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TRANSPORTATION-EFFICIENT LAND USE MAPPING INDEX (TELUMI)

Phase 3 of Integrating Land Use and Transportation Investment Decision-Making

by

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16. ABSTRACT

The objective of this project was to devise a conceptually simple tool that operationalized the complex relationship between land use and travel behavior. The TELUMI is a set of maps that depicts how the region's urban form affects overall transportation system efficiency. Nine map layers represent the effects of individual land-use variables on transportation efficiency. They include density (residential and employment), mix of uses (shopping and school traffic, the presence of neighborhood centers (NC)), network connectivity (block size), parking supply (amount of parking at grade), pedestrian environment (slopes), and affordable housing. The tenth layer is a composite index, which takes into account the relative effects of each of the nine variables on transportation efficiency, based on a statistical analysis that modeled the relationship between the land-use variables and King County bus ridership.

Each land-use variable is mapped by using three categories, which define zones of high, latent, and low transportation efficiency (TE). High TE values correspond to many convenient transportation options, including transit, non-motorized, and other non-SOV travel options. Low TE corresponds to few transportation options beyond SOV travel. Latent TE indicates that travel options remain limited, but that land-use conditions in these zones are favorable enough to permit easy and effective increases in future travel options—either via transportation system investments, demand management or other programmatic actions, or land-use changes.

The visual dimension of the TELUMI's maps make the tool an attractive means of communication with lay audiences, while its quantitative capabilities can speak to transportation and urban planning professionals. While the TELUMI now shows how to rate areas of the Puget Sound for their existing transportation efficiency, it can and should also be used to set goals for future transportation efficiency and to monitor progress over time. Changes in the values of land-use variables can be assessed in terms of their impact on the region's overall transportation efficiency.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY xi
Description of the Tool xi
Important Findings xii
Conceptual and Technical Considerations xiii
Future Uses of the TELUMI xiv
CHAPTER 1. INTRODUCTION 1
Project Context 1
The TELUMI Tool 3
Structure of the Report 3
CHAPTER 2 CONCEPTS, DEFINITIONS, AND METHODS 5
Foundational Concepts 5
Cartographic Modeling 8
Land-Use Variable Selection 10
Threshold Values of land-use variables 13
  Threshold Values and Zones in Cartographic Models 13
  Threshold Values of Transportation Efficiency 13
  Threshold Values from the Literature 15
CHAPTER 3 ESTABLISHING THRESHOLDS OF TRANSPORTATION EFFICIENCY: THE DELPHI METHOD 17
Data 18
Method 21
Results 21
Evaluation and Further Development of Land-Use Variables and Thresholds 30
  Rethinking Mixed-Use Variables 32
  Adding the Effects of Travel Related to Shopping and Educational Uses 32
Conclusions 33
CHAPTER 4 LAND USE MAPPING 35
Data 35
Method 36
  Measurements 36
  Individual Map layers 36
  Development of the Composite Map 39
Results and Discussion 42
  King County Summary 42
  Snohomish County Summary 50
  Pierce County Summary 52
  Kitsap County Summary 54
CHAPTER 5: CONCLUSIONS 56
ACKNOWLEDGMENTS 59
REFERENCES 60
APPENDIX A: EMPLOYEMENT DATA A-1
APPENDIX B: DELPHI INSTRUMENT B-1
APPENDIX C: TECHNICAL ISSUES IN SPATIAL ANALYSIS AND CARTOGRAPHIC MODELING C-1

APPENDIX D: METHODOLOGICAL APPROACH TO A COMPOSITE MEASURE OF THE TELUMI **D-1**

FIGURES

Figure		*Page*
E-1	TELUMI composite layer of Puget Sound showing areas at the three levels of transportation efficiency	xii
1	Three phases of *Integrating Land Use and Transportation Investment Decision-Making*	2
2	Simplified cartographic modeling diagram..	10
3	Distribution of residential density in three geographic zones of transportation efficiency	13
4	Residential densities of the five study areas and the three selected threshold classes.	22
5	Net employment densities of the five study areas and the three selected threshold classes.	23
6	Job/housing ratio in the five study areas and the three selected threshold classes for CBDs.	24
7	Job/housing ratio in the five study areas and selected threshold classes for urban centers.	24
8	Job/housing ratio in the five study areas and selected threshold classes for neighborhood centers.	25
9	Average block size in the five study areas and the three selected threshold classes.	27
10	Percentage of parcels covered by parking lots in the five study areas and the three selected threshold classes.	28
11	Percentage of slope in the five study areas and the three selected threshold classes.	28
12	Average daily traffic in the five study areas and the range of three classes.	29
13	Percentage of residential units below the mean assessed property value in the five study areas and the range of three classes.	30
14	Map of a composite measure (Model 1).	40
15	Examples of the TELUMI layers.	41
16	King County percentage of geographic areas with high, latent and low TE by individual map layer.	43
17	King County percentages of areas with high and latent TE for each map layer, in ascending order.	45
18	King County percentage of residential units and employees at high, latent, and low TE levels.	46
19	King County percentage of high, latent, and low TE zones within 1-km buffer of highways and primary streets.	47
20	Percentage of geographic areas at the three levels of TE in the five sample areas (Composite Layer).	49
21	Snohomish County percentage of geographic areas with high, latent and low TE by individual map layer.	50
22	Snohomish County percentage of residential units and employees in areas with high, latent, and low TE levels.	51

23	Pierce County percentage of geographic areas with high, latent and low TE by individual map layer.	52
24	Pierce County percentage of residential units and employees in areas with high, latent, and low TE.	53
25	Kitsap County percentage of geographic areas with high, latent and low TE by individual map layer.	54
26	Kitsap County percentage of residential units and employees in areas with high, latent, and low TE levels	55

TABLES

Table		*Page*
1	Structure of report	4
2	Domains or groups of variables used to measure the impacts of land use on travel behavior.	11
3	Summary of land-use variables first considered in the TELUMI.	12
4	Classification of transportation options and related constituent CM zones	14
5	The five sample areas (1/2-mile radius buffer).	19
6	Land-use measures for Queen Anne, Wallingford, Bellevue, Kirkland, and Crossroads.	20
7	Question 0: Percentage of trips in SOVs.	22
8	Question 1: Number of residential units per net residential acre.	22
9	Question 2: Employees per net acre of non-residential parcels.	23
10	Question 3: Job/housing ratio (no threshold class selected).	24
11	Question 4-1: Individual destinations conducive to alternative mode use.	25
12	Question 4-2: Groups of destinations conducive to alternative mode use.	26
13	Question 5: Average block size in acres.	26
14	Question 6: Number of parking spaces per 1,000 gross non-residential building sq.ft.–thresholds are not proposed.	27
15	Question 7: Percentage of parcels covered by parking lots.	27
16	Question 8: Percentage of slope.	28
17	Question 9: Average daily traffic along major streets.	29
18	Question 10: Percentage of residential units below the mean assessed property value.	29
19	Question 11: Residential land uses most likely to indicate affordable housing	30
20	Summary variables and measures from the Delphi process.	31
21	Trip generation rate – shopping and school traffic (trips per 1,000 sq.ft. gross floor area).	33
22	Land-use measures.	34
23	The data used in the TELUMI project.	35
24	Summary of variable measurement and layers.	37
25	GIS processes for producing land-use maps.	38
26	Model results (Model 1)	40
27	Summary of King County percentage of geographic areas with high, latent and low TE for all map layers.	42
28	King County residential units and employment at the three TE levels (total number and percentage).	46
29	King County total acres and percentage of high, latent, and low TE zones within 1-km buffer of highways and primary streets.	47
30	TE zones in the five Delphi sample areas, Composite Layer.	49
31	Summary of percentage of Snohomish County geographic areas with high, latent and low TE for all map layers.	50

32 Summary of percentage of residential units and employment at different TE levels in Snohomish County. 51
33 Summary of Pierce County areas with high, latent and low TE for all map layers. 52
34 Summary of residential units and employment in areas with different TE levels in Pierce County. 53
35 Summary of Kitsap County areas with high, latent and low TE for all map layers. 54
36 Summary of residential units and employment in areas with different TE in Kitsap County. 55

EXECUTIVE SUMMARY

This third phase of the Integrating Land Use and Transportation Investment Decision-Making project culminates with the Transportation Efficient Land Use Mapping Index (TELUMI). The TELUMI evaluates the impacts of different land-use variables on transportation system efficiency by using maps and quantitative data. Maps and data are available for the urban growth areas (UGAs) of the Puget Sound region (King, Pierce, Snohomish, and Kitsap counties).

DESCRIPTION OF THE TOOL

The TELUMI is a set of maps that depicts how the region's urban form affects overall transportation system efficiency. Nine map layers represent the effects of individual land-use variables on transportation efficiency. They include density (residential and employment), mix of uses (shopping and school traffic, the presence of neighborhood centers (NC)), network connectivity (block size), parking supply (amount of parking at grade), pedestrian environment (slopes), and affordable housing. The tenth layer is a composite index (see Figure E-1), which takes into account the relative effects of each of the nine variables on transportation efficiency, based on a statistical analysis that modeled the relationship between the land-use variables and King County bus ridership.

Each land-use variable is mapped by using three categories, which define zones of high, latent, and low transportation efficiency (TE). High TE values correspond to many, and convenient, transportation options, including transit, non-motorized, and other non-

SOV (single-occupant vehicle) travel options. Low TE corresponds to few transportation options beyond SOV travel. Latent TE indicates that travel options remain limited, but that land-use conditions in these zones are favorable enough to permit easy and effective increases in future travel options—either via transportation system investments, demand management or other programmatic actions, or land-use changes. From a policy planning and programming perspective, zones with latent TE present the greatest opportunity for high returns on future investments in land use and transportation systems.

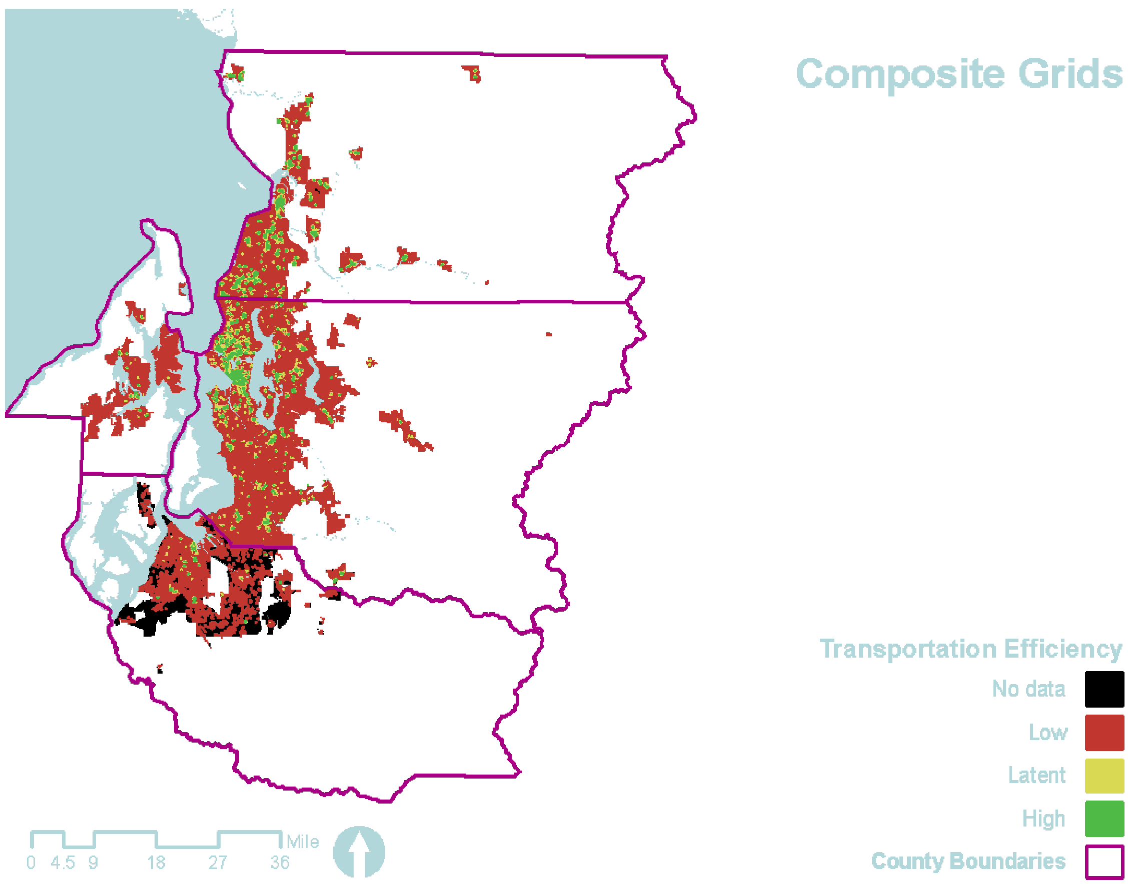

Figure E-1. TELUMI composite layer of Puget Sound showing areas at the three levels of transportation efficiency.

IMPORTANT FINDINGS

The composite layer of the TELUMI in King County yields challenging information about the transportation efficiency of present land-use conditions within the county's UGA. First, the percentages of areas with high and latent TE are small, at 8 and 9 percent, respectively. This is both good and bad news. The fact that existing areas with many transportation options are small means that future investment and/or policy changes can be targeted to small geographic areas and, thus, involve relatively few targeted populations and facilities. But the large areas with low TE (83 percent of King County within the UGA) are likely to be difficult to upgrade without substantial investment.

Second, however, the TELUMI shows that areas with high and latent TE contain a high proportion of residential units and employment. More than 40 percent of the residential units, and nearly 80 percent of the employment in King County's UGA, are in areas with high and latent TE. This indicates that a good proportion of residential and employment activities is concentrated enough already to support many travel options. Future focus on and investment in latent TE zones (with 23 and 30 percent of the King County residential units and employment, respectively) should substantially increase travel options for a sizeable portion of the population.

Third, 1-km buffers along King County's highways and primary streets show that only 20 percent of these facilities are in areas of high and latent TE. This suggests that the road network may be out of balance with, or not supportive of, adjacent land-use patterns. This finding raises difficult questions, since many of these facilities can be major bus corridors. However, the calculations measure only the presence or absence of transportation facilities, not their capacity. Further study is needed to relate transportation systems' capacity to land-use conditions—for instance, calculating areas at the different TE levels that are related to different levels of bus transit service.

Finally, analyses of five sample areas used in the development of the TELUMI support many of the assumptions made during the course of this project. (The sample areas are Wallingford and Queen Anne in Seattle, Downtown Bellevue, Downtown Kirkland, and the Crossroads area of Bellevue). With only 15 percent of its area having high TE, the suburban neighborhood of Crossroads is associated with the fewest and least convenient non-SOV transportation options of all sample areas. Downtown Kirkland comes next, with 33 percent of its area having high TE; while in downtown Bellevue, Wallingford, and Queeen Anne, more than 70 percent of their areas have high TE. Interestingly, in Crossroads and Kirkland, 34 and 38 percent of their areas have latent TE, respectively, a finding that supports the high potential that these two neighborhoods or districts are commonly believed to have for future transportation efficiency.

CONCEPTUAL AND TECHNICAL CONSIDERATIONS

The objective of this project was to devise a conceptually simple tool that operationalized the complex relationship between land use and travel behavior. To be such a tool, the TELUMI required systematic construction, based on extensive review of past research, as well as new studies and substantial inputs from national and local experts in land use and transportation. This report makes explicit the conceptual and technical frameworks employed in the development of this work.

FUTURE USES OF THE TELUMI

The TELUMI is a tool that allows people to test the potential impacts of changes in one land-use variable (such as employment density or amount of parking at ground) on travel options, thereby providing policy makers with a way to assess the relative power of different investments, programs, or policy/regulatory changes on the use of transportation facilities. While the TELUMI now shows how to rate areas of the Puget Sound for their existing transportation efficiency, it can and should also be used to set goals for future transportation efficiency and to monitor progress over time. Changes in the values of such land-use variables as employment density or amounts of parking at grade can be assessed in terms of their impact on the region's overall transportation efficiency. Such changes can be targeted to the entire region or to specific areas such as Designated Urban Centers or the areas lining primary transportation facilities.

The visual dimension of the TELUMI's maps make the tool an attractive means of communication with lay audiences, while its quantitative capabilities can speak to transportation and urban planning professionals. Lay audiences can quickly grasp where zones with latent TE are, and how feasible changes in land use might be in these specific areas to improve transportation options. Professionals can then model the effects of the changes on transportation systems.

The TELUMI's applicability to planning/decision making processes concerned with general transportation issues can also be further focused on transit use, distinguishing, for example, between bus transit and light rail options. It can also be extended to other issues related to land use, such as environmental planning, watershed analysis, brown field redevelopment, or the management of public utilities.

Note: A powerpoint/pdf document is available from the Washington State Department of Transportation (WSDOT) that includes all map layers for King, Snohomish, Pierce, and Kitsap counties.

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CHAPTER 1.
INTRODUCTION

PROJECT CONTEXT

The Washington State Department of Transportation (WSDOT) commissioned the Transportation-Efficient Land Use Mapping Index (TELUMI) as the third and final phase of a larger effort known as *Integrating Land Use and Transportation Investment Decision-Making.* Figure 1 describes the relationships between the three phases of work. The first phase, *Implementing Transportation-Efficient Development: A Local Overview*, reviewed current land-use and development practices by various local jurisdictions in the I-405 and SR 520 corridors (Kavage, Moudon et al. 2002; Kavage, Moudon et al. in press). The second phase, titled *Strategies and Tools to Implement Transportation-Efficient Development: A Reference Manual*, focused specifically on land-use and development practices that support and improve the efficiency and effectiveness of associated transportation systems (Moudon, Pergakes et al. 2003). The third phase, TELUMI, is presented in this report and integrated the findings from phases 1 and 2 with other data to produce criteria for evaluating the transportation efficiency of land-use and development patterns. The final product is not only the maps but a methodology that can be used by WSDOT, local jurisdictions, transit agencies, and others to assess how existing and future land uses can extend, support, or undermine the lifespan of existing or future transportation system capacity.

Phase 1

IMPLEMENTING TRANSPORTATION-EFFICIENT DEVELOPMENT: A LOCAL OVERVIEW

Completed 2002 - Report now available

Phase 1 was a research project that examined the implementation of local land use actions that encourage transportation-efficient development (transportation-efficient development supports the use of alternative transportation modes while reducing the need to drive alone).

This work took a broad view of the effectiveness of local strategies to encourage transportation-efficient development, helped to determine what local actions are best at producing transportation-efficient land use on the ground, and showed where disconnects or barriers inhibit implementation

Phase 2

STRATEGIES AND TOOLS FOR TRANSPORTATION-EFFICIENT LAND USE AND DEVELOPMENT PRACTICES: A REFERENCE MANUAL

Completed 2003 – Report available

Phase 2 documented available resources and served as guidance to local jurisdictions on how, where, and when to encourage transportation-efficient development. The guide includes the following elements:

- An inventory of regulatory tools and related planning processes to implement transportation-efficient development.
- Information on best practices and relevant research.
- A review of financial incentives used in both the public and the private sectors

Phase 3

TRANSPORTATION-EFFICIENT LAND USE MAPPING INDEX (TELUMI)

Focused on the urban portions of the Central Puget Sound region, TELUMI has a number of potential uses:

- Provide a clear, thorough methodology that can be used at the corridor or regional planning level for locating and targeting investments/setting priorities.
- Evaluate how well local land-use strategies, programs, and practices support efficiency of the transportation system as defined by RTPO/MPO plans and regional growth strategies.
- Help WSDOT and others evaluate how local land-use decisions affect the performance of state and regional transportation investments at the programming level.

Figure 1: Three phases of *Integrating Land Use and Transportation Investment Decision-Making.*

THE TELUMI TOOL

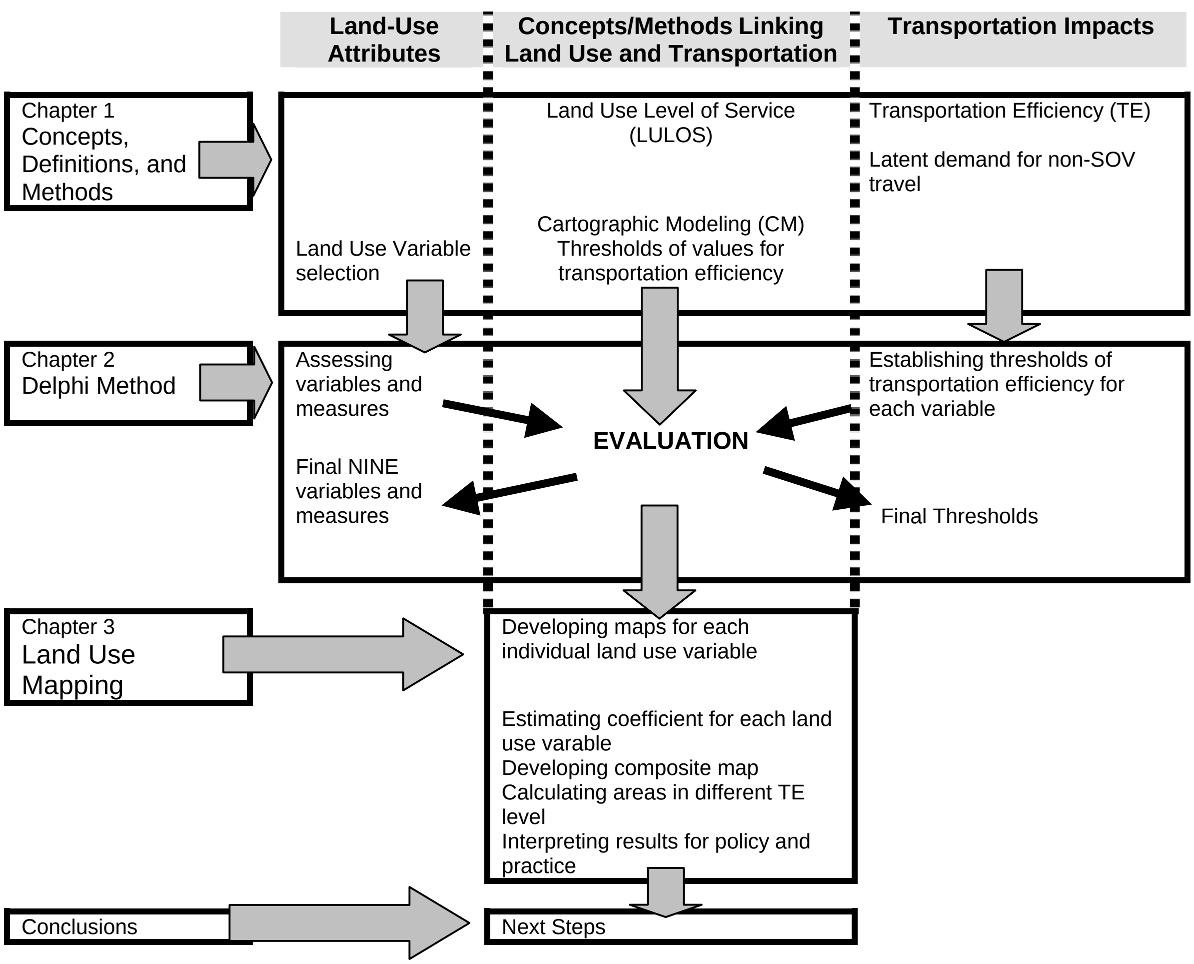
Extensive research over the past decade has shown that land use and transportation are linked by complex but ultimately identifiable sets of relationships. However, tools are lacking to operationalize this relationship and to take it into account when decisions are made about transportation systems in urban and suburban areas. The TELUMI research team recently presented and published a paper for the Transportation Research Board (TRB) that offers a rationale for the types of tools needed to measure and assess the impacts of land use on the performance of metropolitan transportation systems (Moudon , Kavage et al. in press). The paper first lays out major concepts that form the theoretical foundation for evaluating the performance of metropolitan transportation systems. It proceeds with a review of Level of Service (LOS) standards as traditionally used to evaluate transportation systems performance and to make decisions about related investments. This review leads to the need to develop a set of standards akin to a Land Use Level of Service (LULOS). The paper's third section describes the components of the TELUMI, a geographic information system (GIS)-based tool that relates land use to transportation efficiency, as one application of a LULOS. The paper concludes with a discussion of future uses and the TELUMI's development.

