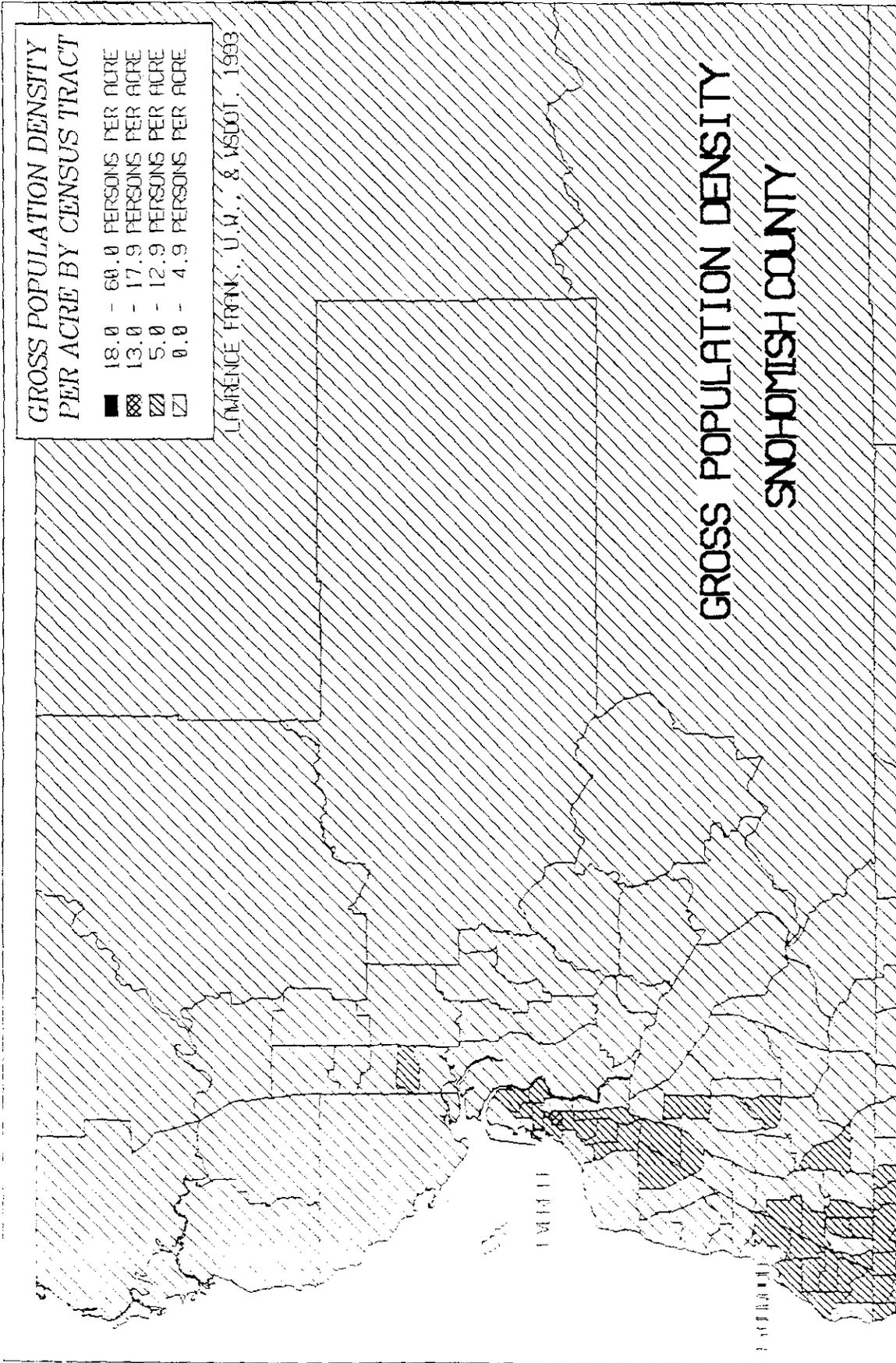
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FEDERAL WAY