STRUCTURE OF THE REPORT

Chapter 2 of this report summarizes the contents of the TRB paper mentioned above, including definitions of foundational concepts to measure the performance of transportation systems, the use of Cartographic Modeling techniques to structure the TELUMI, the selection of land-use variables to be modeled cartographically, and the definition of threshold values to classify the relative transportation efficiency of land-use variables.

This report's third chapter introduces the evaluation and establishment of threshold values for transportation efficiency with a Delphi process. Chapter 4 describes the development of individual and composite maps for indexing transportation-efficient land use. Four appendices provide further technical information on the methods discussed in chapters 3 and 4. The report concludes with a discussion of the results and a list of future steps (Table 1).

Table 1: Structure of report



CHAPTER 2
CONCEPTS, DEFINITIONS, AND METHODS

This chapter introduces concepts important for measuring the transportation efficiency of an area, as well as a method of modeling land use called Cartographic Modeling, which was used to structure the TELUMI. It also briefly reviews the literature to explain how the land-use variables in the final TELUMI were selected. Finally, it discusses how the values of variables can be classified to correspond to thresholds of transportation efficiency.

FOUNDATIONAL CONCEPTS

Key concepts that form the foundation of the TELUMI include *transportation efficiency*; *latent demand* for transit, ridesharing, bicycling, and walking; and *Land Use Level of Service* (LULOS).

Transportation efficiency (TE) is the amount of efficacy and parsimony in transportation investment decisions. An efficient transportation system is one that provides choice and optimizes numbers of people affected, time spent traveling, and cost of travel. In metropolitan areas where the majority of the population lives in relatively compact and often dense settings, the focus of transportation efficiency is typically on decreasing SOV travel. In urban areas, SOV travel consumes too much space given population densities, leading to high levels of congestion and decreased air quality. Transportation-efficient land use supports the use of non-SOV travel modes while decreasing the need to drive alone, and it includes characteristics such as compact development, a mix of land uses, and a pedestrian-friendly environment, among others.

Latent demand for non-SOV travel modes is increasingly evident after fifty years of sustained suburban development shaped for and by automobile travel. Vehicular traffic congestion is reaching a tipping point in fast-growing metropolitan areas, making SOV travel less practical and more costly (Pucher 2002). Also, as suburban development acquires many of the land-use characteristics of older urban areas (with increased density and a full range of office and retail land uses (Jackson 1985)), it is essential to develop an understanding of the conditions that are "right" for introducing, or increasing access to, options of travel other than the SOV. Tools that help define where latent demand exists will come in handy to target areas that optimize and support (rather than undermine) the efficiency of transportation systems.

The concept of *Level of Service* (LOS) has been a standard, long-tested measure in transportation planning and programming. While LOS standards have been developed to guide the design of transportation facilities for automobiles, transit, and non-motorized modes, similar standards are lacking to consider the effects of urban and suburban land uses on travel behavior and transportation systems peformance. The equivalent of a Land Use Level of Service (LULOS) would complement and enhance the existing set of standard LOS measures.

Institutional frameworks at federal, state, and local levels typically separate land use from transportation. Yet a growing awareness of the interconnectedness of the two systems, mounting traffic congestion and pressures of population growth have forced the urban planning and transportation sectors to begin to interact at the local, state, and federal levels. The Institute of Transportation Engineers has long sought to improve its standards reflecting the effects of land use on travel (Institute of Transportation Engineers

1994; Institute of Transportation Engineers 1995; Institute of Transportation Engineers 1999). The U.S. Department of Transportation and the Federal Highway Administration have repeatedly addressed the issue, as reflected in their research and publication programs (Ross and Dunning 1997). Similarly, two major efforts from the urban planning and development realms, the Smart Growth movement and the Congress for New Urbanism, have actively studied and advocated transportation options as an integral part of city planning and building (Urban Land Institute 1999; Litman 2000; McCoy 2000; Porter 2001; Dunphy 2003; Congress for New Urbanism 2004) .

Formalizing the relationship between land use and transportation has been at the center of many growth management and Smart Growth initiatives. So far, policies and measures, such as concurrency and consistency, urban growth boundaries, and the definition of growth centers, all have contributed to making the urban planning and transportation sectors work together. The difficulty is to operationalize the relationship with measures of transportation facilities performance in the *full context* established by adjacent land uses and their own interactive relationships.

The Transportation-Efficient Land Use Mapping Index (TELUMI) explained in this report exemplifies how to operationalize the concept of a LULOS. The TELUMI is an interactive decision-making tool. It consists of a set of land-use measures to assess the potential performance of transportation facilities and networks within specified areas, or to plan where to focus various improvements. It takes into consideration multimodal networks, including streets for cars, pedestrians and bicyclists, and transit, and it considers trip generation based not only on individual land uses but also on the entire context within which these uses are contained. The TELUMI brings into the formulas the numbers and types of people, as opposed to vehicles, likely to engage in travel.

CARTOGRAPHIC MODELING

The TELUMI employs Cartographic Modeling (CM) techniques to map land-use variables, thus showing the distribution of activities in space by type and intensity.

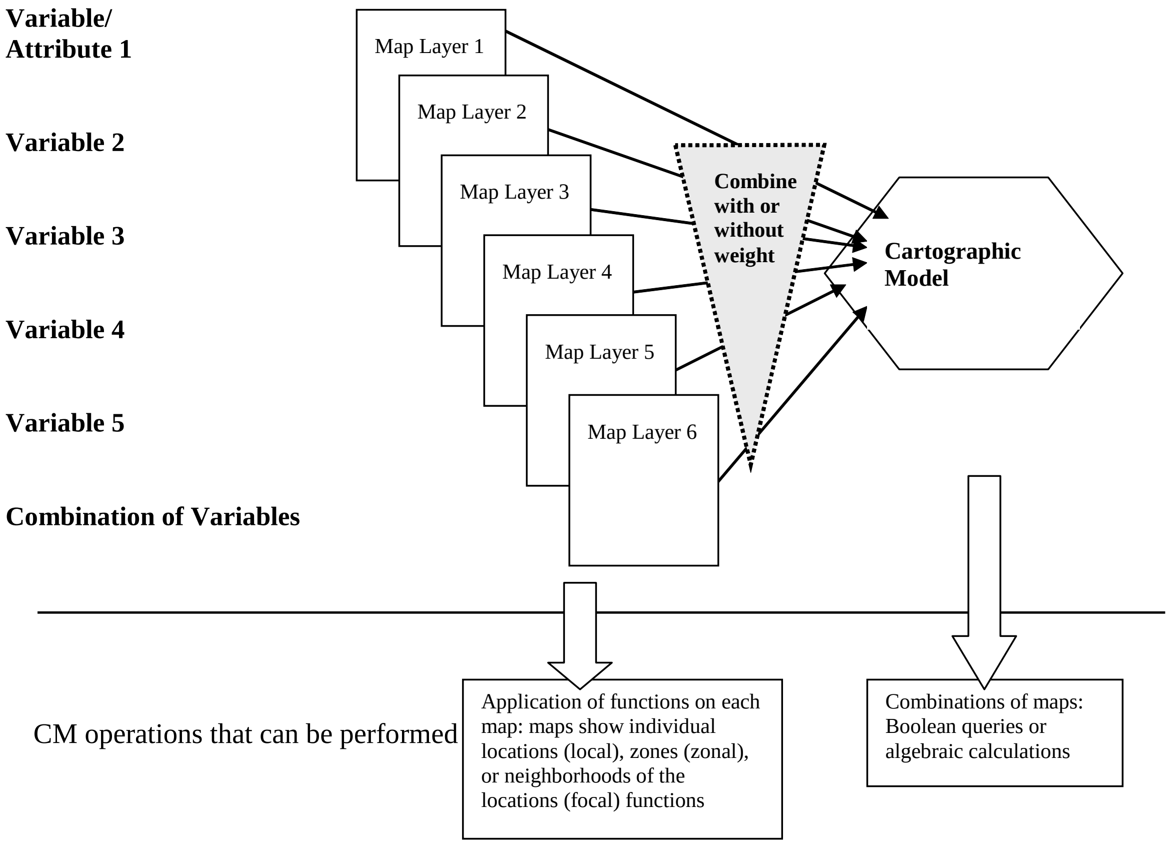
> "A cartographic model is a set of interacting, ordered map operations that act on raw data, as well as derived and intermediate data, to simulate a spatial decision making process" (Tomlin 1990).

The TELUMI maps land use in relation to its transportation efficiency. Cartographic Modeling techniques generate maps of zones within the Puget Sound region that match land-use conditions with different travel behaviors. Zones are defined by individual or combinations of land-use variables, such as density of activities, presence and agglomeration of destinations, block size, and transportation infrastructure attributes.

Cartographic Modeling generates two types of data outputs: (1) maps that *depict locations* or areas at different levels of transportation efficient land use; and (2) tabular data associated with the maps that provide *quantitative information* about the different areas—such as number of residential units, square feet of retail, and linear feet of street—corresponding to the areas at different levels of transportation efficiency. Because CM both produces visual outputs and performs advanced quantitative analyses of map attributes, it is effective with lay and professional audiences and bridges common communication gaps between the two groups.

Furthermore, two types of modeling can be performed, one *descriptive* (answering the question "what is?") and the other *prescriptive* ("what should be?"). The TELUMI uses both types, the former in order to identify existing land-use conditions and the latter to refer to future targeted land uses. Also, both *analytic* and *synthetic* methods are available. These can decompose the data into finer levels of meaning (e.g., look at land-use conditions by each domain of interest—density, mix of use, etc.) as well as recompose or aggregate the data to discover new meanings or to answer larger policy questions (e.g., What are the land-use conditions if both density and mix of use variables are considered?).

The TELUMI's maps are based on individual land-use variables associated with travel behavior (Figure 2). Each map shows the distribution of values contained within one land use variable. The next section describes the initial selection of land-use variables and the definition of threshold values within each that can be associated with a total level of transportation efficiency. A final TELUMI map contains a composite value of all variables derived from a model estimating the weight of each variable relative to transportation efficiency. The development of the composite map is described in Chapter 4.



CM can be *descriptive* or *prescriptive*, helping to establish LULOS for existing land use and development patterns, as well as to assign geographically targets for future LULOS.

Figure 2: Simplified cartographic modeling diagram.

LAND-USE VARIABLE SELECTION

Extensive literature review in the previous phases of this project shaped the selection of land use variables for the TELUMI (Kavage, Moudon et al. 2002; Moudon, Pergakes et al. 2003). The selection process and criteria used for inclusion in the TELUMI are summarized below. A detailed explanation of the selection methodology is forthcoming by the Transportation Research Board (Moudon , Kavage et al. in press).

Table 2 summarizes a conceptual framework that contains six land-use domains that relate to transportation efficiency. This framework helps structure classes of variables that previous research has found to be associated with travel behavior.

Table 2: Domains or groups of variables used to measure the impacts of land use on travel behavior.

Domains/ grouping variables	Domain's principal contribution to understanding land use and travel	Selected references
Density	Identifies critical mass of different types of travelers and their corresponding travel needs	(Steiner 1994; Dunphy and Fisher 1996; Ross and Dunning 1997; Ewing and Cervero 2002; Kavage, Moudon et al. 2002)
Mix of uses	A set of proxy measures of the relationship and distance between trip O and D, which affect mode choice	(Ross and Dunning 1997; Ewing and Cervero 2002)
Connectivity of networks	A set of measures of route directness and choice that affect mode choice	(Ewing 1999; Frank, Stone et al. 1999; Kloster, Daisa et al. 1999; Kulash 2001)
Parking supply and availability	Measures affecting the utility and pricing of car travel—especially in non-residential and popular destination uses	(Shoup 1995; Shoup 1999; Dunphy 2000; Dunphy and Baker 2000)
Pedestrian environment	Captures environmental support for walking and transit use. Often measured as level of comfort, safety, and psychological support provided to non-driving travelers	(Steiner 1998; Hess, Moudon et al. 1999; Cervero 2002)
Affordable housing	Previously captured by the concept of job housing balance. A proxy for the need to reduce travel by reducing the distance between residential and work location for people with a range of incomes, as required by the Service Economy.	(Ross and Dunning 1997; Hirshorn and Souza 2001)

The TELUMI uses at least one variable from each land-use domain that influences travel behavior. Two additional criteria were used to select TELUMI variables. One was the use of individual land-use variables, rather than the composite or factor variables frequently used in research. Individual variables allow easier evaluation of the impacts of specific land-use attribites on travel behavior. They also permit the analyst to target intervention strategies, such as augmenting density or building sidewalks, and to evaluate their potential effectiveness at improving transportation efficiency. This selection criterion was essential for the TELUMI to serve its purpose: assisting transportation and local planning authorities in allocating transportation and land-use investments appropriate to multimodal travel.

A third criterion for selection was data availability. In order for the variables to be mapped, their values had to be available and verifiable from the GIS-based, parcel-level data set from the Washington State Geospatial Data Archive (WAGDA) (University of Washington Libraries ca 2000) and from the real estate property information of the Department of Assessment in King County. Table 3 summarizes the variables initially selected for the TELUMI.

Table 3: Summary of land-use variables first considered for the TELUMI.

Land Use Domains	Primary Spatial Unit Used in Map Layer	Unit of Measurement
Density	Parcel Parcel	▪ Number of residential units per net residential acre of parcel (residential land only) ▪ Employees per NET acre of parcel (non-residential parcels excluding streets)*
Mix of Uses	CBD	▪ Jobs/Housing ratio
	Urban Center	▪ Jobs/Housing ratio ▪ Individual destinations ▪ Groups of destinations
	Neighborhood Center	▪ Jobs/Housing ratio ▪ Individual destinations** ▪ Groups of destinations
Network Connectivity	Street-block	▪ Block size (acres)
Parking Supply and Management	Parcel CBD Urban Center Neighborhood Center	▪ % of parcels covered by parking lots ▪ # of parking spaces per 1,000 gross building sq.ft.
Pedestrian Environment	30m raster Segment/ ½ mile 30M raster Bus stop/1/4 mile 30M raster Segment/1/2 mile 30M raster	▪ Percentage of slope ▪ Average daily traffic (total number of cars) per mile of arterials and major streets ▪ Bus usage ▪ Sidewalk length along major streets
Affordable Housing	Parcel Parcel Urban Center Neighborhood Center	▪ Percentage below mean assessed land and improvement value (80 and 70%) ▪ Count of residential land uses likely to indicate affordable housing

*Employment data sources are explained in Appendix A
** Restaurant, Grocery (food) store, Daycare center, School, Government/civic use, Convenience store, Coffee shop, Entertainment, Retail, Office, Sports

THRESHOLD VALUES OF LAND-USE VARIABLES

Threshold Values and Zones in Cartographic Models

Each map layer in a Cartographic Model shows constituent geographic zones. These *geographic zones* (Figure 3) correspond to *classes of values for each variable* used to map the zones. Each class of values represents a level of TE. In general, the number of classes of variable values, and the upper and lower limits of each class, convey important meaning: they represents *thresholds* at which travel behavior is cast as significantly different from the classes above and below the thresholds.

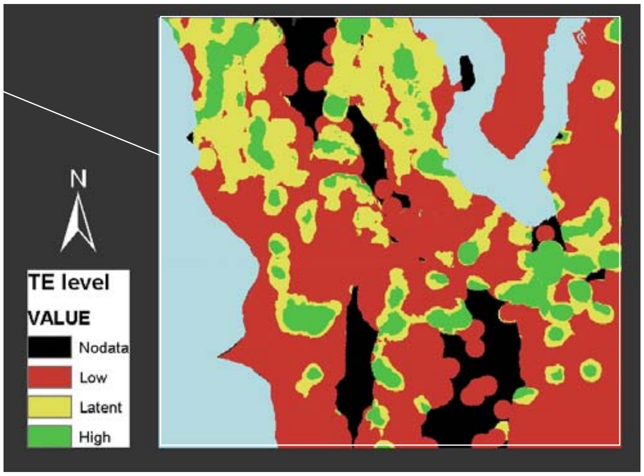


Figure 3: Distribution of residential density in three geographic zones of transportation efficiency.

Threshold Values of Transportation Efficiency

Generally, thresholds are limits or edges that help determine where change (in our case, change in travel behavior) is projected to take place. It is a basic concept in statistics (e.g., significance threshold) and at the root of all standards (e.g., minimum width of traffic lane, sidewalk, minimum lot size, minimum wage). Threshold definition in socially determined processes typically involves *judgment*, as it is difficult to quantify precisely the exact point at which behavior changes—as opposed to physical processes in which changes in state may be precisely measured, such the boiling point of water. Yet the definition of effective thresholds (thresholds that do entail behavior or state change) provides a powerful tool for the management of processes of all kinds, as shown by Malcolm Gladwell in his best seller, *The Tipping Point* (Gladwell 2000). Transportation investments such as road widening or increases in transit service have been associated with tipping points in travel behavior—e.g., the University of Washington's U Pass program, or carpooling (Giuliano and Wachs 1997; Winters 2000). Land-use changes can also produce important changes in travel behavior—e.g., changes in zoning that enable suburban households to move to urban centers (Sohmer 1999).

The TELUMI considers three general classes of travel behavior relating to core concepts of transportation options and related efficiency. The three classes are mapped as the constituent zones in Cartographic Models (Table 4). From a transportation investment perspective, zones with latent transportation efficiciency (TE) will present challenging but promising opportunities to maximize returns in the short run. Zones that already have high TE may only require continued support and maintenance but not likely major investment in new facilities. Investments in low TE zones are likely to be beneficial only in the long or very long term.

Table 4: Classification of transportation options and related constituent CM zones.

Transportation Systems		Cartographic Model		
Transportation Options	**Investment Outcomes**	**Zone/Threshold Name**	**Zone Characteristics**	**Example of Threshold Measure**
Low number and types of options	Likely to be ineffective	**Low TE**	Zones with high number of SOV and low number of transit trips	>90+ % of trips in SOV
Latent number and types of options	Likely to be highly effective	**Latent TE**	Zones with medium number of transit or para-transit trips	>75 % of trips in SOV
High number of types and options	Likely to be effective	**High TE**	Zones with high number of transit, para-transit, and non-motorized trips, and low SOV number of trips	<75 % of trips in SOV

Defining the lower and upper limits of each class for each map layer entails a combination of (1) “hard,” objective knowledge on travel behavior and its association with land use and (2) “expert,” subjective judgment. The former is literature derived, while the latter is achieved through a Delphi process, involving national and local experts in transportation. The Delphi process is described in Chapter 3.

Threshold Values from the Literature

A new literature review was conducted to examine threshold values identified in past research for land-use variables affecting travel behavior. The review updated earlier attempts to evaluate the state of knowledge in transportation efficiency (Federal Highway Administration 1999; Schwartz, Porter et al. 1999) and included more recent overviews of research results in land use and transportation (Ewing and Cervero 2001). An inventory of measures and threshold values for the land-use variables associated with different types and intensities of travel modes summarized the literature review results.

Land-use variables found were classified into one of the six land-use domains in Table 3. Density was the variable most studied, followed by mixed use and connectivity. Many fewer studies addressed parking supply and pedestrian environment, and none researched affordable housing (although there was some research on job-housing balance).

The dependent variables in most studies yielded information about mode choices, often focusing on only one or two modes. Studies generally focused on transit use separately from auto use. Many more studies of transit use addressed light rail than bus transit. Furthermore, most studies concentrated on specific locales and provided little information on the generalizability of results. In particular, land-use measures typically were not specified in enough detail for generalizability. For example, density measures were not specified by unit of data collection (e.g., census block group or tract) or by unit of normalization (e.g., entire census tract, area in residential use in census tract). Measures of mixed use were even more difficult to decipher, as they consisted of composite measures of several variables and were taken at different spatial extents (e.g., census tracts of different sizes).

Overall, past research was useful in providing a sense of the land-use conditions that affect travel behavior, but cross-comparisons remained unreliable, with the effect that threshold values could not be precisely pinpointed from existing studies. Informed by the preliminary results of literature review, the Delphi process then served as the next step in determining thresholds.

CHAPTER 3
ESTABLISHING THRESHOLDS OF TRANSPORTATION EFFICIENCY: THE DELPHI METHOD

The Delphi method is a group communication structures used to facilitate communication on a specific task. It uses a systematic approach to derive consensus in a group on a subject for which the required information is not available (Adler and Ziglio 1996). The method usually involves anonymity of responses, feedback to the group as a whole of individual and/or collective views, and the opportunity for any respondent to modify an earlier judgment. Despite some criticisms in the early literature (Hill and Fowles 1975), the Delphi method is considered to be a valid method for judgmental forecasting (Richey, Mar et al. 1985; Tolley 2001).

The Delphi method consists of a series of interviews, usually by means of questionnaires, to a group of knowledgeable individuals whose opinions or judgments are of interest. In this case, questionnaires were distributed via email. After the initial interview of each individual, each subsequent interview is accompanied by the results of the preceding round of replies, usually presented anonymously. The individual is thus encouraged to reconsider and, if appropriate, to change his/her previous reply in light of the replies of other members of the group. After two or three rounds, the group position is determined by averaging.

In this project, the goal of the Delphi inquiry was to obtain group responses from experts in the fields of transportation and land use on thresholds of values for the selected land-use variables. The process served to validate and enhance thresholds of values identified in the literature and established in previous research.

DATA

A questionnaire was developed for the Delphi process (see Appendix B for a copy of the questionnaire). The questionnaire addressed each one of the land-use variables and provided a format for the participants to fill in their estimates of threshold values. Delphi participants were requested to report their comfort level with their answers for each of the questions on a scale of 1 to 3 (1: not comfortable / 2: comfortable (pretty sure) / 3: very comfortable).

The specific calculations for each variable's threshold values were clearly spelled out on the questionnaire. This was an important aspect of the instrument because GIS protocols require that "net" or "gross" parcel-level measures be precisely specified in terms of areas—i.e., groups of parcels considered in the computations as, for example, residential-, retail-, or office-only parcels, or for all parcels, or for parcel and street areas. A radial distance also had to be specified for variables that can not be measured at the parcel level but are calculated at the area-level, such as job-housing balance or percentage of affordable housing. For such measures, the GIS performs "neighborhood analyses" (Appendix C), searching for the value of individual parcels or cells and calculating combination of values (sums, averages) of adjacent parcels or cells. The radial distance from a central point, known as the buffer, defined the geographic extent of "adjacency" or "neighborhood."

The questionnaire also established three categories to represent the level of transportation options available (see Table 4). The number and type of transportation options available ranged from "high" to "low," which corresponded to a high, medium, or low percentage of trips taken by SOV.

The questionnaire was accompanied by examples of land-use values from five existing neighborhoods and districts of the Puget Sound to guide the Delphi panel of experts in determining thresholds for each measure. The five sample areas are relatively well known and well documented as transportation “hubs,” and they included two pre-war neighborhoods in Seattle, Queen Anne and Wallingford; two suburban downtowns, Bellevue and Kirkland; and the post-war suburban neighborhood of Crossroads in Bellevue. Table 5 shows the areas’ block structure and provides a brief descriptive background. Values of land use variables and corresponding travel data for the sample areas provide baseline information for other areas of the Puget Sound (Table 6).

Table 5. The five sample areas (1/2-mile radius buffer).

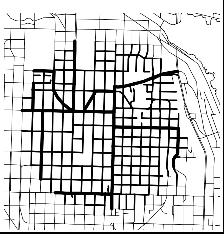
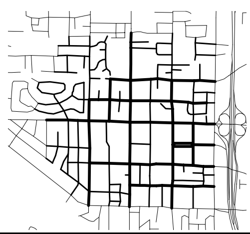
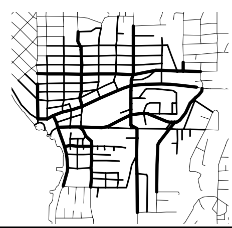
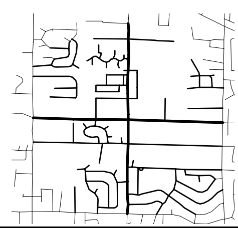
Queen Anne	Wallingford	Downtown Bellevue	Downtown Kirkland	Crossroads
STREET-BLOCKS				
				
DESCRIPTION				
Turn of the century Seattle neighborhood on top of a 600-ft hill. Linear, street-car era retail development on NS street in the center of the map above. **1500 travel diaries available (Rutherford, Ishimaru et al. 1995)	Early 19th century Seattle neighborhood. Linear, street-car era retail development on EW street in the center of the map above. **1500 travel diaries available (Rutherford, Ishimaru et al. 1995)	Region’s second employment center after Seattle. Post-1950 “edge-city” development, with 4+ high-rise office and hotel buildings, a regional mall and new housing. **Good local travel data.	Downtown of a small, progressive suburban city, subject to 20+ years of rigorous planning. One of the densest suburban centers of the region after Bellevue. **1500 travel diaries available (Rutherford, Ishimaru et al. 1995)	Dense, post-1960 suburban residential area centered around a neighborhood mall. With condos and apartments surrounding the retail. **Local travel data available

Table 6. Land-use measures for Queen Anne, Wallingford, Bellevue, Kirkland, and Crossroads (figures derived from within 1/2-mile radius from 100% corner).

Domain/Measure	Unit of Measurement	Queen Anne	Wallingford	Downtown Bellevue	Downtown Kirkland	Crossroads
Area of all parcels	Acre	341.16	321.56	435.60	386.82	500.64
Area of residential parcels	Acre	266.19	258.83	165.10	193.18	261.08
Total # of Res. Units	#	3,997	3,510	2,467	2,290	2,561
Total # of Jobs	#	3,331	4,122	27,918	6,843	3,166
Job/Housing ratio	Total # of jobs / Total # of Res. Units	0.8	1.2	11.3	3.0	1.2
Residential Density	Residential Units per net residential acre (area in residential parcels only)	15.02	13.56	14.94	11.85	9.81
Employment Density	Employees per NET acre (non-residential parcels excluding streets)	44.4	65.7	103.2	35.3	13.2
	Employees per GROSS acre (all parcels excluding streets)	9.76	12.82	64.09	17.69	6.32
Mix of Uses	Jobs-housing ratio (# of Jobs/# of DUs)	0.83	1.17	11.32	2.99	1.24
Connectivity of Networks	Average block size (acres)	3.80	3.24	10.70	7.94	24.3
	Length of streets in miles (clipped)	22.43	23.68	15.10	16.95	10.16
	Length of sidewalks in miles (clipped) – sidewalks on local streets are not included	7.80	8.21	15.69	9.07	5.80
Parking	# of parking spaces per 1,000 commercial building sq.ft.	N/A	2.32	2.89	3.45	5.43
	% of site covered by at-grade parking lots (commercial parcels only)	0.51	0.44	0.65	0.52	0.78
Pedestrian Environment	Total daily traffic (total number of cars on all arterials and major streets	135,172	246,950	623,263	152,885	93,405
	Average daily traffic (total number of cars) PER MILE of arterials and major streets	33,242	71,698	142,978	44,543	17,773
	Topography (average % of slope)	3.23%	1.90%	1.36%	2.32%	1.34%
Affordable Housing (1)	Count of land uses available in database (# of group homes, nursing homes, and retirement facilities)	3	1	1	0	2
	% of affordable housing units *Threshold: mean assessed property value of King Co ($ 294,402) (2)	19.7%	52.0%	8.8%	18.5%	21.9%
	% of affordable housing units *Threshold: 90% mean assessed property value of King Co ($ 264,961) (3)	11.5%	34.8%	6.6%	14.1%	19.2%
	% of affordable housing units *Threshold: 80% mean assessed property value of King Co ($ 235,521) (4)	5.1%	17.3%	3.2%	9.2%	12.4%
	% of affordable housing units *Threshold: 70% mean assessed property value of King Co ($ 206,081) (5)	1.7%	7.0%	0.7%	4.0%	4.3%

Table 6. Land-use measures (continued)

Domain/Measure	Unit of Measurement	Queen Anne	Wallingford	Downtown Bellevue	Downtown Kirkland	Crossroads	Domain/Measure
Destinations conducive to alternative mode use	# of destinations	Grocery store	6	2	3	1	1
		Convenience store	0	4	0	1	3
		Daycare center	0	1	0	1	1
		Restaurant	8	20	19	7	3
		School	8	6	4	3	4
		Theater	1	2	0	1	2

(1) Condominiums are not included because the assessed property value data are not available.
(2) 554% of the median household income of King County 1999
(3) 498% of the median household income of King County 1999
(4) 443% of the median household income of King County 1999
(5) 388% of the median household income of King County 1999

METHOD

A panel of nine local and national experts in transportation and land use was selected in collaboration with staff at the WSDOT. (Appendix B provides a list of panel participants.)

Two rounds of Delphi surveys were conducted between May and August 2004. After the responses from the first round had been analyzed, the second round questionnaire and the summary of the first round mean results (including comfort levels) were distributed to the panel members. The purpose of the second round was to verify previous responses. Panel members were asked to reconsider their previous answers in light of the given feedback and to make a final decision on the thresholds.

RESULTS

The results of the second Delphi round were reviewed by the transportation and urban planning panel of experts at a meeting with WSDOT staff in September 2004. The discussion focused on the selection of land-use measures for GIS mapping, as well as on the validation of the thresholds suggested in the Delphi survey. Below are the results of the two rounds and the final thresholds adopted (tables 7 through 19). Comparisons with the five sample areas are also shown (figures 4 through 13).

The percentage of SOV trips was used in the first question (Table 7) because it provided a single measure of travel behavior and mode share, allowing the questionnaire to avoid specifying different types of non-SOV travel for which data are not readily available, especially at the neighborhood or district scales. The two measures are inversely related, and a high share of SOV trips correspond to low TE.

Table 7: Question 0: Percentage of trips in SOVs.

		Round 1	Round 2	National	Selected
Mean of comfort level		1.9	1.7		
Range of each class	Low	83%<	61.8%<	90%<	90%
	Latent	64%-83%	56.6%-61.8%	64%-90%	75%-90%
	High	0%-64%	0-56.6%	64%>	75%>

Table 8: Question 1: Number of residential units per net residential acre.

		Round 1	Round 2	Selected
Mean of comfort level		2.1	2.3	
Range of each class	Low	0-7	0-7	6<
	Latent	7-15	7-14.7	6- 10
	High	<15	14.7<	10>

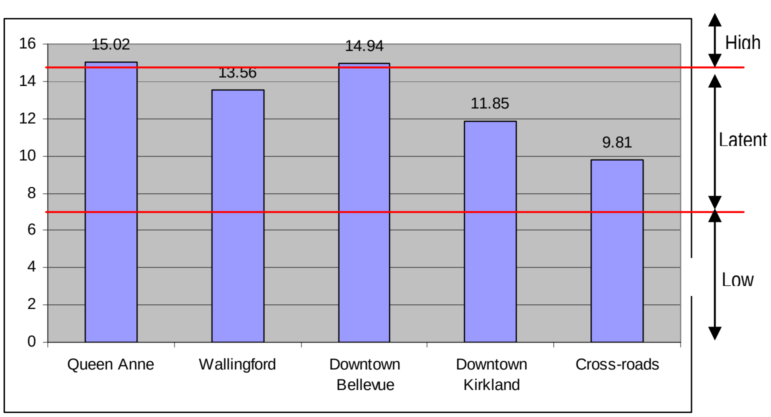


Figure 4: Residential densities of the five study areas and the three selected threshold classes.

Table 9: Question 2: Employees per net acre of non-residential parcels.

		Round 1	Round 2	Selected
# of respondents		6	6	
Mean of comfort level		1.8	2.2	
Range of each class	Low	0-35.8	0-38.2	0-30
	Latent	35.8-83	38.2-80.6	30-70
	High	83<	80.6<	70<

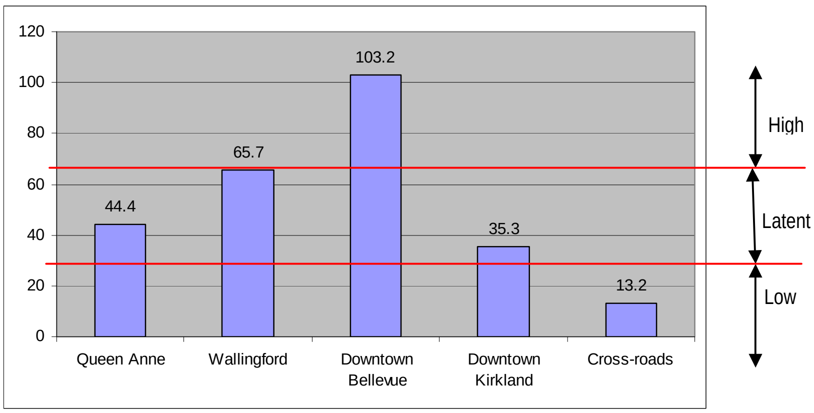


Figure 5: Net employment densities of the five study areas and the three selected threshold classes.

The measure of job/housing ratio (Table 10, figures 6 and 7) was dropped from the analyses after extensive discussion for several reasons. First, the ratio can vary greatly, depending on the types of "centers" considered—e.g., CBDs typically have higher ratios than neighborhood centers. This wide range of values would require extensive research to classify the Puget Sound region's nodes, an exercise that seemed somewhat arbitrary because past and current planning efforts have not yielded agreement on the hierarchy of centers in the region and have only designated 21 urban centers. Second, single residential and employment measures were already taken into consideration as two of the TELUMI's layers, effectively duplicating the data that would be provided by job/housing ratios.

Table 10: Question 3: Job/housing ratio (no threshold class selected).

			Round 1	Round 2	Proposed
# of respondents			6	6	
CBD	Mean of comfort level		1.7	1.8	
	Range of each class	Low	20.2<	17.7<	NA
		Latent	7-20.2	6.2-17.7	NA
		High	0-7	0-6.2	0-20
Urban Center	Mean of comfort level		1.7	1.8	
	Range of each class	Low	13.2<	10.8<	13<
		Latent	6-13.2	4.5-10.8	11-13
		High	0-6	0-4.5	0-11
Neighborhood Center	Mean of comfort level		1.7	1.6	
	Range of each class	Low	4.7<	4<	4<
		Latent	2.4-4.7	2-4	2-4
		High	0-2.4	0-2	0-2

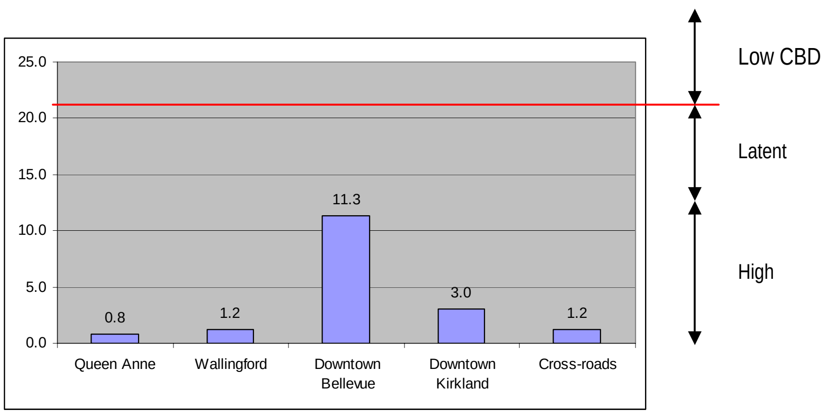


Figure 6: Job/housing ratio in the five study areas and selected threshold classes for CBDs .

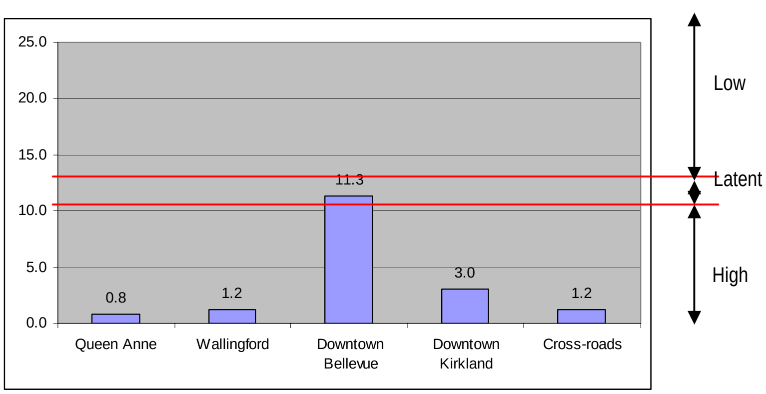


Figure 7: Job/housing ratio in the five study areas and selected threshold classes for urban centers.

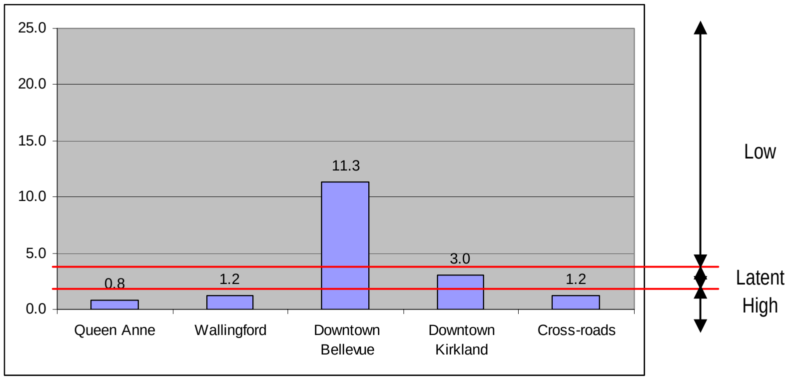


Figure 8: Job/housing ratio in the five study areas and selected threshold classes for neighborhood centers.

The results of the Delphi process regarding the selection of types and number of individual destinations and groups of destinations conducive to non-SOV travel (tables 11 and 12) were inconclusive. Further work on the definition of variables that capture mixed use and related thresholds is discussed at the end of Chapter 3.

Table 11: Question 4-1: Individual destinations conducive to alternative mode use.

	Individual Destination	# of responses	Mean of ranges			Comfort Level
			Low	Latent	High	
ROUND 1	Restaurant	6	0-2	3-5.3	5.3<	2
	Grocery(food) store	3	0	1	1<	2.3
	Daycare center	3	0-0.3	0.3-1.7	1.7<	2.3
	School	1	0-1	2-3	3<	2
	Mid-high density housing	1	0-1	2-4	4<	2.3
	Government/civic use	1	0	1	1<	2.7
	Convenience store	1	0	1	1<	1.5
	Coffee shop	1	0	1	1<	1.5
	Entertainment	1	0-3	4-8	8<	1
ROUND 2	Grocery(food) store	4	0	1	1<	2.33
	Restaurant	3	0-1.5	1.5-3	3<	2.5
	Daycare center	3	0	1	1<	2.5
	School	1	0-1	1-3	3<	3
	Mid-high density housing	1	1	1-4	4<	2.33
	Government/civic use	1	0	1	1<	2.67
	Convenience store	1	1	2	2<	2

Table 12: Question 4-2: Groups of destinations conducive to alternative mode use

	Group of Destinations	# of responses	Mean of ranges			Comfort Level
			Low	Latent	High	
ROUND 1	Daycare+grocery+drugstore	1	0	1	1<	1
	School+daycare+grocery	1	0	1	1<	1
	Restaurant+dry clean+grocery	1	0	1	1<	1
	Grocery+drugstore+dry clean	1	0	1	1<	2
	School+community center+library	1	0	1	1<	2
	Restaurant+café+specialty retail	1	0	1	1<	2
	General retail	1	0-4	5-10	10<	2.3
	Entertainment uses	1	0-2	3-5	5<	2
	Office uses	2	0-3	4-6	6<	1.8
	Retail	1	0-1	2	2<	1.5
	Service	1	0-1	2	2<	1.5
ROUND 2	Daycare+grocery +drugstore	1	0	1	1<	2
	School+daycare+grocery	1	0	1	1<	2
	School+community center+library	1	0	1	1<	2
	General retail	1	0-4	5-10	10<	2.33
	Entertainment uses	1	0-2	3-5	5<	2
	Office uses	1	0-5	6-10	10<	2
	School+daycare +convenience store	1	0-1	2-3	3<	3
	Grocery+drug store+coffee shop	1	0-1	2	2<	2
	Restaurant+café +specialty retail	1	0	1	1<	2

Table 13: Question 5: Average block size in acres.

		Round 1	Round 2	Selected
# of respondents		6	6	
Mean of comfort level		2.3	2.6	
Range of each class	Low	10.5 acres <	9 acres<	10<
	Latent	4.2 acres -10.5 acres	4.8 acres - 9.0 acres	10-6
	High	0 acres -4.2 acres	0 - 4.8 acres	0-6

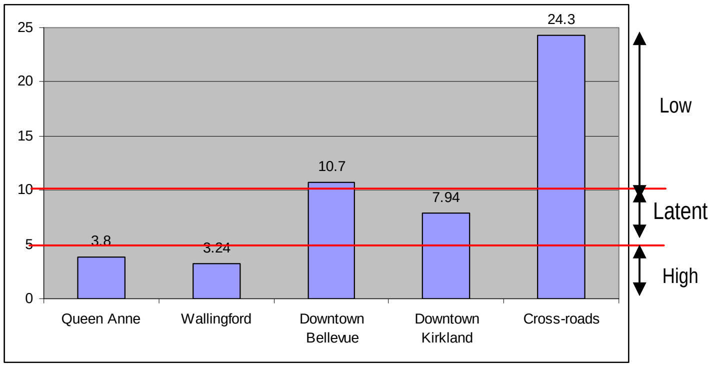


Figure 9: Average block size in the five study areas and the three selected threshold classes.

The number of parking spaces per 1,000 gross non-residential building square feet (Table 14) was dropped as a measure because of lack of reliable data for the Puget Sound region. However, the expert panel was relatively confident of the threshold classes obtained through the Delphi process, and these data would be extremely useful to have in future efforts to assess transportation systems.

Table 14: Question 6: Number of parking spaces per 1,000 gross non-residential building sq.ft. – thresholds are not proposed.

		Round 1	Round 2	Selected
# of respondents		6	5	
Mean of comfort level		2	2.3	
Range of each class	Low	3.6<	3.8<	3.8<
	Latent	1.9-3.6	2.0-3.8	2.0-3.8
	High	0-1.9	0-2.0	0-2.0

Table 15: Question 7: Percentage of parcels covered by parking lots.

		Round 1	Round 2	Selected
# of respondents		6	6	
Mean of comfort level		1.9	2.1	
Range of each class	Low	52.5%<	50.0 % <	75% < <
	Latent	31.7%-52.5%	27.5% - 50.0 %	35%- 75 %
	High	0%-31.7%	0-27.5%	0—35%

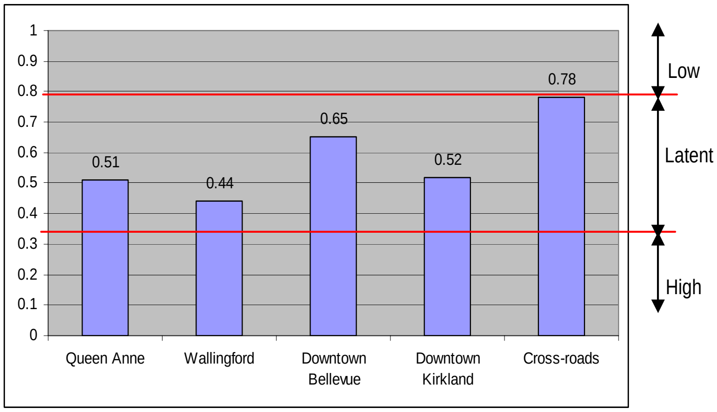


Figure 10: Percentage of parcels covered by parking lots in the five study areas and the three selected threshold classes.

Table 16: Question 8: Percentage of slope.

		Round 1	Round 2	Selected
# of respondents		5	5	
Mean of comfort level		1.7	2.0	
Range of each class	Low	5.6%<	5.0% <	5.0% <
	Latent	2.7%-5.6%	2.5%-5.0%	2.5%-5.0%
	High	0%-2.7%	0-2.5%	0-2.5%

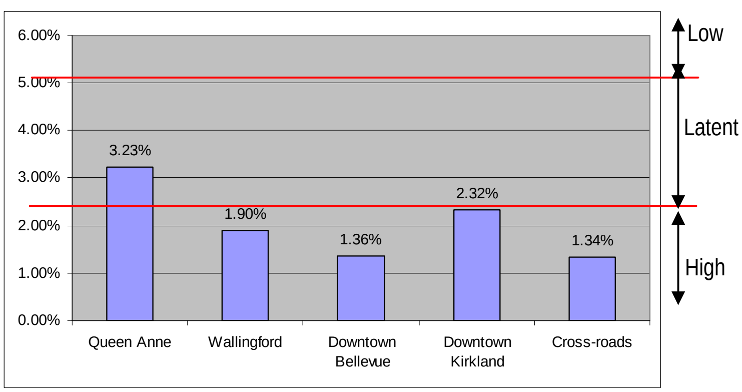


Figure 11: Percentage of slope in the five study areas and the three selected threshold classes.

Average daily traffic (ADT) turned out to be an unreliable measure of transportation efficiency (Table 17, Figure 12) because arterials with high traffic volume also typically have good transit access, but they may or may not have good support for non-motorized travel. The five study areas illustrate this point. This measure was dropped from further consideration.

Table 17: Question 9: Average daily traffic along major streets.

		Round 1	Round 2	
# of respondents		3	3	
Mean of comfort level		1.9	1.7	
Range of each class	Low	0-166,667	0-110,000	0-150,000<
	Latent	166,667-216,667	110,000.0-183,333.3	150,000-250,000
	High	216,667<	183,333.3<	250,000<

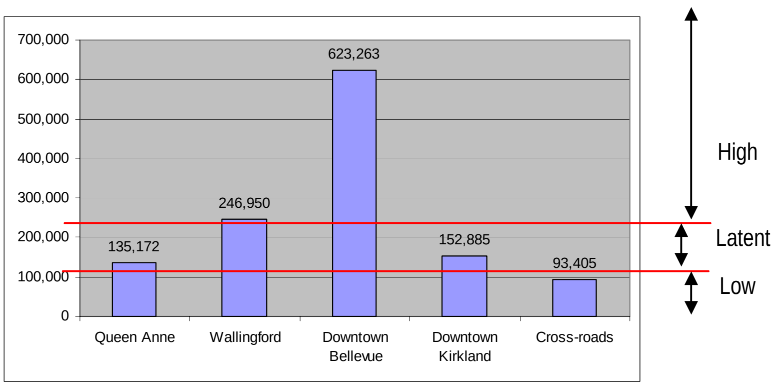


Figure 12: Average daily traffic in the five study areas and the range of three classes.

Table 18: Question 10: Percentage of residential units below the mean assessed property value.

		Round 1	Round 2	
# of respondents		4	4	
Mean of comfort level		1.8	2.1	
Range of each class	Low	0%-15%	0-16.3%	0-40
	Latent	15%-26.3%	16.3% - 29.0%	40-70
	High	26.3%<	29.0% <	70<

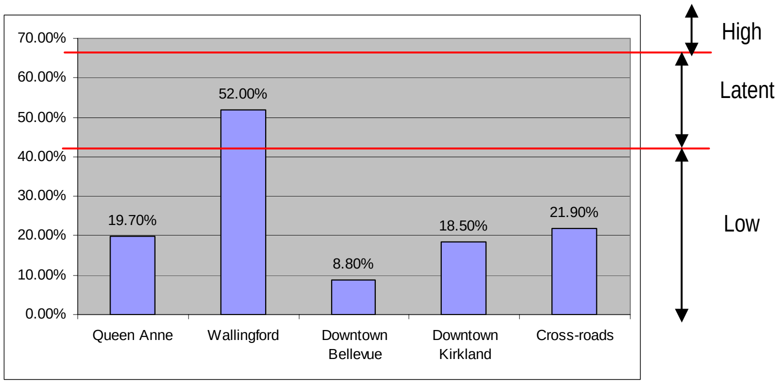


Figure 13: Percentage of residential units below the mean assessed property value in the five study areas and the range of three classes.