LINCOLN

**GROSS POPULATION DENSITY
PER ACRE BY CENSUS TRACT**

- ■ 18.0 - 60.0 PERSONS PER ACRE
- ▨ 13.0 - 17.9 PERSONS PER ACRE
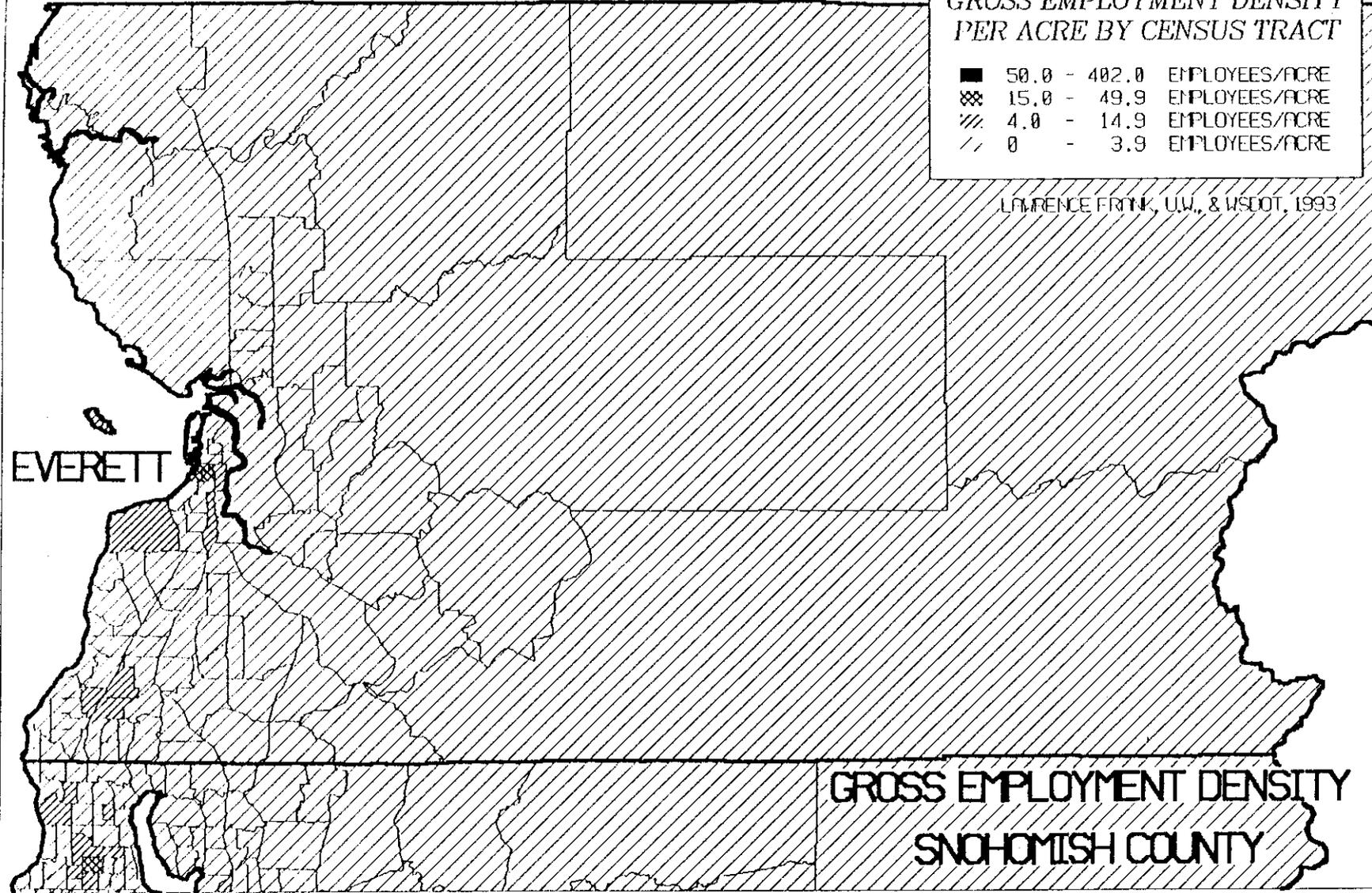- ▧ 5.0 - 12.9 PERSONS PER ACRE
- ▨ 0.0 - 4.9 PERSONS PER ACRE