Table 19: Question 11: Residential land uses most likely to indicate affordable housing.

Round 1			Round 2		
Residential Use	# of responses	Comfort Level	Residential Use	# of responses	Comfort Level
Apartment	4	1.95	Apartment	3	2.1
Manufactured housing	1	2	Manufactured	2	2
Public housing	1	2	Public/subsidized	1	2
Senior housing	1	2	Senior housing	1	2
Accessory dwelling units(ADUs)	1	2	Accessory dwelling units(ADUs)	1	2
Subsidized housing	1	2.3	Subsidized housing	2	2.15
Row houses (5-10 units)	1	1.5	--	--	--
Duplex, triplex (2-5 units)	1	1.5	Duplex, triplex, fourplex	1	2
Small lot residential	1	2	Small lot residential	1	2

EVALUATION AND FURTHER DEVELOPMENT OF LAND-USE VARIABLES AND THRESHOLDS

The Delphi process produced density, connectivity, pedestrian environment, and affordable housing variables (variables 1,2,5,6,7,8 in Table 20) whose thresholds were defined with a high level of agreement among participants and with support from the literature. However, it also raised important doubt about the ability of the variables selected to capture mixes of uses to support non-SOV travel with the data on hand (variables 3 and 4 in Table 20). Participants were further aware of the limitations of employment density data, which are not a good reflection of travel activity related to shopping and education trips. These land uses are associated with low numbers of employees, and many more trips are generated by shoppers and students than by the employees of these land uses. Further work was therefore needed to take these limitations into account.

Table 20: Summary variables and measures from the Delphi process*.

			TE Threshold (% SOV trips)	>90	75-90	<75
Domain		Variables	Measure			
Density	1	Residential Density	Net acre (residential parcels	>10	6-10	<6
	2	Employment Density	Net acre(non-residential parcel)	>30	30-70	>70
Mix	*3***	*Destinations conducive to non-SOV modes*	*Restaurant*	*0*	*1-4*	*>4*
			Grocery	*0*	*1*	*>1*
	*4***	*Group of Destinations*	*NA*	*NA*	*NA*	*NA*
Connectivity	5	Block size	acre	>10	6-10	<6
Parking Supply	6	Parking Supply	% of non-residential parcel (Net)	>75	35-75	<75
Ped Environment	7	Topography	% slope	>5	2.5-5	<2.5
Affordable Housing	8	Percentage of affordable housing in a neighborhood	% area in residential parcels (Net) with the property value per unit below the county average.	<40	40-70	>70

* Variables deleted (reason for deletion)

- Job/housing ratio (lack of established classification of employment cores)
- Number of parking spaces per 1,000 gross non-residential building sq.ft (lack of regional data)
- Average daily traffic (lack of relationship with non-SOV mode use)
- Residential land uses associated with affordable housing (assessed property value variable is sufficient to capture housing affordability, and data on the specific land uses are incomplete)

** Threshold values for variables 3 and 4 are difficult to estimate for lack of empirical data on associations between travel and specific individual and groups of destinations

Given the findings of the literature and the results of the Delphi survey, further work was needed to develop the measures of mixed use to support non-SOV travel and to consider the transportation impacts of retail and schools. The process for doing so is described in the following two sections.

Rethinking Mixed-Use Variables

Indidivual and groups of retail travel destinations were captured by variables found to be significantly related to walking in neighborhoods in another project. The project, the Walkable and Bikable Communities (WBC) project, relied on a survey of 608 randomly selected respondents in King County matched individually to objective measures of the environment surrounding their homes. In this project, amounts of walking were found to be highly and significantly associated with groups of destinations that included at least one grocery store, one restaurant, and one retail facility within 50 M of each other (Moudon, Lee et al. 2005). These groups of destinations were called Neighborhood Centers or NC2, and their locations in King County were identified. Areas within and around the NC2 clusters were coded as highly transportation efficient, as anyone living or working in close proximity could walk to them.

Adding the Effects of Travel Related to Shopping and Educational Uses

The limitations of employment data, which do not reflect well on actual travel activity related to retail and school trips, were addressed by identifying these land uses in the parcel data and assigning them a value related to the transportation activity they generated. The values were derived from ITE trip generation standards (Institute of Transportation Engineers 2003) (Table 21). The average value for shopping trips was estimated to be 50 trips per 1,000 sq.ft, and the value for education uses was estimated to be 14 trips per 1,000 sq.ft.

Table 21: Trip generation rate – shopping and school traffic (trips per 1,000 sq.ft. gross floor area) (Institute of Transportation Engineers 2003).

	Land use types	# of Samples	Weekday	# of Samples	Saturday
Shopping trips	Free-Standing Discount Superstore	10	49.21	10	57.5
	Specialty Retail Center	4	44.32	3	42.04
	Free-Standing Discount Store	23	56.02	21	71.19
	Hardware/Paint Store	3	51.29	3	82.52
	Nursery (Garden Center)	11	36.08	12	72.71
	Nursery (Wholesale)	39	1	7	29.9
	Shopping Center	302	42.94	123	49.97
	Factory Outlet Center	11	26.59	2	40.97
	Supermarket	4	102.24	2	177.59
	Convenience Market (24hs)	8	737.99	4	863.1
	Convenience Market with Gas Pumps	10	845.6	3	1448.33
	Discount Supermarket	7	96.82	11	117.03
	Wholesale Market	1	6.73	1	1.59
	Discount Club	19	41.8	16	53.75
	Arts and Crafts Store	1	56.55		
	Average	30.2	146.35	15.57143	222.0136
	Median	10	50.25	7	71.19
Suggested trip generation rate: 50 trips per 1,000 sq.ft.					
School trips	Elementary School	31	14.49		
	Middle/Junior High School	20	13.78		
	High School	43	12.89		
	Junior/Community College	4	27.49		
	Average	24.5	17.16		
	Median	25.5	14.14		
Suggested trip generation rate: 14 trips per 1,000 sq.ft.					

CONCLUSIONS

At the conclusion of the Delphi evaluation process, nine land-use measures were selected for GIS mapping. Table 22 shows the list of land-use measures with their definitiona and the data needed for their estimation.

Table 22: Land-use measures.

Domains		Measure	Description (formula)	Required data
Density	1	Net residential density	This measure is estimated for the residential parcels only. Formula: Total number of residential units in a parcel / Area of a parcel in acres	Parcel data - # of res.units in a parcel - Area of a parcel
	2	Employment density	This measure is estimated for non-residential parcels. Formula: Total number of employees in a parcel / Area of a parcel in acres	Employment data Parcel data - Area of a parcel
Mix Use	3	Existence of NC2	NC2 is defined as the area where at least one restaurant, one retail, and one grocery store are located with a maximum distance of 50m to each other.	NC2 data
	4	Shopping traffic volume	Total number of trips per day generated from the retail facilities. Formula: Traffic volume = Trip generation rate per 1000 sq.ft. (50) * building sq.ft. of retail facilities /1000	Trip generation rate Parcel data - Building square footage
	5	School traffic volume	Total number of trips per day generated from the schools. Formula: Traffic volume = Trip generation rate per 1000 sq.ft. (14) * building sq.ft.of schools / 1000	Trip generation rate Parcel data - Building square footage
Connectivity	6	Block size in acres	The size of the street block defined by the surrounding streets	Street-block Data
Parking Supply	7	Net % of surface parking lots	It is an approximated measure assuming that the open space in a parcel is parking lots. Formula: (Area of a parcel – Area of the 1st floor)/Area of a parcel *100 *Area of the 1st floor is approximated using FAR, building square footage and the number of stories. 1st floor area = (Area of a parcel * FAR) /# of stories	Parcel data Area of a parcel FAR Number of stories (Bldg)
Ped. Environment	8	% of slope	Steepness of the slope in percent	Slope data
Affordable Housing	9	% of area of affordable housing	Percent of the area of the residential parcels with the assessed property value per residential unit below the average of King County (1)	Assessed property value data Parcel data - # of res. units in a parcel
(1) The average assessed property value per residential unit in King County is $ 188,270 * All measures are estimated within a spatial extent of a quarter-mile radius buffer				

CHAPTER 4
LAND USE MAPPING

DATA

The project used several types of transportation, land-use, urban form, and property value data. Table 23 provides a brief description of each data source. The data sources were either used directly as the one of the land-use measures (e.g., slope, street block size) or in the calculation of another land-use measure (e.g., densities, assessed property values).

Table 23: The data used in the TELUMI project.

Data	Description
Parcel-level GIS data of King County	The Urban Form Lab (UFL) in the Department of Urban Design and Planning at the University of Washington developed parcel-level GIS data of King County based on the parcel data set from the Washington State Geospatial Data Archive (WAGDA) (University of Washington Libraries ca 2000) and real estate property information from the Department of Assessment in King County. This data set contains information such as a parcel identifier, area of the parcel, and dominant land-use types, as well as information about buildings on the parcel, such as floo- area ratio (FAR), building square footage, number of stories, and total number of residential units.
Street-block GIS data	The street-block GIS data set was developed by the UFL. It contains the information of the size of street-blocks (in acres and sq.ft.) for King County.
Slope data	The slope data for King County were obtained from the WAGDA. These data provide the level of steepness (%).
Assessed property value data	The Department of Assessment in King County provides up-to-date assessed property value data at the parcel level (e.g., land value and improvement value). This data set was attached to the parcel GIS data and used to estimate the measure of housing affordability.
Shopping and School Trip Generation Rate	The Institute of Transportation Engineers (Institute of Transportation Engineers 2003) reports the trip generation rates for various facilities every five years. The trip generation rates are estimated on the basis of national samples.

METHOD

The TELUMI mapping took place in two steps: (1) the development of individual map layers to describe and assess the impact of each variable on transportation efficiency, and (2) the development of a weighting system for each variable to obtain a composite index.

Measurements

The land-use measures estimated in the analysis are the average of a given land-use measure in a neighborhood, defined as a circular area with a quarter-mile radius. This spatial extent is sufficient to capture the characteristics of the neighborhood for evaluating the level of transportation demand for alternative modes to SOV (Moudon and Lee 2003; Lee 2004).

Individual Map layers

Table 24 summarizes the variables and measures of land use considered.

Each land-use map produced in the GIS analyses illustrates the distribution of three zones of transportation efficiency, each classified by the predetermined thresholds. Table 25 illustrates the process and products of the GIS spatial analyses needed to create the land-use maps. The technical issues and details of GIS methodology are explained in Appendix C.

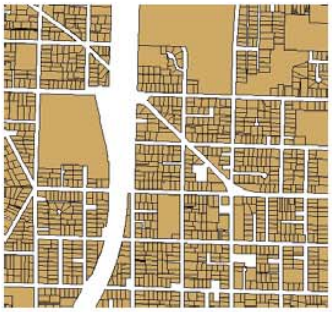
Table 24: Summary of variable measurement and layers.

Variable	Measure	Analysis area	Measurement Description	Variable classification scheme		
				Model	Mapping	TE Zone Calculations
Residential density	Net residential density	Residential parcels (1)	An average of residential density in a neighborhood (3)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)
Employment density	Net employment density	Non-residential parcels (1)	An average of employment density in a neighborhood	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)
NC2 (2)	Proximity to NC2	Countywide	A quarter-mile radius buffer area around identified NC2	Dichotomous (High/Low)	Dichotomous (High/Low)	Dichotomous (High/Low)
School traffic	Number of school trips	School parcels (1)	Total number of school trips in a neighborhood (quarter-mile radius buffer)	Continuous	Categorical (3 classes - quantiled)	Dichotomous (High/Low)
Shopping traffic	Number of shopping trips	Retail parcels (1)	Total number of shopping trips in a neighborhood (quarter-mile radius buffer)	Continuous	Categorical (3 classes - quantiled)	Dichotomous (High/Low)
Average block size	Average street block size in acres	Countywide	An average size of street blocks in a neighborhood	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)
Percentage of parking at grade	Net percentage of surface parking lots in commercial parcels	Commercial parcels (1)	An average percentage of surface parking lots of commercial parcels in a neighborhood	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)
Slope	Percentage of slope	Countywide	An average percentage of slope in a neighborhood	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)
Affordable housing	Net percentage of area of affordable housing	Residential parcels	An average percentage of area of affordable residential parcels in a neighborhood	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)
Composite 1	Composite layer	Countywide	Significant variables are highlighted in grey—all variables except affordable housing	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)	Categorical (High/Latent/Low)

(1) See Appendix D for land use classification
(2) NC2: A neighborhood center containing at least one retail parcel, one restaurant parcel, and one grocery store parcel
(3) A neighborhood: a quarter-mile radius buffer around the data measurement point (cell)

Table 25: GIS processes for producing land-use maps.

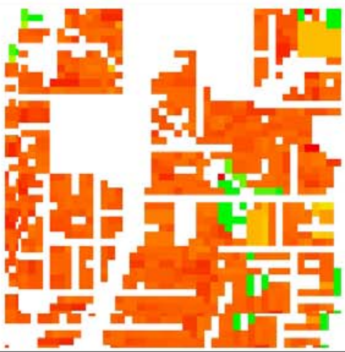
1. Data development



The first step for the GIS spatial analysis is to construct the master parcel database that contains the information of all attributes required for the estimation of the land use measures. Since the attributes utilized in this research were obtained from different data source, they need to be systematically combined together. All attribute data sets used in this research share the information of a parcel identifier number (PIN*) and are systematically assigned to the parcel GIS database using it. In addition, all land use measures for each parcel is calculated using the attached attributes. The values of the measurement are also attached to the mater parcel database.

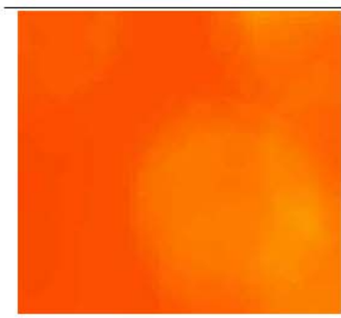
* Parcel level information is recorded and managed using a parcel identifier. It consists of ten-digit numeric codes obtained from two attributes called "major" and "minor".

2. Data transformation (Vector to Raster)



The land use measures recorded in the master parcel database need to be converted to Raster in order to conduct the GIS analysis utilizing cartographic modeling method. In this study, a grid of 30m by 30m pixels is used. We decided to use the resolution of 30m by 30m pixels based on the findings of pixel size test for some neighborhoods in King County (see Appendix C: Raster resolution). The output of this process illustrates the distribution of the land use measure at the parcel level on the grid of 30m by 30m pixels.

3. Neighborhood analysis



Using a Raster neighborhood analysis technique, overall TE level of a neighborhood (an average land use measure in a quarter-mile radius buffer centered on a cell) is estimated. The land use layers produced through this process are used as the final output representing the spatial distribution of the single land use measure at the neighborhood level.

4. Data reclassification (see Appendix C):

The measure of neighborhood analysis is reclassified into three categories (low, latent, and high) based on the thresholds decided in previous phase. The value of 0 is given to the pixels with invalid data (nodata) in order to synchronize the Raster frame; this is needed to operate composite-measure calculation.

Development of the Composite Map

The final step of the analysis is to create a composite map that depicts the spatial distribution of different TE levels and that considers the impacts of multiple land-use measures on travel behavior. Past research has shown that the effects of different domains of land use on travel behavior are substantially different (Ewing and Pendall 2001; Krizek 2003). In order to identify the different weights of the individual variables used in this project, a statistical model was estimated by using bus ridership data as the dependent variable (described in detail in Appendix D). The purpose of this analysis was to gauge the level of association between land-use measures and the level of bus usage. The beta values for each land use measure estimated in the analysis are used as the weights for individual land-use measures in the composite TELUMI measure.

Table 26 shows the results of one of the binary-logit models used to develop the composite map. The resulting model has a Pseudo R-square value of 0.344. All the TELUMI variables are statistically significant in the model, with the exception of Affordable Housing. The Residential and Employment Density, Percentage of Parking at Grade, and NC2 variables show relatively strong association with the dependent variable, while the effects of school and retail traffic volumes are weak.

The GIS maps of a composite measure of the TELUMI and selected individual land-use variables are shown in figures 14 and 15.

Table 26: Model results (Model 1).

Model 1: Land-use variables				
Nagelkerke R-square: 0.344				
Variable Name	B*	S.E.	Sign.**	Exp(B)
res_den	0.662	0.053	0	1.939
p_parking	0.506	0.076	0	1.659
nc2	0.471	0.08	0	1.602
emp_den	0.416	0.056	0	1.517
slope	0.324	0.07	0	1.383
blk_size	0.311	0.046	0	1.365
sch_traff	0.002	0	0	1.002
ret_traff	0	0	0	1
Constant	-5.181	0.179	0	0.006

*B values are the weights applied to each variable to calculate the composite layer
**Significant at 0.99 level

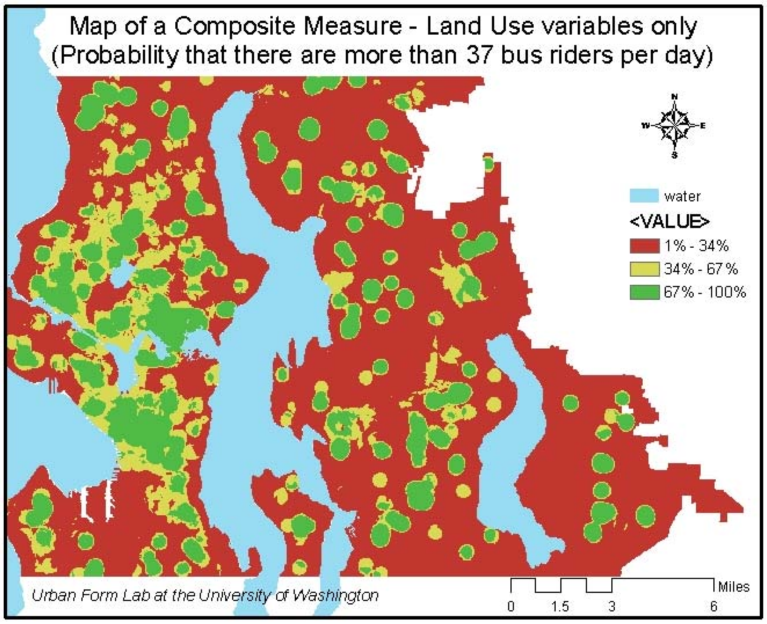
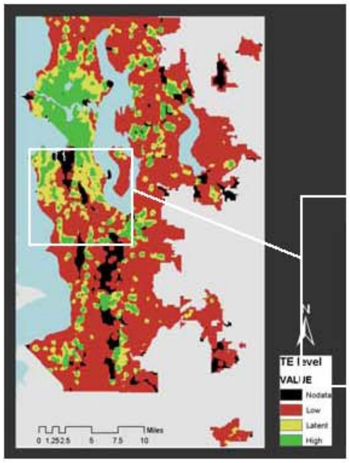
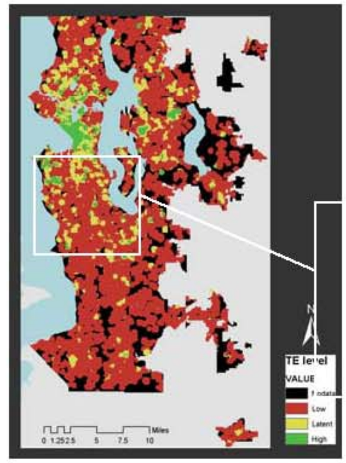


Figure 14: Map of a composite measure (Model 1). (The B values in Table 26 are the weights applied to each variable to calculate the composite layer.)

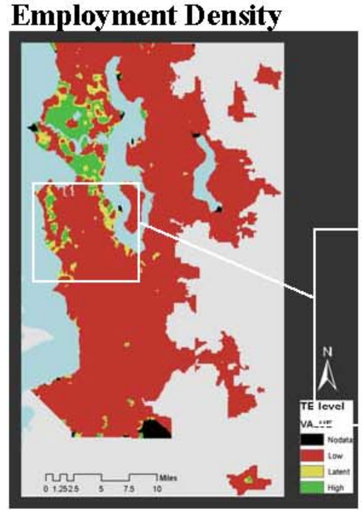


Residential Density

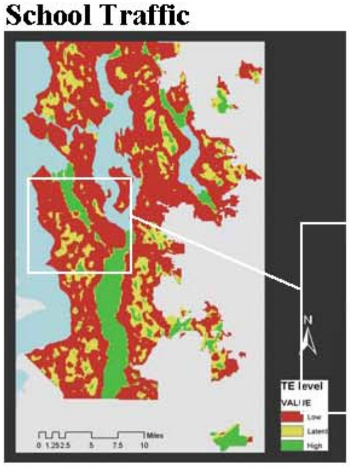


Employment Density

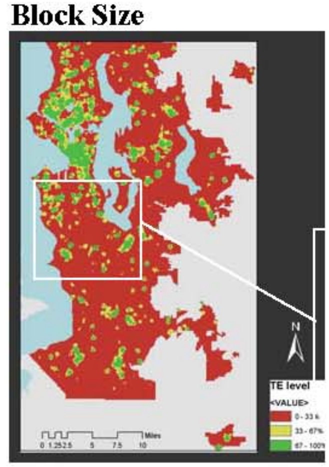
School Traffic



Block Size



Slopes



Composite Layer

Figure 15: Examples of the TELUMI layers

RESULTS AND DISCUSSION

Powerpoint and pdf documents are available from WSDOT with all map layers for the urban growth areas (UGAs) of King, Snohomish, Pierce, and Kitsap counties.

Results are presented below for each TELUMI layer, including the composite layer. Calculations include (1) percentage of areas with high, latent, and low TE, (2) intensity of development at the three TE levels, measured by the number of residential units and employment, (3) areas at all three levels of TE within 1 km of major transportation facilities, and (4) areas by levels of TE in the five sample areas used to guide the Delphi process. The focus is on results in the King County urban growth area.

King County Summary

Percentage of Areas with Three Levels of TE

The TELUMI can calculate areas in the King County UGA that have low, latent, and high levels of TE for each layer and for the composite measure layer (Table 27).

Table 27: Summary of King County percentage of geographic areas with high, latent and low TE for all map layers.

	Layer	High TE	Latent TE	Low TE	No data*	Total**
1	Residential density	13.0%	14.0%	65.0%	8.0%	100.0%
2	Employment density	3.3%	11.5%	64.0%	21.2%	100.0%
3	NC2***	13.3%	N/A	N/A	86.7%	100.0%
4	Shopping traffic**	31.9%	N/A	68.1%	N/A	100.0%
5	School traffic**	30.0%	N/A	70.0%	N/A	100.0%
6	Block size	5.0%	5.0%	88.0%	2.0%	100.0%
7	Percentage of parking at grade**	0.3%	12.3%	66.3%	21.1%	100.0%
8	Slope	15.0%	18.0%	67.0%	0.0%	100.0%
9	Affordable housing	22.0%	28.0%	50.0%	0.0%	100.0%
10	Composite 1	8.0%	9.0%	83.0%	0.0%	100.0%
	* Areas where no valid classification is available **Total area of parcels In King County UGB = 472.4 square miles ***Only commercial parcels are taken into account					

Figure 16 shows the percentage of geographic areas with high, latent, and low TE for each variable. The total area included in King County covers 472.4 square miles (1,359,471 raster cells of 900 square meters)

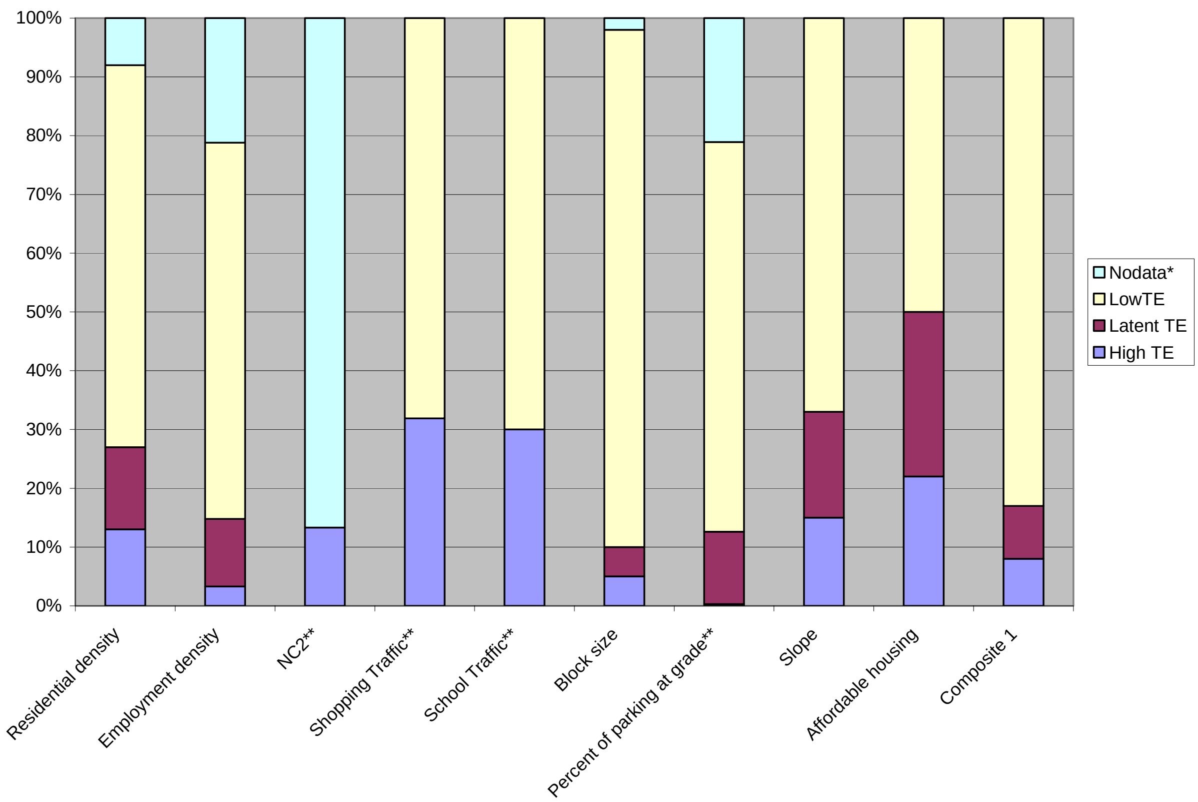


Figure 16: King County percentage of geographic areas with high, latent and low TE by individual map layer (total area = 472.4 square miles).

The analyses of individual layers show the following:

- The residential density layer has a larger percentage of area with high TE than the employment density layer. This indicates that residential uses are more evenly distributed in terms of density than employment uses. Employment uses that create areas with low TE likely include manufacturing and industrial businesses. However, further examination of low TE employment uses may reveal possibilities to use these lands more efficiently.

- The shopping and school traffic layers have large percentages of area with high TE. This is expected because these land uses tend to nucleate. In addition, the criteria to define high TE zones in this layer are comparatively generous because they include all parcel areas of these uses.
- Within the layers describing block size and percentage of parking at grade, high percentages of areas with large block size and large amounts of parking at ground contribute to low overall TE. Incentives to reduce parking at ground and to reduce block size could change this pattern.
- Sizeable percentages of areas with medium residential and employment density, a medium percentage of parking at grade, and a medium amount of affordable housing have latent TE. Addressing these land-use attributes could improve overall TE.

The results of each individual layer need to be interpreted in light of the regression model used to define the composite layer. The model shows that all variables used in the map layers are significant. However, residential density, percentage of parking at grade, NC2, employment density, slopes, and block sizes have the highest coefficients, meaning that these variables are the ones that should be specifically addressed in considering future land-use policies intended to improve transportation efficiency.

With respect to the composite layer, a low pecentage of the King County UGA area (less than 20 percent) has high or latent TE. This may be advantageous in that the sizes of the land areas involved have a direct impact on the length of transportation systems to be provided to serve these lands. Hence future improvements to transportation systems in areas of latent TE (where improvements are most likely to be beneficial) may involve not only a limited number of areas but also relatively few facilities. However, the large percentage of areas with low TE also means that low future transportation investments would "leave out" large areas of the county.

Figure 17 combines the percentages of areas with high and latent TE by individual layer.

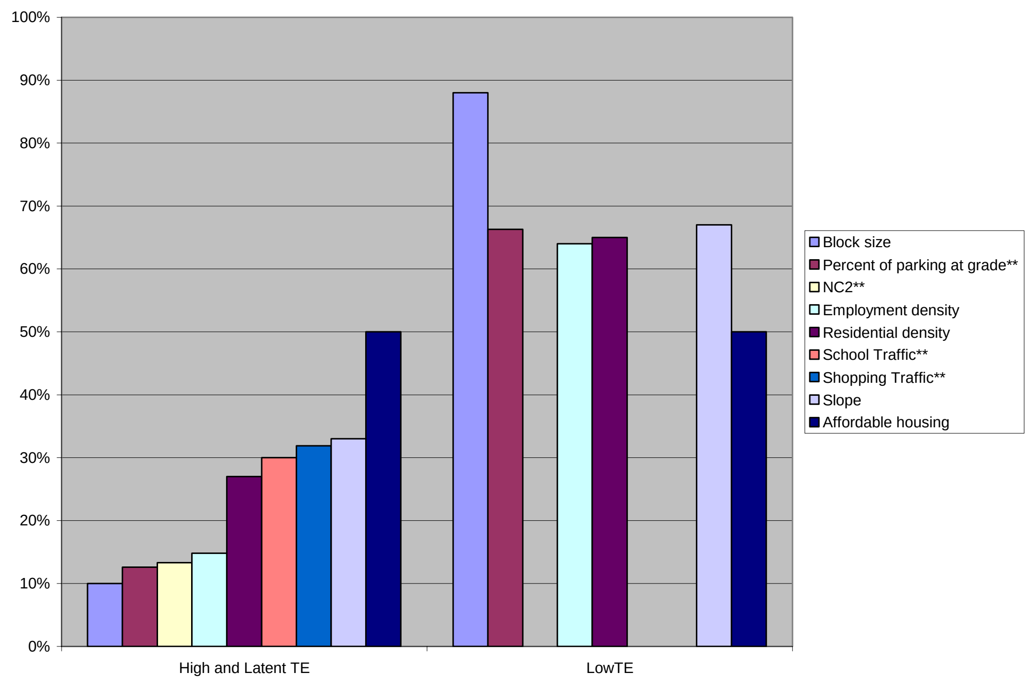


Figure 17: King County percentages of areas with high and latent TE for each map layer, in ascending order.

Intensity of Development at the Three Levels of TE

The intensity of development of the three TE zones can also be calculated in terms of number of residential units and employment in each zone (Table 28).

Table 28: King County residential units and employment at the three TE levels (total number and percentage

	High TE	Latent TE	Low TE	King County (Total)
Residential units	150417	170909	424700	746026
(percent)	20%	23%	57%	100%
Employees	600595	373605	268625	1242825
(percent)	48%	30%	22%	100%

The figures reflect the distribution of residential and employment actitivities at each level of TE. They do not provide information on the actual size of areas involved—for example, land areas in residential uses are much larger than those in employment uses, likely requiring longer transportation routes for proper servicing.

Figure 18 summarizes the percentage of residential units and employees at the three TE levels in the King County UGA.

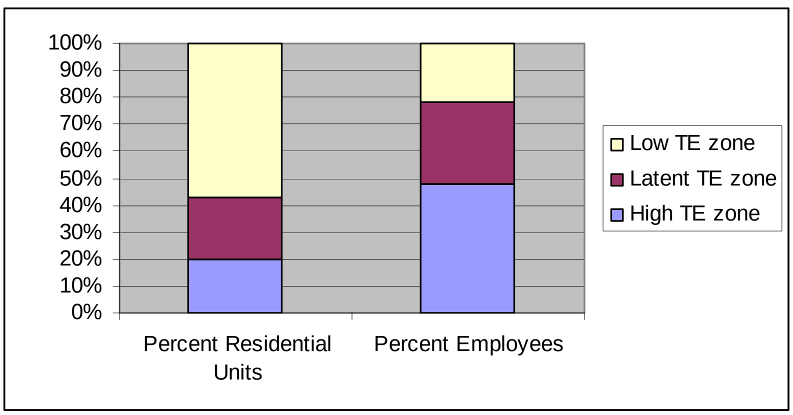


Figure 18: King County percentage of residential units and employees at high, latent, and low TE levels.

These results are promising in that 20 percent of the residential units and almost 50 percent of the employment are within high TE zones, indicating fairly high concentrations of activities with high TE levels. Furthermore, more than 40 percent of the residential units are within high and latent TE zones, and almost 80 percent of the employment is within high and latent TE zones.

These findings show that while areas with high and latent TE levels are small, they hold a substantial share of housing and employment. This means that upgrading the latent areas to high TE levels could be relatively economical—there would be fewer roads, shorter transit routes, and shorter sidewalks. to attend to in terms of investment because of these latent areas' small sizes.

Transportation Efficiency of Areas Near Existing Transportation Facilities

These analyses assess how much of the areas with high and latent TE levels are near existing transportation infrastructure. Figure 19 shows the distribution of TE zones within 1 km of highways and primary streets (Table 29).

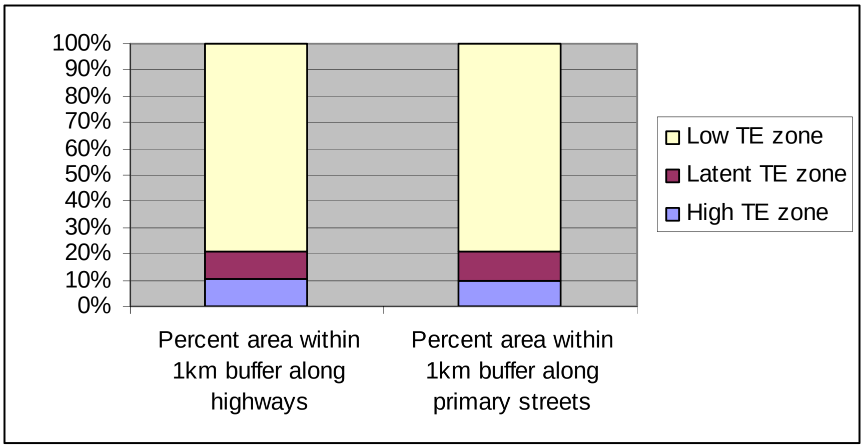


Figure 19: King County percentage of high, latent, and low TE zones within 1-km buffer of highways and primary streets.

Table 29: King County total acres and percentage of high, latent, and low TE zones within 1-km buffer of highways and primary streets.

King	Buffer (sub total)	High TE zone	Latent TE zone	Low TE zone
Area within 1km buffer along highways (in acres)	114,589	11971	11888	90731
(percent)	100.0%	10.4%	10.4%	79.2%
Area within 1km buffer along primary streets (in acres)	224,587	22448	24111	178027
(percent)	100.0%	10.0%	10.7%	79.3%

These findings show that less than 20 percent of the county's highways and primary streets are adjacent to areas with high and latent TE. This may indicate that the existing transportation system may be diffused and not supportive enough of actual development and activities. However, because only the presence of facilities is considered in this analysis, it is possible that measures of facility capacity (e.g., number of lanes, traffic speed, bus routes) would show a level of service more directly related to adjacent land uses and activities. Further analyses are required to investigate this issue.

Regarding future transportation investments, detailed analyses of facilities along high and latent TE zones should help assess and target improvements. Also, similar analyses need to be carried out on specific facilities such as freeway, bus, and rail routes. Comparisons of results using several buffer sizes (½ and 2 km) would also be worthwhile.

Transportation Efficiency in the Five Delphi Sample Areas

Coming full circle regarding the development of the TELUMI, analyses of the five sample areas used in the Delphi process resulted in findings that are not surprising—and in fact support many of the assumptions made during the course of this project (Table 30). Zones with high TE levels (composite layer) in the five sample areas range from 15 to 70 percent of the total sample areas (Figure 20). Crossroads is the least transportation-efficicent sample, as expected. Bellevue has the lowest proportion of area with latent TE, perhaps reflecting the tight zoning envelope separating the downtown from surrounding neighborhoods. A sizeable proportion of the areas of Queen Anne, downtown Kirkland, and Crossroads have latent TE, indicating promising potential for future improvements.

Table 30: TE zones in the five Delphi sample areas, Composite Layer.

Sample Area	Total (area in acres)	High TE zone	Latent TE zone	Low TE zone
Crossroads	500	73	172	255
(percent)	100.0%	14.6%	34.4%	51.0%
Queen Anne	500	357	128	15
(percent)	100.0%	71.4%	25.6%	2.9%
Bellevue	500	361	82	57
(percent)	100.0%	72.2%	16.5%	11.4%
Kirkland	500	167	191	143
(percent)	100.0%	33.3%	38.2%	28.5%
Wallingford	500	361	110	29
(percent)	100.0%	72.2%	21.9%	5.9%

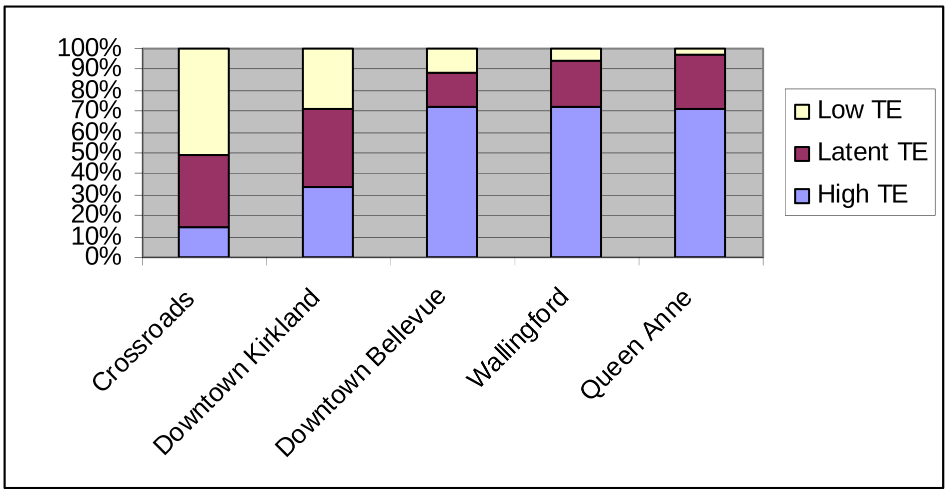


Figure 20: Percentage of geographic areas at the three levels of TE in the five sample areas (Composite Layer).

Further analyses should assess the extent to which existing plans support what is already "on the ground," including the Urban Centers designated under current regional and local plans.

Snohomish County Summary

Table 31: Summary of percentage of Snohomish County geographic areas with high, latent and low TE for all map layers.

Layer	High TE	Latent TE	Low TE	No data*	Total**
Residential density	4.70%	10.20%	78.20%	7.00%	100.00%
Employment density	1.30%	6.90%	29.60%	62.10%	100.00%
NC2***	9.70%	N/A	90.30%	N/A	100.00%
School traffic	28.20%	N/A	71.80%	N/A	100.00%
Shopping traffic	38.70%	N/A	61.30%	N/A	100.00%
Average Block Size	1.00%	0.50%	96.40%	2.20%	100.00%
Percent of Parking at grade	0.00%	1.90%	71.10%	26.90%	100.00%
Slope	21.50%	29.30%	47.00%	2.20%	100.00%
Affordable housing	30.80%	15.70%	46.50%	7.00%	100.00%
Composite 1	7.10%	8.10%	78.90%	5.90%	100.00%

* Areas where no valid classification is available
**Total area of parcels In King County UGB = 91.2 square miles (262,564 raster cells of 900 sq. m)
***Only commercial parcels are taken into account

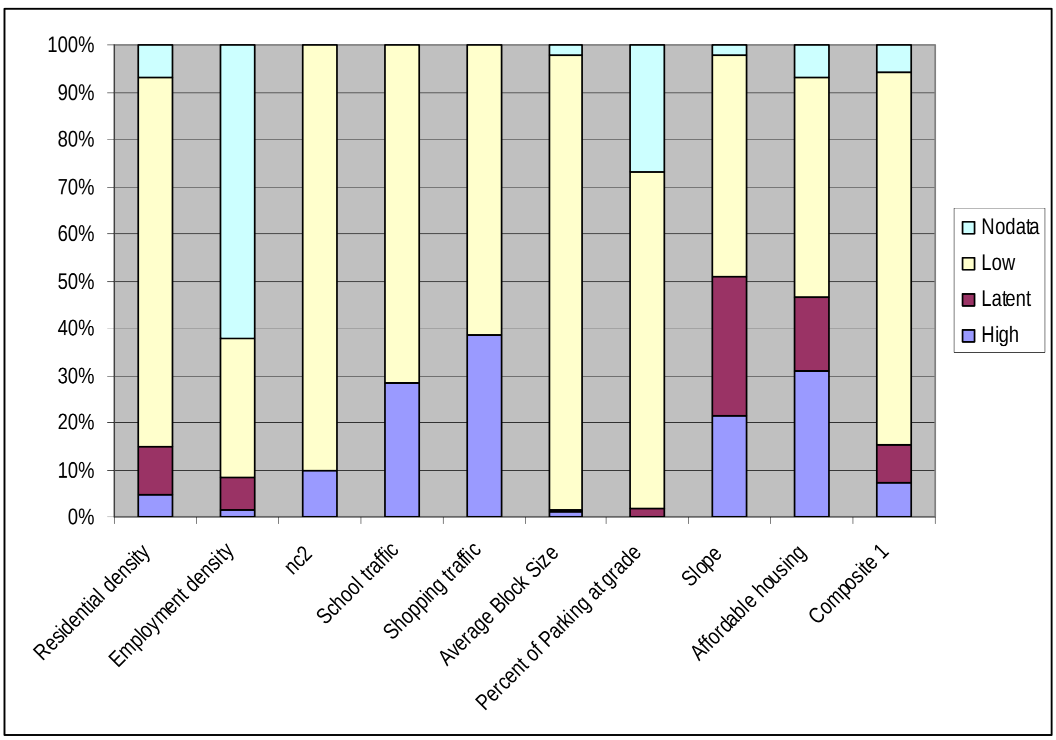


Figure 21: Snohomish County percentage of geographic areas with high, latent and low TE by individual map layer (total area = 91.2 sq. mi.).

Table 32: Summary of percentage of residential units and employment at different TE levels in Snohomish County.

Snohomish County

	High TE	Latent TE	Low TE	Total*
Residential units	19818	24916	169917	214651
(percent)	9%	12%	79%	
Employees	16489	20826	51014	88329
(percent)	19%	24%	58%	

*within Urban Growth Boundary

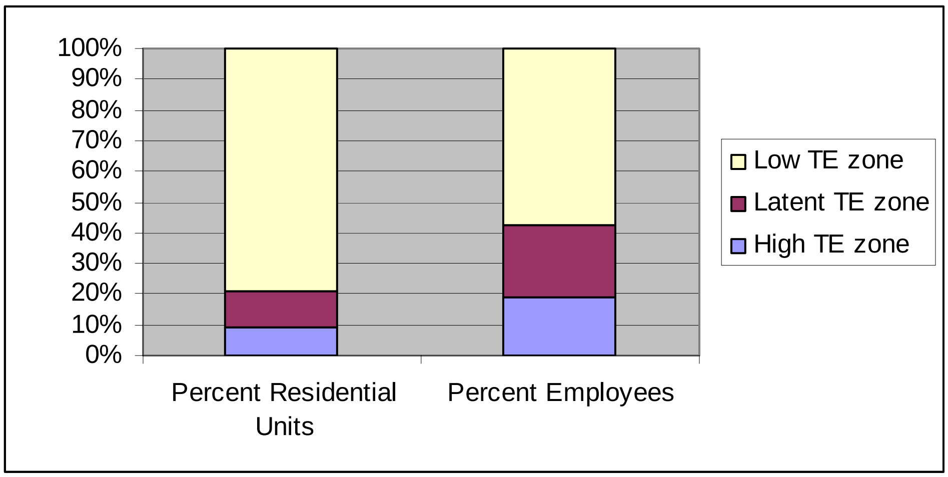


Figure 22: Snohomish County percentage of residential units and employees in areas with high, latent, and low TE.

Pierce County Summary

Table 33: Summary of Pierce County areas with high, latent and low TE for all map layers.

Layer	High TE	Latent TE	Low TE	No data*	Total**
Residential density	3.10%	1.10%	67.50%	28.30%	100.00%
Employment density	0.10%	1.00%	62.30%	36.60%	100.00%
NC2***	3.20%	N/A	96.80%	N/A	100.00%
School traffic	6.00%	N/A	94.00%	N/A	100.00%
Shopping traffic	17.10%	N/A	82.90%	N/A	100.00%
Average Block Size	2.00%	1.70%	94.90%	1.50%	100.00%
Percent of Parking at grade	0.00%	1.20%	62.30%	36.60%	100.00%
Slope	2.50%	3.90%	91.40%	2.20%	100.00%
Affordable housing	37.60%	12.10%	22.00%	28.30%	100.00%
Composite 1	1.50%	1.40%	60.40%	36.60%	100.00%

* Areas where no valid classification is available
**Total area of parcels In King County UGB = 262 square miles (754,082 raster cells of 900 sq. m)
***Only commercial parcels are taken into account

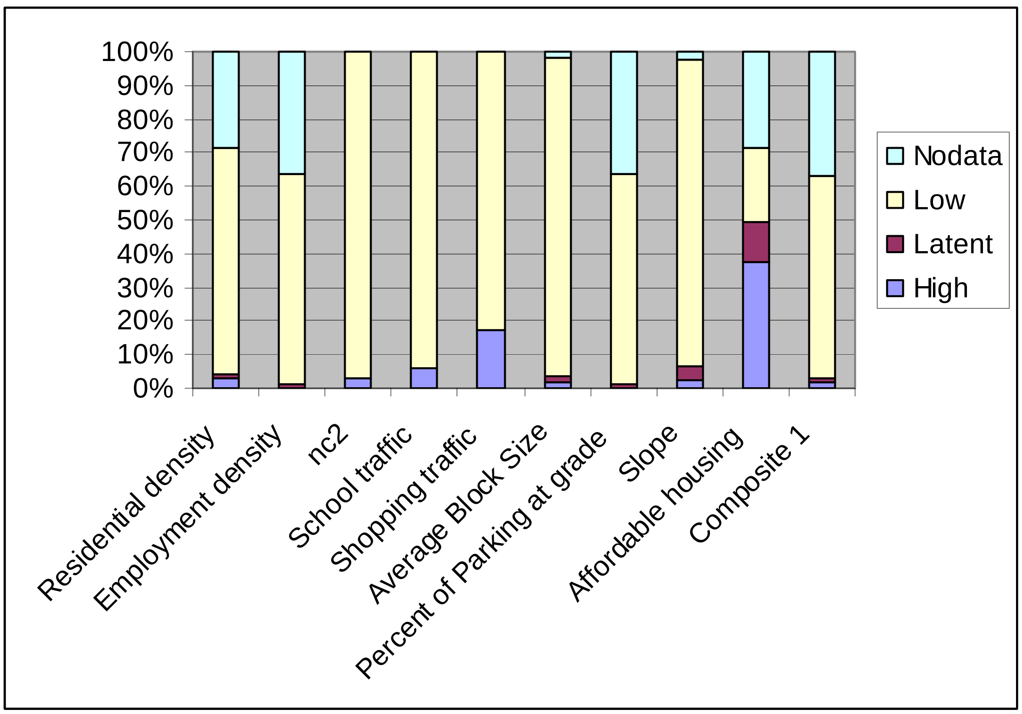


Figure 23: Pierce County percentage of geographic areas with high, latent and low TE by individual map layer (total area = 262 sq. mi.).

Table 34: Summary of residential units and employment in areas with different TE levels in Pierce County.