GROSS POPULATION DENSITY
PIERCE COUNTY

GROSS EMPLOYMENT DENSITY
PER ACRE BY CENSUS TRACT

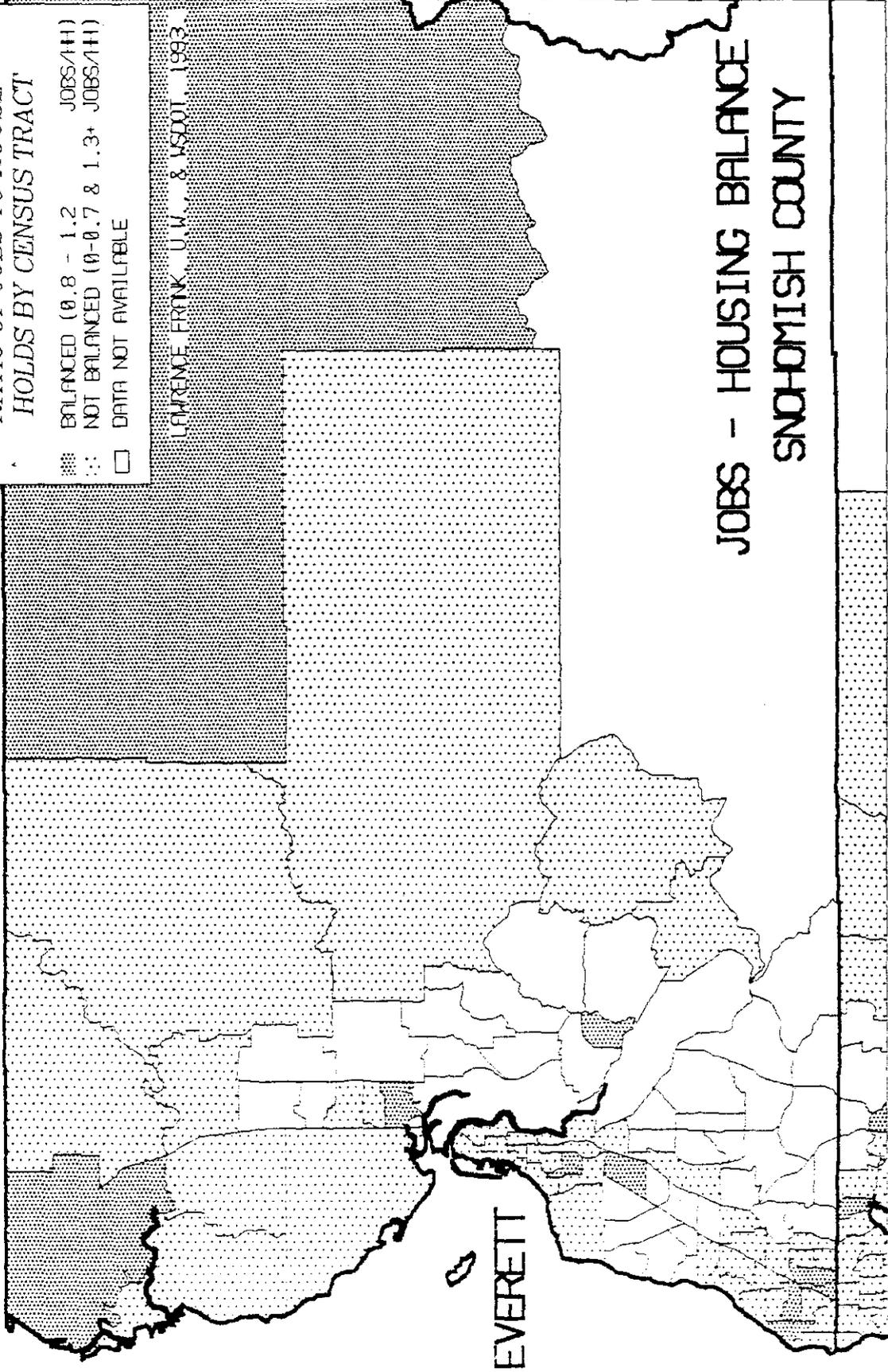|		
50.0 – 402.0	EMPLOYEES/ACRE
15.0 – 49.9	EMPLOYEES/ACRE
4.0 – 14.9	EMPLOYEES/ACRE
0 – 3.9	EMPLOYEES/ACRE

LAWRENCE FRANK, U.W., & WSDOT, 1993

GROSS EMPLOYMENT DENSITY
PIERCE COUNTY

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

Source: PSRC, DOL, & PCPD, 1993.

TACOMA

JOBS – HOUSING BALANCE
PIERCE COUNTY