Pierce County

	High TE zone	Latent TE zone	Low TE zone	Total*
Residential units	9224	10978	197977	218179
(percent)	4%	5%	91%	
Employees	9905	12045	47871	69821
(percent)	14%	17%	69%	

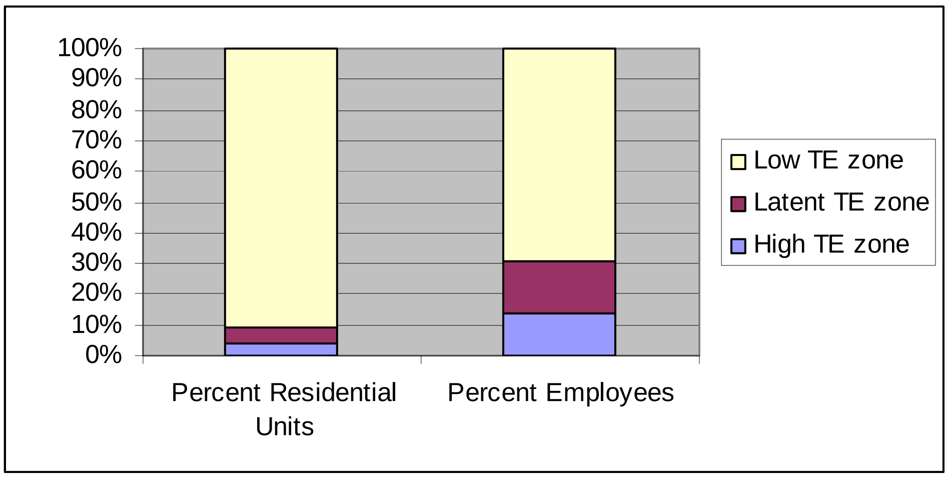


Figure 24: Pierce County percentage of residential units and employees in areas with high, latent, and low TE.

Kitsap County Summary

Table 35: Summary of Kitsap County areas with high, latent and low TE for all map layers.

Layer	High TE	Latent TE	Low TE	No data*	Total**
Residential density	0.20%	2.70%	80.20%	17.00%	100.00%
Employment density	0.70%	3.30%	55.20%	40.70%	100.00%
NC2***	5.70%	N/A	94.30%	N/A	100.00%
School traffic	13.40%	N/A	86.60%	N/A	100.00%
Shopping traffic	22.40%	N/A	77.60%	N/A	100.00%
Average Block Size	1.40%	0.70%	93.20%	4.80%	100.00%
Percent of Parking at grade	0.50%	1.50%	57.30%	40.70%	100.00%
Slope	14.70%	69.90%	15.50%	0.00%	100.00%
Affordable housing	42.40%	7.30%	33.30%	17.00%	100.00%
Composite 1	2.00%	2.50%	95.50%	0.00%	100.00%

* Areas where no valid classification is available
**Total area of parcels In King County UGB = 183.1 square miles (526,913 raster cells of 900 sq.m)
***Only commercial parcels are taken into account

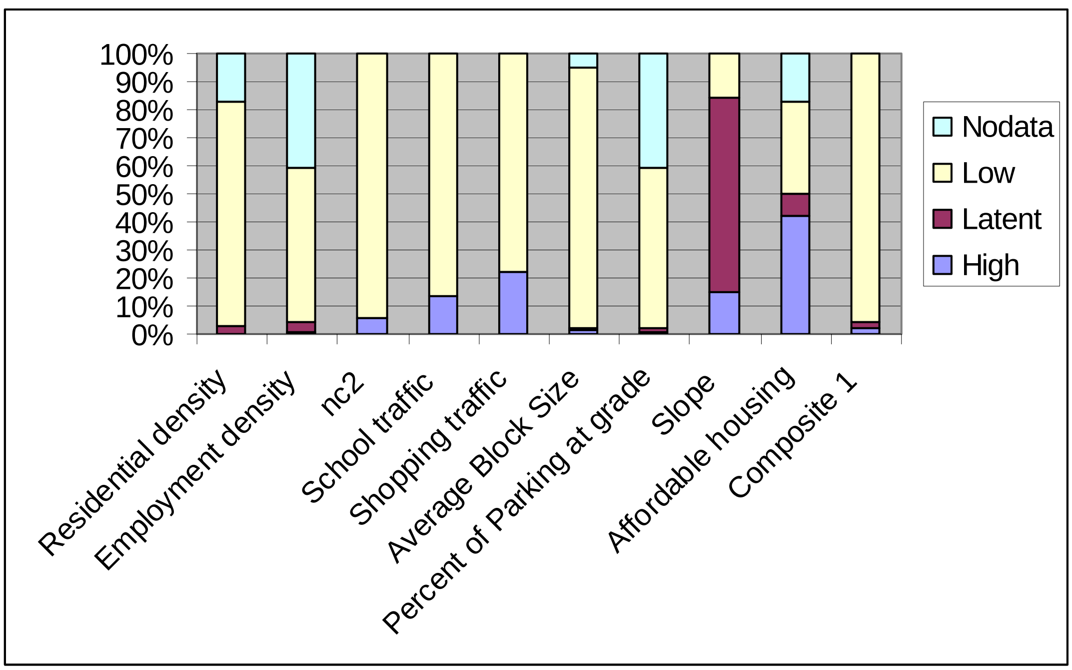


Figure 25: Kitsap County percentage of geographic areas with high, latent and low TE by individual map layer (total area = 183.1 sq. mi).

Table 36: Summary of residential units and employment in areas with different TE in Kitsap County.

Kitsap County

	High TE zone	Latent TE zone	Low TE zone	Total*
Residential units	1602	2480	36617	40699
(percent)	4%	6%	90%	
Employees	17242	6978	35026	59246
(percent)	29%	12%	59%	

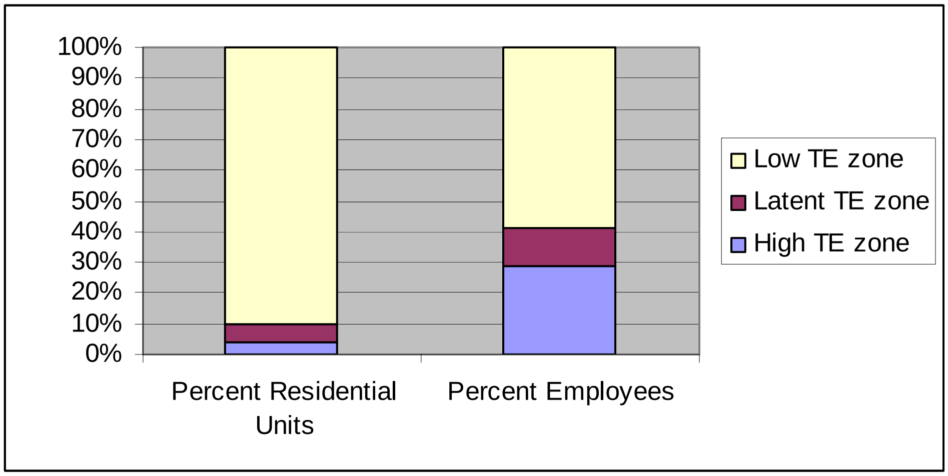


Figure 26: Kitsap County percentage of residential units and employees in areas with high, latent, and low TE.

CHAPTER 5:
CONCLUSIONS

The TELUMI is a series of maps that can be used to assess transportation systems and, specifically, to explore the relationships between land use and travel behavior. The maps graphically display zones at different levels of transportation efficiency, thus permitting a hands-on, readily understandable assessment of the region's transportation context. In addition, the GIS basis of the TELUMI provides a powerful means for quantitatively gauging the region's present transportation efficiency and for evaluating scenarios to improve future transportation systems.

A systematic process was used to delineate and calculate zones in the Puget Sound region that are at high, latent, or low levels of transportation efficiency. The land-use variables selected for the TELUMI maps are significantly and strongly associated with travel behavior. As such, these variables represent aspects of land use that could and can be effectively changed to affect travel.

In King County, the TELUMI shows that residential units and employment are already fairly well concentrated in relatively small areas that are transportation efficient. Focusing future transportation improvement and investment programs on areas within latent transportation efficiciency zones will further increase the size of zones with high TE and the number of residents and employees living and working in such zones.

The work performed to date needs further development as follows:

- **Need for testing the impact of future land-use policies**

The TELUMI is an interactive tool. To fully utilize its potential to support decisions regarding future transportation investments, several scenarios need to be tested. The scenarious need to address such questions as, How would changes in the values of individual land-use variables affect areas with different TE levels? For example, scenarios that increase employment or residential density, or reduce the amount of parking at ground, which are already well accepted strategies for supporting changes in transportation options, can be quantified by using precise targets and evaluated for their impacts on overall transportation efficiency. New target values of individual variables can be plugged into the model generating the composite layer, and areas of new zones at different TE levels will be calculated in the composite layer.

The TELUMI is a multi-scale tool, meaning that scenarios of the future can be tested for either parts of or the entire region. Assessments of transportation efficiency can focus on specific areas, such as designated Urban Centers, or, as mentioned, areas along primary transportation spines, areas around specific land uses, such as schools and parks, or areas currently assessed as having latent TE.

- **Need for testing the composite layers for Snohomish, Pierce, and Kitsap counties**

Composite layers for the region's other counties need to be developed following a method similar to the one used for King County. Bus ridership for these counties may not be a suitable dependent variable, given the relatively low ridership levels in these counties. Mode split would likely be a preferred dependent variable, but the data are difficult to come by. Modeled data from the Puget Sound Regional Council's regional models may be the only available alternative .

Threshold values of transportation efficiency were developed for the urban areas of King County only. Given this county's longer history of development and corresponding higher level of urbanization, it would be desirable to review the values used and to determine whether they are appropriate to support future transportation investment decisions in the other counties of the region.

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APPENDIX A: EMPLOYMENT DATA

METHOD

The Space Utilization Rate (SUR) standard (square footage per employee for certain building type) is used to estimate the employment density over the study area (the Urban Growth Areas of the central Puget Sound region) on the basis of the building types of each parcel. Each building type (e.g., offices, retails, restaurants) has its own space utilization rate; thus the total employment and/or employment density for each parcel can be estimated by using the information of building type that is available in the parcel data set. The parcel data set for the TELUMI project was originally obtained from the Washington Geospatial Data Archive (WAGDA), which contained the information of building type and the commercial building square footage for each parcel.

DATA SOURCES

The Space Utilization Rate data sources listed below were used to decide the Urban Form Lab (UFL) Space Utilization Rate (SUR) standard. In addition to these data, several SUR standards were estimated by using parcel level employment data obtained from the UrbanSim Lab in the Department of Urban Design and Planning, University of Washington.

- Snohomish County. Sq. ft. per employee assumptions for the 2002 Buildable Lands analysis. These estimates were derived from research previously conducted in Snohomish County in cooperation with the Snohomish County Economic Development Council (1985 Snohomish County Business and Industrial Land

Survey, updated in 1995 as the Employment Land Capacity Analysis for Unincorporated Snohomish County). The county said that this information was also compared with recent estimates published by the Institute of Transportation Engineers and was found to compare favorably.

- Institute of Transportation Engineers. Trip Generation, 4^{th} Ed. 1987: Space Utilization Rate was measured on the basis of survey samples. The number of samples varied by building types, and often it was very small.
- Institute of Transportation Engineers. Trip Generation, 5^{th} Ed. 1991: 12 more categories were added to those in the 4^{th} edition, while the categories for office buildings were reduced, and the space utilization rates for retails, mini-warehouses, and research centers were excluded.
- Building Owners and Managers Association (BOMA), 1996 Office Space Utilization Rates Summary
- Study of the San Diego Association of Governments, 2001
- Portland, Oregon. Metro Employment Density Study 1997
- Urban Growth Report, 1997, Metro, Portland, Oregon

DETERMINATION OF UFL SPACE UTILIZATION RATE STANDARD

Most of the SUR standards for the Land Use Level of Service (LULOS) project were determined by comparing existing data from listed sources; otherwise, the SUR standards were calculated by using the parcel level employment data obtained from the UrbanSim lab. Table A-1 shows the UFL standard determined through the process described above.

Table A-1. UFL Space Utilization Rate standard (square feet per employee).

	LULOS Class	SUR (sqft/employee)	Data Source
1	Single Family	0	N/A
2	Multi Family	0	N/A
3	Shopping Center	514	Urban Sim
4	Retail/Service	600	Snohomish Co.
5	Restaurant	134	ITE (5th)
6	Entertainment	499	Urban Sim
7	Sport Facilities	544	Urban Sim
8	Office	300	ITE (5th)
9	Manufacturing	500	Snohomish Co.
10	Warehouse	833	Snohomish Co.
11	Terminal (Rail/Marina/Bus)	908	Urban Sim
12	Church	2477	Urban Sim
13	Education	182	Urban Sim
14	Hospital	250	Average of ITE, BOMA, and San Diego
15	Institutional	500	Approximation from the values for Warehouses and offices
16	Auto facilities	600	Approximation from the value for retails
17	Agriculture	0	N/A
18	Open Space	0	N/A
19	Others	0	N/A
20	Hotel/Motel	1347	Urban Sim

APPENDIX B: DELPHI INSTRUMENT

DELPHI SURVEY PARTICIPANT LIST

- Rocky Piro, Puget Sound Regional Council
- Wendy Compton Ring, Washington State Department of Community, Trade and Economic Development
- Kevin O'Neill, City of Bellevue, Washington
- Michael Hubner, King County Suburban Cities Association
- Tim Trohimovich, 1000 Friends of Washington
- Larry Frank, University of British Columbia
- Keith Lawton, Portland Metro (Oregon)
- Jonathan Levine, University of Michigan
- Julie Matlick, Seattle Department of Transportation
- Robert Dunphy, Urban Land Institute

DELPHI QUESTIONNAIRE

Question 0: Transportation Outcomes
Please specify thresholds OR ranges to define low, latent, and high alternative mode demand.

Demand for Alternative Modes	Land Use Pattern	Measure	Threshold	Range	Comfort Level
Low	Disconnected, low density, difficult to serve with transit	High % of trips in SOV	NA		
Latent	Some transportation-efficient land use characteristics present but not others	Medium % of trips in SOV			
High	High to moderate densities, supportive walking and transit environments, well-connected street network	Low % of trips in SOV			

Part I: Density

Question 1: Residential Density
Please specify thresholds OR ranges for each class.

Demand for Alternative Modes	Unit of Measurement	Threshold	Range	Comfort Level
Low	Number of residential units per net residential acre (residential parcels only)	NA		
Latent	Number of residential units per net residential acre (residential parcels only)			
High	Number of residential units per net residential acre (residential parcels only)			

Question 2: Employment Density
Please specify thresholds OR ranges for each class.

Demand for Alternative Modes	Unit of Measurement	Threshold	Range	Comfort Level
Low	Employees per **NET** commercial acre (non-residential parcels only)	N/A		
Latent	Employees per **NET** commercial acre (non-residential parcels only)			
High	Employees per **NET** commercial acre (non-residential parcels only)			

Part II: Mix of Uses

Question 3: Jobs-Housing Balance

Please specify thresholds OR ranges for each class and center type listed below.

a) Central Business District: A major employment Center, with both office and retail uses, e.g. Downtown Seattle, Bellevue, or Tacoma.

Demand for Alternative Modes	Unit of Measurement	Threshold	Range	Comfort Level
Low	Jobs/Housing Ratio			
Latent	Jobs/Housing Ratio			
High	Jobs/Housing Ratio	N/A		

(Jobs/Housing Ratio = # of jobs / # of residential units)

b) Urban Center: A second-level, yet large employment center with both office and retail uses, such as Northgate or the U-District; may include several independent administrative districts.

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	Jobs/Housing Ratio			
Latent	Jobs/Housing Ratio			
High	Jobs/Housing Ratio	N/A		

c) Neighborhood Center: A third-level employment center, with primarily retail services, such as Wallingford, Queen Anne, or Crossroads.

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	Jobs/Housing Ratio			
Latent	Jobs/Housing Ratio			
High	Jobs/Housing Ratio	N/A		

Question 4: Destinations conducive to alternative mode use

Please list the suitable TYPE and NUMBER of INDIVIDUAL AND GROUPS OF destinations that should be located within ½ mile of a residential, retail, or employment concentration, as shown in the example table below.

INDIVIDUAL Destinations e.g.) restaurants, drug stores, grocery stores, daycare, schools, etc.			
Destination	**Demand for Alternative Modes**	**Number of individual destinations**	**Comfort Level**
Individual destination 1:	**Low**		
	Latent		
	High		
Individual destination 2:	**Low**		
	Latent		
	High		
Individual destination 3:	**Low**		
	Latent		
	High		

GROUPS of Destinations e.g., general retail and institutional uses			
Group of Destinations	**Demand for Transportation Options**	**Total number of GROUPS of destinations**	**Comfort Level**
Group of destinations 1:	**Low**		
	Latent		
	High		
Group of destinations 2:	**Low**		
	Latent		
	High		
Group of destinations 3:	**Low**		
	Latent		
	High		

Part III: Connectivity of Networks

Question 5: Block size

Please specify thresholds OR ranges for each class.

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	Average block size (acres)			
Latent	Average block size (acres)			
High	Average block size (acres)	N/A		

Part IV: Parking Supply and Management

Question 6: Parking Supply

Please specify thresholds OR ranges for each class.

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	# of parking spaces per 1,000 gross building sq.ft.	N/A		
Latent	# of parking spaces per 1,000 gross building sq.ft.			
High	# of parking spaces per 1,000 gross building sq.ft.			

Question 7: Parking Supply

Please specify thresholds OR ranges for each class.

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	% of parcel covered by parking lots*	N/A		
Latent	% of parcel covered by parking lots*			
High	% of parcel covered by parking lots*			

*Formula: [(Area of a parcel – area of building foot print at grade) / Area of a parcel]*100

Part V: Pedestrian Environment

Question 8: Topography

Please specify thresholds OR ranges for each class.

Information about Slope Standard

Source: ADA Standards for Accessible Design

http://www.usdoj.gov/crt/ada/reg3a.html#Anchor-17516

4.3 Accessible Route

4.3.7 Slope. An accessible route with a running slope greater than 1:20 (5%) is a ramp and shall comply with 4.8. Nowhere shall the cross slope of an accessible route exceed 1:50 (2%).

4.8 Ramps

4.8.2* Slope and Rise. The least possible slope shall be used for any ramp. The maximum slope of a ramp in new construction shall be 1:12 (8%).

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	% of Slope	N/A		
Latent	% of Slope			
High	% of Slope			

Question 9: Traffic Volumes

Please specify thresholds OR ranges for each class.

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	Average daily traffic (total number of cars PER MILE of arterials and major streets)			
Latent	Average daily traffic (total number of cars PER MILE of arterials and major streets)			
High	Average daily traffic (total number of cars PER MILE of arterials and major streets)	N/A		

Part VI: Affordable Housing

Question 10: Percent below mean assessed residential land and/or improvement value of surrounding area

Please specify thresholds OR ranges for each class.

Demand for Alternative Modes	Unit of Measurement	Thresholds	Range	Comfort Level
Low	% res units below 100% mean assessed property value in King County ($294,402)			
Latent	% res units below 100% mean assessed property value in King County ($294,402)			
High	% res units below 100% mean assessed property value in King County ($294,402)	N/A		

Question 11: Residential land uses most likely to indicate affordable housing

Please specify residential uses that could serve as indicators for affordable housing, such as rooming houses, retirement communities, apartments, public housing, mobile homes, etc.

Destination	Comfort Level
Residential use 1:	
Residential use 2:	
Residential use N:	

APPENDIX C: TECHNICAL ISSUES IN SPATIAL ANALYSIS AND CARTOGRAPHIC MODELING

VECTOR AND RASTER DATA MODELS

Significant technological developments since Tomlin's book on Cartographic Models allow for great flexibility in working with either vector or raster data, and going back and forth between these data models (Tomlin 1990). ArcView has several extensions in its Spatial Analyst that enable back and forth conversion between data models. ArcView ModelBuilder and programs such as Fragstad, which have been applied in landscape ecology (Turner and Garner 1991) and used in the Pedestrian Location Identifier tool (PLI_2) (Moudon, Hess et al. 2002), allow for detailed quantitative analyses of raster layers.

The vector data model represents geographic features similar to the way ordinary paper maps do. Points represent geographic features too small to be depicted as lines or areas; lines represent geographic features too narrow to depict as areas; and polygons (areas) represent homogenous geographic features. In a vector data model, each location is recorded as a single *x,y* coordinate. Lines are recorded as a series of *x,y* coordinates. Area are recorded as a series of *x,y* coordinates defining line segments that enclose an area (polygon). Points, lines, and polygons are represented by a list of coordinates instead of a picture or graph (Figure C-1).

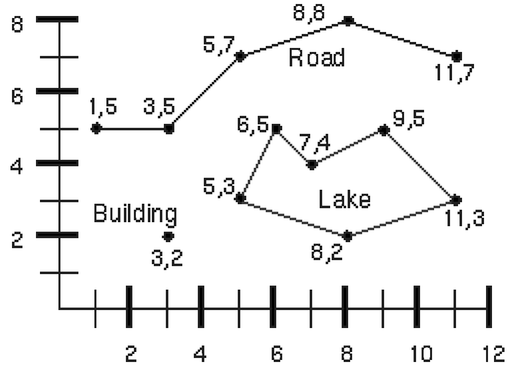


Figure C-1 Illustration of vector data (http://www.du.edu/~mramsey2/Vector.html).

The raster model uses image formats set in a small grid of squares called pixels as graphic representations. Each pixel in a raster image has a specific location and a color value assigned to it. In the raster model, each location is represented as a cell. The matrix of cells, organized into rows and columns, is called a grid. Each row contains a group of cells with values representing a geographic phenomenon. Cell values are numbers, which represent nominal data such as land use classes, measures of light intensity, or relative measures (Figure C-2).

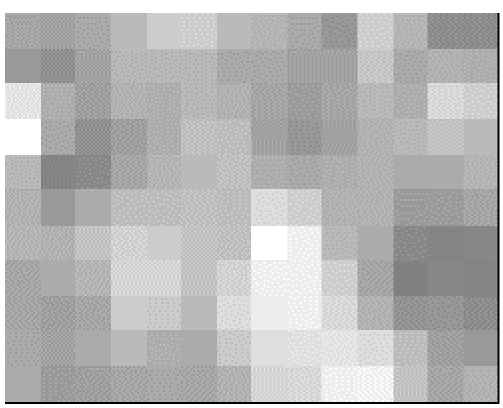


Figure C-2. Illustration of raster data (http://www.du.edu/~mramsey2/Raster.html).

Both vector and raster data models served to develop the TELUMI maps. The original data are in vectors, providing a rich set of attributes attached to each parcel. However, most of the cartographic modeling is done in rasters. The differences between these data models are that Raster models associate features (e.g., FAR values) with locations (e.g., spatially distributed on map layer), whereas vector models associate location (e.g., point, line, area) with features (e.g., bus stop, street, retail establishment) (Samet n.d.). In other words, rasters express discrete locations (general units of space) whereas vectors express specialized locations (specialized units of space). Furthermore, rasters have one "attribute value" per cell, whereas vectors are associated with a table of multiple attributes.

Because of the "discretization" of space, rasters affect the quality and, specifically, the accuracy of measurements. For example, a land parcel in a vector data model is mapped with its exact dimensions, but when rasterized, the parcel's boundaries are normalized to the raster grid, which means that the parcel in a raster data model may be smaller or larger than the actual parcel, depending on the size and shape of the parcel and the size of the pixel. Clearly, the smaller the pixel or raster size, the more accurate the measurement will be.

Applying the models to mapping residential density, and assuming three classes of residential density (0 to 5; 5.1 to 10; and 10+ residential units per acre), a map of residential density in the vector model will show parcels in three levels of TE, one at a time. In the raster model, the three density classes will be shown on the map in pixels of, say, 30 M square in the approximate location of the parcels (Figure C-3). The Raster model “loses” the parcel boundaries, and therefore is an approximation of parcel size and shape.

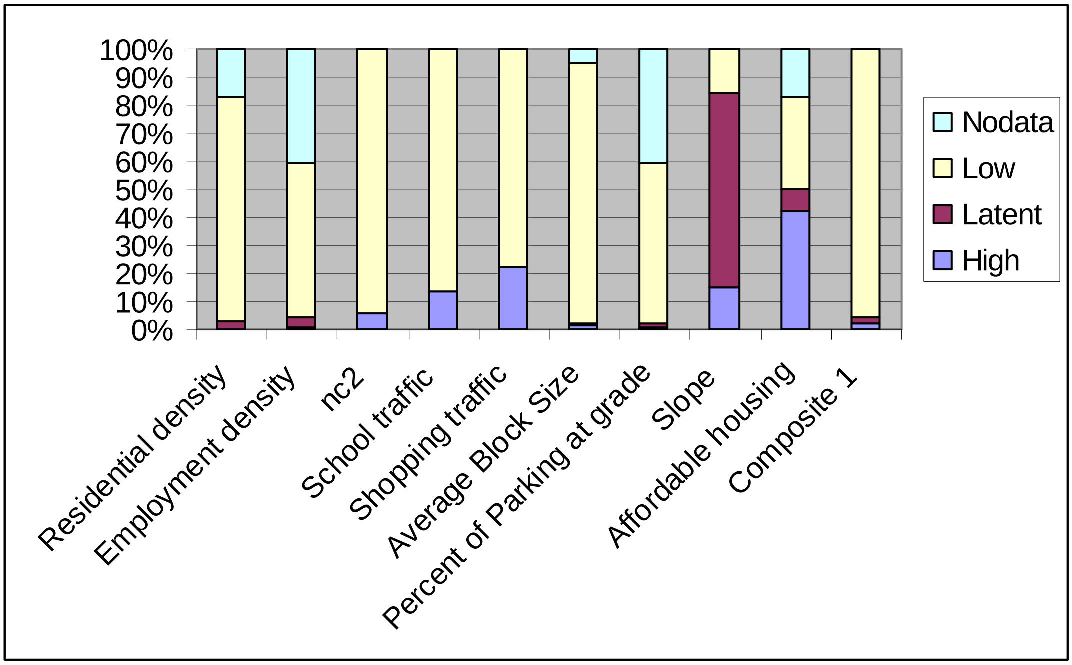


Figure C-3: Kitsap County percentage of geographic zones areas in high, latent and low TE zones by individual map layer.

Both data models provide quantitative information associated with the maps—e.g., total area in density class A, B, and C. However, as mentioned, the raster data will be less accurate than the vector data. As well, the quantitative data available in the raster model will relate solely to residential density classes, whereas those in the vector model will include all of the attributes associated with each parcel (e.g., tax assessment, building square footage). Because of their single attribute data tables, raster maps need to be translated back into vector data to capture or re-capture other attributes of the constituent zones and specific locations within the zones. For example, a raster layer of residential density needs to be translated back into a vector model in order to measure the distribution of single-family and multifamily units in the various density zones.

Vector models and the simplified nature of raster models offer unique characteristics that fall into several categories:

Visual—Vectors depict actual spatial boundaries and, thus, show space that may have personal meaning. Someone can, for example, "see" that his or her lot or a neighbor's has been classified as being transportation efficient or inefficient. The personal dimension of vector data (i.e., showing individual parcels) may distract from the purpose of mapping the TELUMI, which is not to point a finger to specific parcels or properties but to evaluate *areas* for their level of transportation efficiency. Rasters, on the other hand, erase parcel boundaries. They further allow for spreading the map values into adjacent pixels—smoothing or filtering the data (see Raster-Based Neighborhood Analyses below).

Computational—Raster models are faster to process because the spatial units are normalized. The smaller the pixel, the longer the processing time will be. This advantage may be somewhat reduced when several map layers are combined and need to be processed, while multiple attributes or variables can be programmed simultaneously in vector models and processed in a single operation.

Representational—Rasterization is the best way to model the impact area of point data—e.g., the impact or the area of influence of a bus stop, a signalized intersection, a cul-de-sac, or an arterial. Rasters are used to create continuous surfaces from scattered point or line features or to create density maps from themes containing point features.

Rasters served the TELUMI in that the particular level of transportation efficiency of individual parcels has little or no meaning in terms of representing specific travel behaviors. For example, my own parcel (where I live) may have a residential density that is transportation efficient, but if most other parcels in my neighborhood do not have that density, it is unlikely that I will be able to travel more efficiently than my neighbors. Raster models have the ability to "average out" the attribute values captured at the parcel level for entire areas, via neighborhood analyses, thus more appropriately representing the transportation performance characteristics of areas. This advantage goes beyond representational capabilities, since the smoothened data are quantifiable as well. So, for example, while vector data will yield quantities of acres, dwellings, or square feet of building, which are "precisely accurate" according to the thresholds selected to define the different TELUMI zones, raster data will yield quantities that *take into account the characteristics of adjacent parcels,* averaging out the effects of adjacent parcels that are in different classes of TE. These latter measures will *technically* be less precisely accurate than vector derived measures, but they will more *realistically* capture area-based dimensions of TE—a case of avoiding the conundrum of being precisely wrong versus being approximately correct.

Raster-Based Neighborhood Analyses—Surface Differentiation and Data Smoothing

Neighborhood spatial analyses involve a variety of spatial operations performed on the map surface. The neighborhood itself is usually isomorphic (square or circular) (Burrough and McDonnell 1998). Spatial operations include the following:

- Interpolation (prediction of an attribute value at an unsampled site from measurements made at other sites within a given neighborhood)

- Spatial filtering (data smoothing with high- or low-pass filters)
- First and higher-order derivatives, derivation of surface topology (drainage networks and catchment delineation)
- Contiguity assessment (clumping)
- Non-linear dilation (spreading with friction)
- Viewsheds, shared relief, and irradiance (Burrough and McDonnell 1998:185).

Spatial filtering is the most common operation. It involves passing a square "window" over the rasterized map surface and computing the new value of the central cell of the window as a function of the cell values covered by the window. The usual size of a window is 3 x 3 cells, though larger cells and distance measurements are also possible. The larger the window, the "smoother" the data. The new central cell value can be a function of the window cells' total value; mean, minimum or maximum values; range (difference between max and min value); diversity (number of different values in the window); standard deviation; or mode. Different types of filters can be used:

- Low-pass filter = removing extremes from the data, producing a "smoother" image
- High-pass filter = the original data minus the low-pass filter data, enhancing the short-range spatial properties of a surface
- *Edge filtering* is possible to extract the boundaries of the filtered surfaces.

Note that for point data (e.g., intersection density, bus stop usage), this extension selects each individual raster, analyzes data by using a specified circle (e.g., 0.5-mile radius), assigns the highest value to the center of the circle, and decreases the value progressively toward the edge of the circle. When circles overlap, the values of both circles are added, creating a high value overlap area, which can be a problem because the highest values are "away" from the actual points (e.g., intersections).

Spatial Unit of Data and Analysis

With data acquired from the parcel-level GIS, disaggregation will occur as a result of the rasterization process because rasters will be smaller than most parcels (Bian and Butler 1999). Aggregation and disaggregation issues will be addressed if and when neighborhood-level travel or other (e.g., parking utilization, apartment rental rates) data are used.

Layer Synchronization

In order to create a composite layer (a layer derived from a combination of multiple individual layers), all individual layers need to have an identical distribution of pixels with valid data; otherwise, the output layer (the composite layer) is appropriately generated due to the calculation error. Figure C-4 illustrates the Raster calculation mechanism.

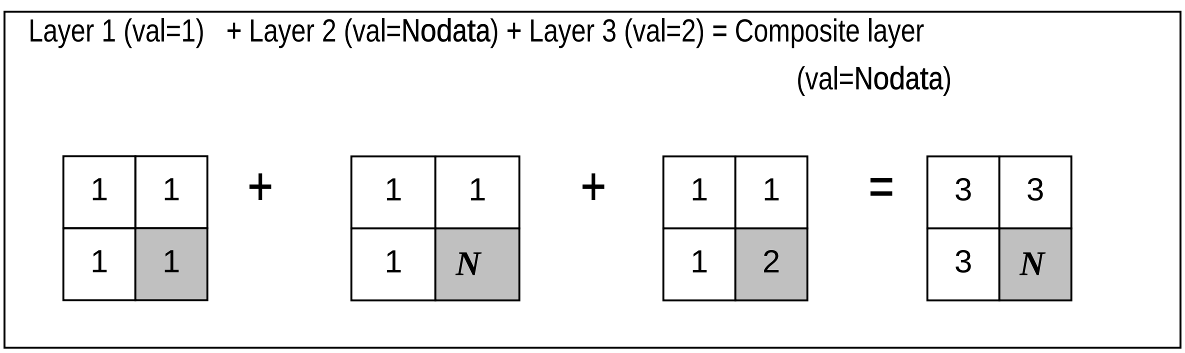


Figure C-4: Raster calculations when cells have no value.

To solve this problem, each single land-use layer has been modified so that it can work properly through the process of the composite measure calculation (raster calculation). The modification is primarily conducted for the pixels with no valid value; they are to be reclassified (the value of each cell is replaced with new one) so that they have a value of 0. Once the modification is done for every single layer, the final composite layer can be produced for all study areas.

Data are then reclassified into the following:

Values in the range of high transportation efficiency class	→ 3 (Green)
Values in the range of latent transportation efficiency class	→ 2 (yellow)
Values in the range of low transportation efficiency class	→ 1 (red)
No data	→ 0 (black)

<u>Raster Resolution</u>

The conversion of vector data into vaster requires careful determination of the vaster or pixel size. The goal in the conversion process is to use as large a vaster size as possible to facilitate data processing without, however, losing accuracy due to a change in resolution.

Tables C-1 and C-2 summarize tests performed on the King County data for two area extents: Queen Anne and the SR 520/I-405 slice of the county. Queen Anne's residential density was used for the test because of the large number of small parcels in the neighborhood. Small parcels are more likely to be distorted if large rasters are used. The tests showed that the difference in area size between the vector and the 10M raster is minimal. It is within 10 percent in accuracy in the 30M and 50M rasters. For the larger sample area along SR 520, which includes both urban and suburban residential parcel sizes, the accuracy level is higher than in Queen Anne, as expected. This means that for a suburban sample, larger rasters afford little loss in accuracy. The tests suggested that a 30M Raster unit will adequately capture both urban and suburban parcel sizes.

Table C-1: Raster resolution test for residential density: Comparing vecto-r and raster-generated areas of residential parcels in Queen Anne at three levels of TE.

Areas	VECTOR (parcels)		RASTER-10M		RASTER-30M		RASTER-50M	
	%	acres	%	acres	%	acres	%	acres
All parcels/cells	100.00%	271.23	100.31%	272.06	101.76%	275.99	115.93%	314.44
All “low” TE parcels/cells*	100.00%	9.42	103.04%	9.71	110.91%	10.45	104.87%	9.88
All “latent” TE parcels/cells	100.00%	106.41	100.46%	106.90	104.29%	110.98	114.95%	122.32
All “high” TE parcels/cells	100.00%	150.20	100.09%	150.34	99.65%	149.67	118.04%	177.30
# of acres per Raster cell			0.0247		0.2224		0.6178	

*Low = 0.01 to 5 dwelling units per acre (all parcel-level data)

Latent = 5.01 to 10 dwelling units per acre

High = +10 dwelling units per acre

Table C-2: Raster resolution test for residential density: Comparing vector- and raster-generated areas of residential parcels in a sample area along SR 520 at three levels of TE.

Areas	VECTOR (parcels)		RASTER-10M		RASTER-30M		RASTER-50M	
	%	acres	%	acres	%	acres	%	acres
All parcels/cells	100.00%	31946.11	102.15%	32,634.3	102.27%	32,671.14	102.36%	32,700.1
All “low” TE parcels/cells	100.00%	15864.25	102.71%	16,294.82	102.91%	16,326.45	102.61%	16,278.1
All “latent” TE parcels/cells	100.00%	9,228.29	101.99%	9,411.92	101.86%	9,399.96	103.59%	9,559.2
All “high” TE parcels/cells	100.00%	5,923.88	100.87%	5,975.43	101.31%	6,001.33	99.89%	5,917.5

DESCRIPTION OF THE TELUMI GIS MAPPING PROCESS

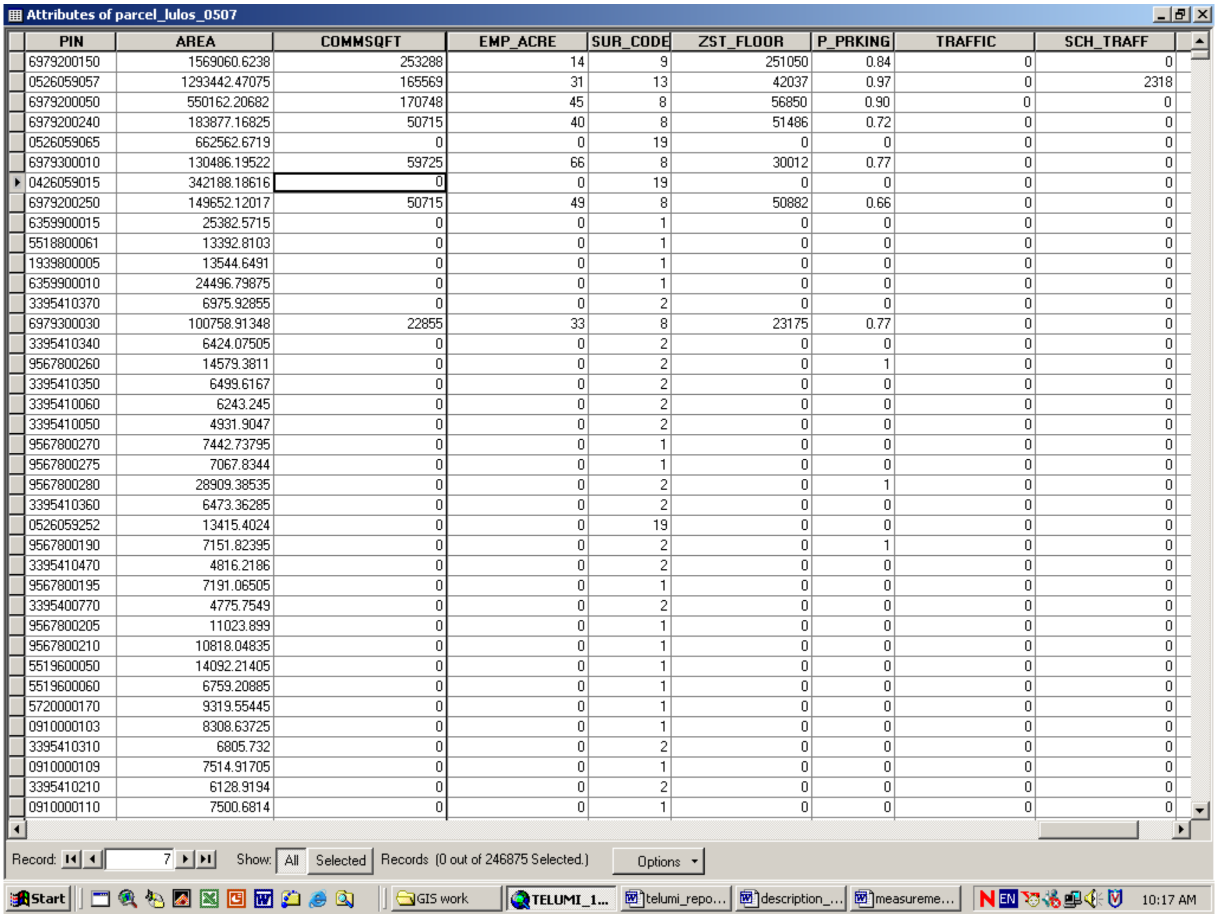
The GIS analysis process used to develop the TELUMI land-use maps includes three steps. The first step constructs the master parcel database with land-use measures estimated from several sources, such as property value, the number of employees in a parcel, and percentage of slope. The second step addresses data conversion from vector data to raster data format. It results in raster maps for individual land-use measures. The third step estimates neighborhood-level land-use measures by using a quarter-mile radius buffer around a central point. Average values are calculated for the given area with the neighborhood statistics function in ARCGIS. The output data of this analysis are then reclassified into the three TE classes to delineate the spatial distribution of three TE zones for each individual land-use measure.

Development of the Master Parcel Data

The parcel data set for King County used in this project came from the Washington State Geospatial Data Archive (University of Washington Libraries ca 2000). The data were initially generated by the King County assessor and further developed by the Urban Form Lab at the University of Washington. The data set contains information based on the parcel identification number (PIN), including parcel area, land use, building characteristics (floor/area ratio, building square footage, number of stories), and assessed property value. Other data such as traffic volumes and sidewalks came from the Puget Sound Regional Council. The TELUMI land-use measures for each parcel are estimated from these various data and attached to the master parcel database (Figure C-5).

Development of Individual Land-Use Maps

Land-use measures estimated in the previous step are transformed into rasters. Each land-use map created by the transformation process represents the spatial distribution of the land-use measure on a grid of 30M by 30M pixels. The following steps describe the processes for creating the raster land-use maps.



Attributes of parcel_lulos_0507

PIN	AREA	COMMSQFT	EMP_ACRE	SUR_CODE	ZST_FLOOR	P_PRKING	TRAFFIC	SCH_TRAFF
6979200150	1569060.6238	253288	14	9	251050	0.84	0	0
0526059057	1293442.47075	165569	31	13	42037	0.97	0	2318
6979200050	550162.20682	170748	45	8	56850	0.90	0	0
6979200240	183877.16825	50715	40	8	51486	0.72	0	0
0526059065	662562.6719	0	0	19	0	0	0	0
6979300010	130486.19522	59725	66	8	30012	0.77	0	0
0426059015	342188.18616	0	0	19	0	0	0	0
6979200250	149652.12017	50715	49	8	50882	0.66	0	0
6359900015	25382.5715	0	0	1	0	0	0	0
5518800061	13392.8103	0	0	1	0	0	0	0
1939800005	13544.6491	0	0	1	0	0	0	0
6359900010	24496.79875	0	0	1	0	0	0	0
3395410370	6975.92855	0	0	2	0	0	0	0
6979300030	100758.91348	22855	33	8	23175	0.77	0	0
3395410340	6424.07505	0	0	2	0	0	0	0
9567800260	14579.3811	0	0	2	0	1	0	0
3395410350	6499.6167	0	0	2	0	0	0	0
3395410060	6243.245	0	0	2	0	0	0	0
3395410050	4931.9047	0	0	2	0	0	0	0
9567800270	7442.73795	0	0	1	0	0	0	0
9567800275	7067.8344	0	0	1	0	0	0	0
9567800280	28909.38535	0	0	2	0	1	0	0
3395410360	6473.36285	0	0	2	0	0	0	0
0526059252	13415.4024	0	0	19	0	0	0	0
9567800190	7151.82395	0	0	2	0	1	0	0
3395410470	4816.2186	0	0	2	0	0	0	0
9567800195	7191.06505	0	0	1	0	0	0	0
3395400770	4775.7549	0	0	2	0	0	0	0
9567800205	11023.899	0	0	1	0	0	0	0
9567800210	10818.04835	0	0	1	0	0	0	0
5519600050	14092.21405	0	0	1	0	0	0	0
5519600060	6759.20885	0	0	1	0	0	0	0
5720000170	9319.55445	0	0	1	0	0	0	0
0910000103	8308.63725	0	0	1	0	0	0	0
3395410310	6805.732	0	0	2	0	0	0	0
0910000109	7514.91705	0	0	1	0	0	0	0
3395410210	6128.9194	0	0	2	0	0	0	0
0910000110	7500.6814	0	0	1	0	0	0	0

Record: 7 Show: All Selected Records (0 out of 246875 Selected.) Options

Start GIS work TELUMI_1... telumi_repo... description_... measureme... EN 10:17 AM

Figure C-5. Table of the parcel database.

Activation of the "Spatial Analyst"

Spatial Analyst is an ARC GIS extension that performs various spatial analyses for raster and vector data. To activate it:

1. Go to tools (Figure C-6).
2. Go to extension (Figure C-6).
3. Select "Spatial Analyst" on the pop-up window (Figure C-7).

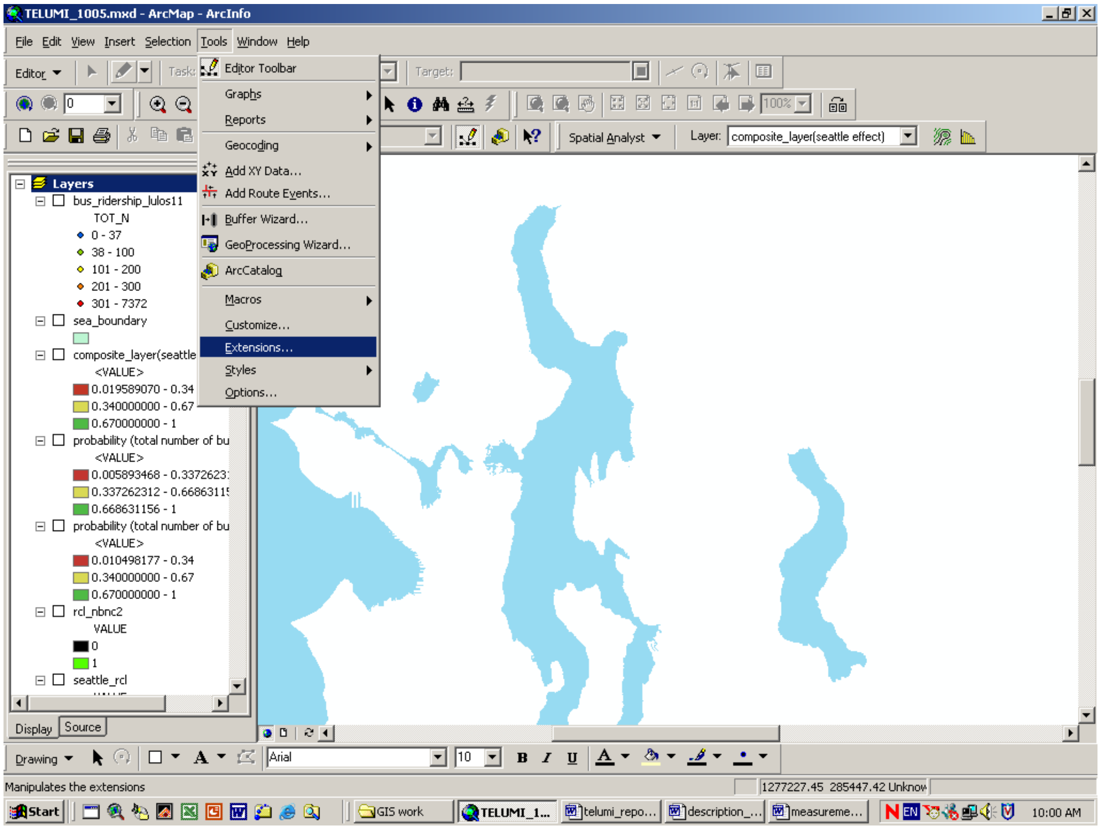


Figure C-6. Opening ARC GIS Extensions.

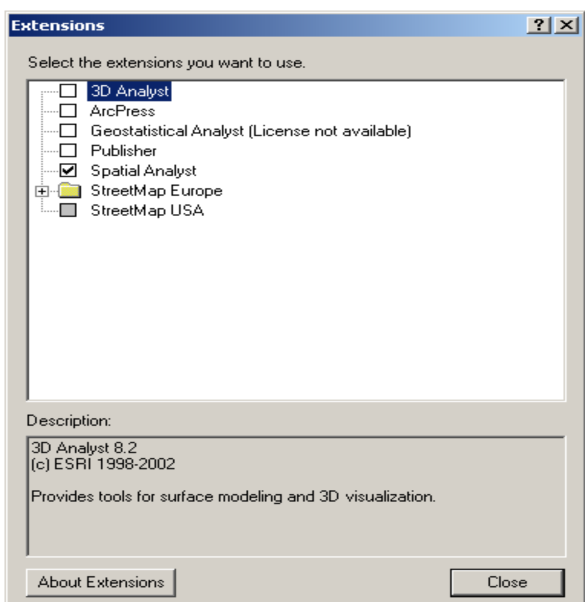


Figure C-7. Pop-up window for activating extensions.

Vector to Raster Transformation

The first step for creating the individual land use maps is to convert the vector data of land-use measures to the raster data. The vector data of each lan- use measure are assigned to the matrix of 30Mm by 30M cells through these steps:

1. Go to "Spatial Analyst" on the menu (Figure C-7).
2. Go to Convert → Features to Raster (Figure C-8).

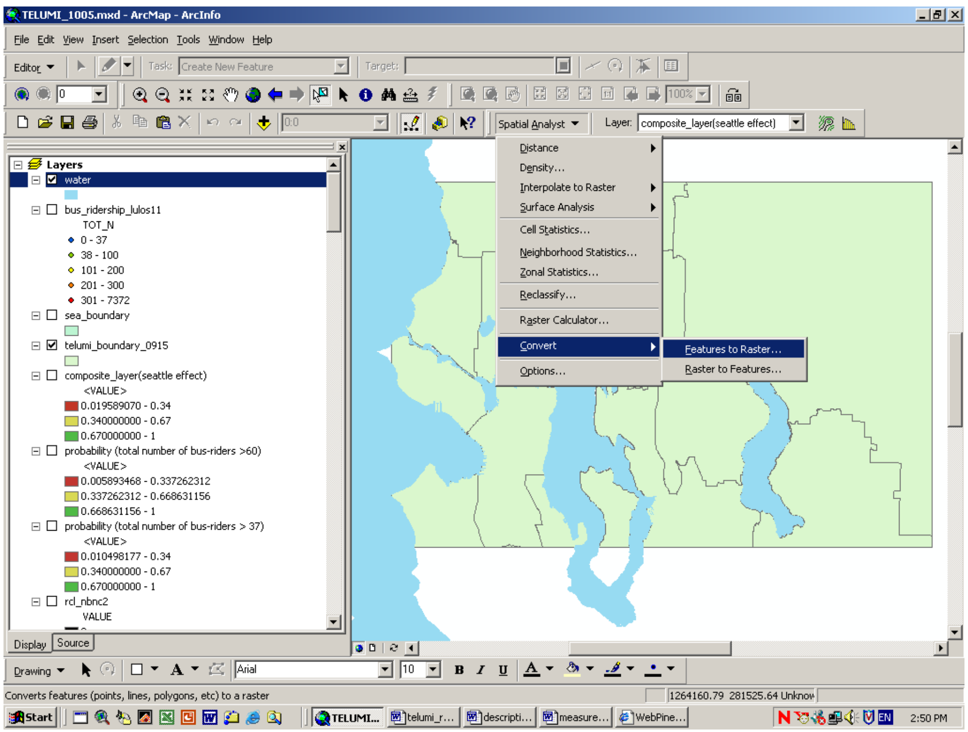


Figure C-8. Vector to raster transformation.

3. Define the input features (parcel data set), field (the attribute column of land-use measures), output cell size (30M = 98.42519685ft), and the location where the output raster data should be restored (Figure C-9).
4. Click "OK."

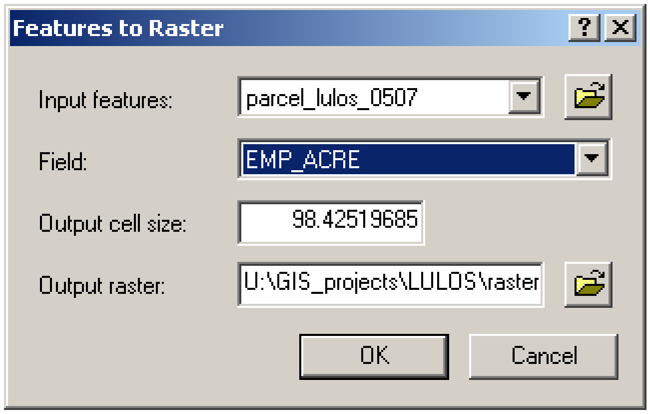


Figure C-9. Pop-up window for raster transformation.

<u>Neighborhood Analysis</u>

This analysis produces a new raster map showing the average of the values estimated in a quarter-mile radius buffer centered on a given pixel (Figure C-10). This neighborhood analysis estimates the land use measure at the neighborhood level, defined as within a quarter-mile radius buffer, as assumed in the determination of land-use measure thresholds.

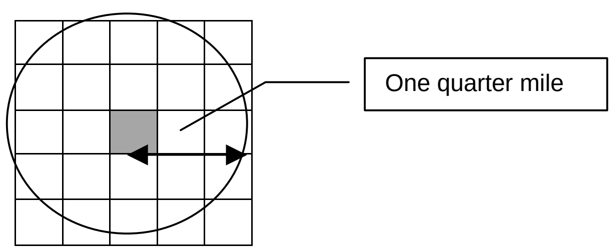


Figure C-10. Neighborhood analysis.

Steps of the neighborhood analysis include the following:

1. Go to Neighborhood Statistics under Spatial Analyst (Figure C-11).
2. Specify the options for the condition of the output (Figure C-12):

- Input data: select one of the raster maps created through the previous raster transformation
- Statistic type: mean
- Neighborhood type: circle (using the quarter-mile radius buffer)
- Radius for the buffer: 1320 ft (a quarter mile)
- Units: map
- Output cell size: 98.42519685 (30m)
- Output Raster: specify the location where the output raster data should be saved.

3. Click “OK.”

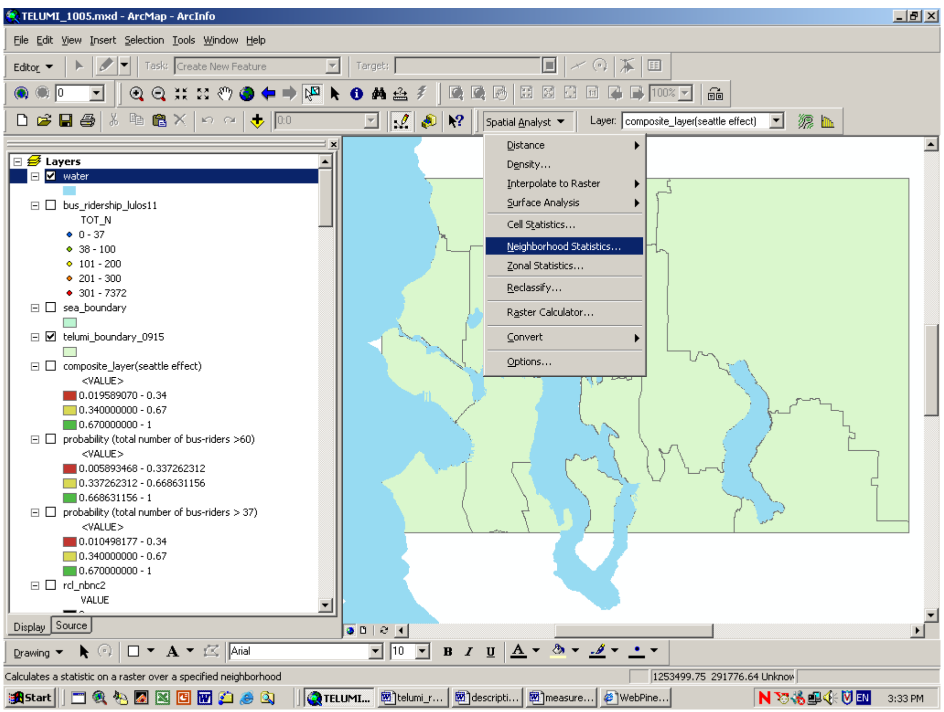


Figure C-11. Neighborhood statistics.

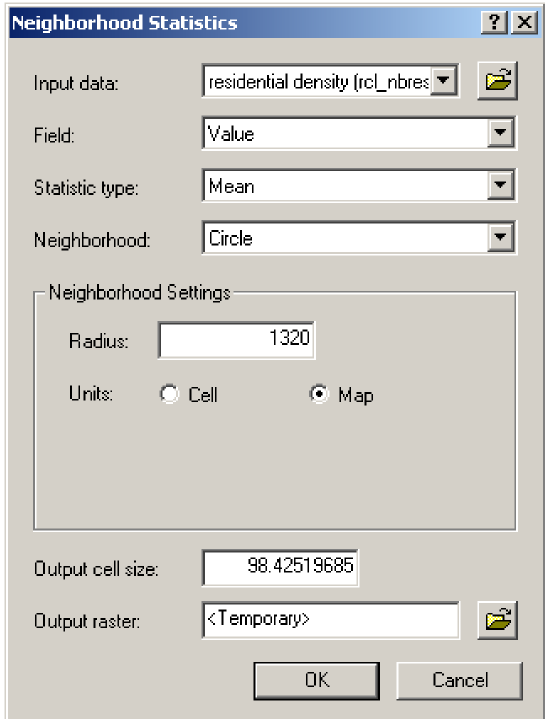
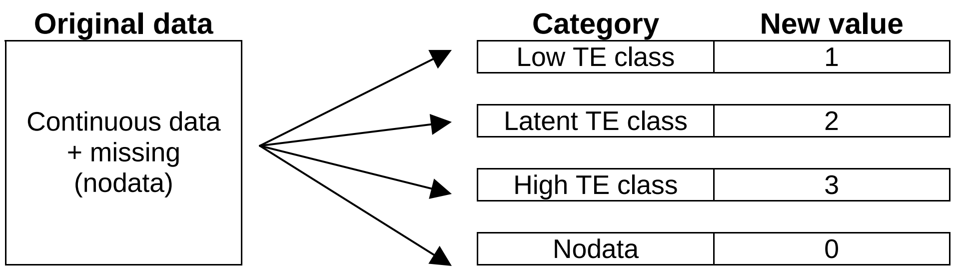


Figure C-12. Pop-up window for neighborhood statistics.

Value Reclassification

Each neighborhood analysis output map contains continuous data, the average of the specified land use measure in a given area. These continuous data are regrouped into three categories on the basis of predetermined threshold values. They are assigned one numeric value (1, 2, or 3) corresponding to each one of these categories (Table C-6). The value of 0 is given to the cells having invalid data ("nodata" cells) to prevent raster calculation errors (Figure C-4).

Table C-6. Data reclassification



Steps for data reclassification are as follows:

1. Go to “Reclassify” under Spatial Analyst.
2. Define the input data, number of new groups and the values for them on the pop-up window (Figure C-13).
3. Define the file name and the location where the output raster data should be saved.
4. Click “OK.”

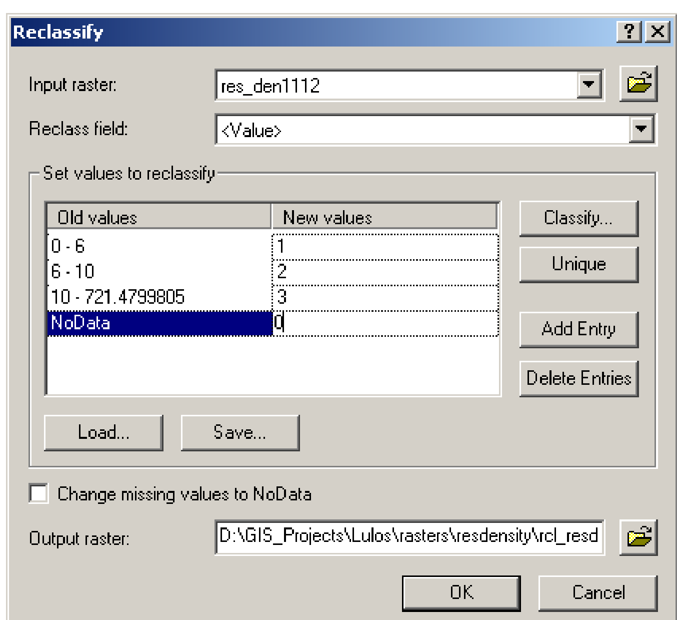


Figure C-13. Pop-up window for data reclassification.

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APPENDIX D: METHODOLOGICAL APPROACH TO A COMPOSITE MEASURE OF THE TELUMI

The dependent variable used to evaluate the relative effects of land-use variables was the total number of daily boardings and alightings per bus stop location in King County. Bus ridership data were the automatic passenger counts (APC) obtained from King County Metro and averaged for two counting periods, fall 2000 and fall 2001. Data distribution was 63 percent (3,356 out of 5,363) of the bus stops and 91 percent of boardings and alightings (430,684 out of 473,169) within the Seattle city limits. The averages of land-use measures in a quarter-mile radius buffer, centered on the locations of bus stops, were used as independent variables (Table D-1). The binary logit model was selected as the preferred statistical method because the original ridership data were substantially skewed.

The dependent variable in the model was the dichotomized ridership data, with the data reclassified into two groups: bus stops having less than 37 riders per day versus bus stops having more than 37 riders per day. The threshold of 37 riders per stop (or about 37x4=148 per intersection) divided the sample population of bus users into those in the top 30 percent of higher bus usage, and all the others. The independent variables included the nine land-use measures plus a Seattle identifier (0: suburb, 1: Seattle) to take into account the skewed distribution of bus ridership (91 percent of the ridership is in the City of Seattle).

Two binary logit models were tested. Each model estimated the probability that the total number of bus riders at a given location was more than 37. The first model included the nine measures of transportation-efficient land use, but not the effect of the Seattle location (tables D-1 and D-2). The second model included the nine land-use measures and the Seattle identifier in order to examine the effect of a Seattle versus non-Seattle location. It was expected that adding the Seattle identifier would increase the explanatory power of the model because it could be a proxy for other critical socio-demographic factors that were not reflected in the land-use measures, such as age and income.

Table D-1. Summary of variables used in the models.

Variable		Definition	The range of the values	Type of data
Dependent variable	Number of bus-riders	# of bus-riders for each bus stop per day	0: less than 37 riders 1: 37 and above	Dichotomous
Independent variables	Net Residential density	Residential units per acre of residential parcels	0: Nodata 1: 0 - 6 2: 6 - 10 3: 10 <	Discrete
	Employment density	# of employees per acre of non-residential parcels	0: Nodata 1: 0 - 30 2: 30 - 70 3: 70<	Discrete
	Block size in acres	Average block size in acres	0: Nodata 1: 10 < 2: 6 – 10 3: 0 – 6 acres	Discrete
	Net % of surface parking lots	% of surface parking lots of commercial parcels	0: Nodata 1: 75% < 2: 35% - 75% 3: 0 – 35%	Discrete
	% of slope	Steepness of the slope	0: Nodata 1: 5%< 2: 2.5% - 5% 3: 0 – 2.5%	Discrete
	% of area of affordable housing	% of the area of residential parcels with the property value per unit below the mean of King County	0: Nodata 1: 0 - 25% 2: 25% - 47% 3: 47%<	Discrete
	Shopping Traffic Volume	Total number of trips per day generated from the retail facilities.	N/A	Continuous
	School Traffic Volume	Total number of trips per day generated from the schools.	N/A	Continuous
	Existence of NC2	Existence of NC2 within a quarter mile distance from the bus-stop	0: No 1: Yes	Dichotomous
	Seattle	Location of the bus-stop (Seattle vs. Suburb)	0: Suburb 1: Seattle	Dichotomous
	* All land use measures are estimated using a quarter-mile radius buffer.			

Table D-2: Land-use classisfication.

Parcel Data King County Assessor's		TELUMI	
USE CODE1	DESCRPT1	Telumi Code	Definition
2	Single Family(Res Use/Zo	1	Single Family
6	Single Family(C/I Zone)	1	Single Family
8	Mobile Home	1	Single Family
7	Houseboat	1	Single Family
9	Single Family(C/I Use)	1	Single Family
3	Duplex	2	Multi Family
4	Triplex	2	Multi Family
5	4-Plex	2	Multi Family
11	Apartment	2	Multi Family
17	Apartment(Co-op)	2	Multi Family
18	Apartment(Subsidized)	2	Multi Family
20	Condominium(Residential)	2	Multi Family
38	Mobile Home Park	2	Multi Family
16	Apartment(Mixed Use)	2	Multi Family
25	Condominium(Mixed Use)	2	Multi Family
49	Retirement Facility	2	Multi Family
56	Residence Hall/Dorm	2	Multi Family
57	Group Home	2	Multi Family
59	Nursing Home	2	Multi Family
272	Historic Prop(Residence)	2	Multi Family
29	Townhouse Plat	2	Multi Family
48	Condominium(M Home Pk)	2	Multi Family
60	Shopping Ctr(Nghbrhood)	3	Shopping Center
61	Shopping Ctr(Community)	3	Shopping Center
62	Shopping Ctr(Regional)	3	Shopping Center
63	Shopping Ctr(Maj Retail)	3	Shopping Center
104	Retail(Big Box)	3	Shopping Center
190	Vet/Animal Control Srvc	4	Retail/Service
96	Retail(Line/Strip)	4	Retail/Service
101	Retail Store	4	Retail/Service
162	Bank	4	Retail/Service
167	Conv Store without Gas	4	Retail/Service
168	Conv Store with Gas	4	Retail/Service
274	Historic Prop(Retail)	4	Retail/Service
189	Post Office/Post Service	4	Retail/Service
105	Retail(Discount)	4	Retail/Service
193	Daycare Center	4	Retail/Service
171	Restaurant(Fast Food)	5	Restaurant
183	Restaurant/Lounge	5	Restaurant
188	Tavern/Lounge	5	Restaurant
166	Club	6	Entertainment
147	Movie Theater	6	Entertainment
157	Art Gallery/Museum/Soc S	6	Entertainment
160	Auditorium//Assembly Bld	6	Entertainment
141	Campground	7	Sport Facilities
142	Driving Range	7	Sport Facilities
140	Bowling Alley	7	Sport Facilities
156	Sport Facility	7	Sport Facilities
143	Golf Course	7	Sport Facilities
145	Health Club	7	Sport Facilities
149	Park Public(Zoo/Arbor)	7	Sport Facilities
152	Ski Area	7	Sport Facilities
153	Skating Rink(Ice/Roller)	7	Sport Facilities
146	Marina	7	Sport Facilities
106	Office Building	8	Office
118	Office Park	8	Office
126	Condominium(Office)	8	Office
273	Historic Prop(Office)	8	Office
202	High Tech/High Flex	8	Office
210	Industrial Park	9	Manufacturing
223	Industrial(Gen Purpose)	9	Manufacturing
245	Industrial(Heavy)	9	Manufacturing
246	Industrial(Lignt)	9	Manufacturing
276	Historic Prop(Loft/Wareh	9	Manufacturing
247	Air Terminal and Hangers	9	Manufacturing
266	Utility Public	9	Manufacturing
267	Utility Private, Radio,	9	Manufacturing
138	Mining/Quarry/Ore Proces	9	Manufacturing
195	Warehouse	10	Warhouse
252	Mini Warehouse	10	Warhouse
261	Terminal(Rail)	11	
262	Terminal(Marine/Comm Fis	11	
264	Terminal(Auto/Bus/Other)	11	
271	Terminal(Marine)	11	Terminal (Rail/Marina/Bus)
165	Church/Welfare/Relig Srv	12	Church
184	School(Public)	13	Education
185	School(Private)	13	Education
		13	Education
55	Rehabilitation Center	14	Hospital
122	Medical/Dental Office	14	Hospital
173	Hospital	14	Hospital
172	Governmental Service	15	Institutional
216	Service Building	15	Institutional
159	Parking(Assoc)	16	Auto facilites
180	Parking(Commercial Lot)	16	Auto facilites
182	Parking(Garage)	16	Auto facilites

186	Service Station	16	Auto facilites
194	Mini Lube	16	Auto facilites
163	Car Wash	16	Auto facilites
161	Auto Showroom and Lot	16	Auto facilites
130	Farm	17	Agriculture
137	Greenhse/Nrsry/Hort Srvc	17	Agriculture
179	Mortuary/Cemetery/Cremat	18	Open Space
150	Park Private(Amuse Ctr)	18	Open Space
326	Open Space(Curr Use-RCW	18	Open Space
327	Open Space(Agric-RCW 84.	18	Open Space
328	Open Space TmbrLand/Gree	18	Open Space
331	Reserve/Wilderness Area	18	Open Space
324	Forest Land(Class-RCW 84	19	Others
325	Forest Land(Desig-RCW 84	19	Others
277	Historic Prop(Park/Billb	19	Others
280	Historic Prop(Misc)	19	Others
330	Easement	19	Others
332	Right of Way/Utility, Ro	19	Others
333	River/Creek/Stream	19	Others
334	Tideland 1st Class	19	Others
335	Tideland 2 nd class	19	Others
337	Water Body Fresh	19	Others
339	Shell Structure	19	Others
299	Historic Prop(Vacant Lan	19	Others
300	Vacant(Single-family)	19	Others
301	Vacant(Multi-family)	19	Others
309	Vacant(Commercial)	19	Others
316	Vacant(Industrial)	19	Others
51	Hotel/Motel	20	Hotel/Motel
58	Resort/Lodge/Retreat	20	Hotel/Motel
191	Grocery Store	21	Grocery

CORRELATION ANALYSIS

Table D-3 shows the results of correlation analyses for the variables used in the logit-model. All independent variables (land-use variables and the Seattle identifier) are significantly correlated to the dependent variable (dichotomized bus ridership data). Employment density has the strongest correlation. Correlations between bus ridership and school traffic volume, percentage of area of affordable housing, and percentage of slope are relatively weak. All independent variables except percentage of area in affordable housing are positively correlated. The negative relationship between bus usage and percentage of area in affordable housing is unexpected. It may be explained by the strength of the correlation with employment density and, specifically, the number of employment locations where high bus usage corresponds to a low percentage of affordable housing (such as Seattle and Bellevue downtown areas, as well as high employment areas near park-and-rides in the suburbs).

Table D-3: Results correlation analysis to bus ridership variable

N=5363	Definition	Pearson Correlation	N DELETE?
n_intersc	Number of intersections	.367(**)	5363
sch_traff	School Traffic Volume	.086(**)	5363
ret_traff	Shopping Traffic Volume	.246(**)	5363
p_afford	% of area of affordable housing	-.105(**)	5363
p_parking	Net % of surface parking lots	.331(**)	5363
blk_size	Block size in acres	.324(**)	5363
emp_den	Employment density	.367(**)	5363
res_den	Net Residential density	.376(**)	5363
nc2	Existence of NC2	.279(**)	5363
slope	% of slope	.058(**)	5363
prc_sidewk	% of areas of the sidewalk	.254(**)	5363
seattle	Seattle	.320(**)	5363

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

MODEL RESULTS

Table D-4 shows the results of the two binary-logit models. The first model (land-use variables only) has a pseudo R-square value of 0.344. It is slightly improved (0.359) after the Seattle variable is included. The independent variables in each model are selected with the stepwise method. The school traffic volume, retail traffic volume, percentage of surface parking lots, employment density, and NC2 variables are statistically significant in both models. Employment density and NC2 show relatively strong association with the dependent variable, while the effects of school and retail traffic volumes are substantially lower than those of other variables. Residential density and average block size drop out in the second model because they are highly correlated with the Seattle identifier. In the second model, the percentage of the area of affordable housing becomes significant and is positively correlated with bus ridership.

Table D-4: Summary of the model results.

Model 1: Land-use variables					**Model 2: Land-use variables + Seattle identifier**				
Nagelkerke R-square: 0.344					Nagelkerke R-square: 0.359				
Variable Name	B	S.E.	Sig.	Exp(B)	Variable Name	B	S.E.	Sig.	Exp(B)
res_den	0.662	0.053	0	1.939	seattle	1.552	0.1	0	4.72
p_parking	0.506	0.076	0	1.659	nc2	0.755	0.079	0	2.127
nc2	0.471	0.08	0	1.602	emp_den	0.425	0.059	0	1.529
emp_den	0.416	0.056	0	1.517	p_parking	0.22	0.079	0.005	1.246
slope	0.324	0.07	0	1.383	p_afford	0.17	0.063	0.007	1.186
blk_size	0.311	0.046	0	1.365	n_intersc	0.056	0.008	0	1.057
sch_traff	0.002	0	0	1.002	sch_traff	0.002	0	0	1.002
ret_traff	0	0	0	1	ret_traff	0.001	0	0	1.001
Constant	-5.181	0.179	0	0.006	Constant	-4.083	0.181	0	0.017

Results significant at the 0.99 level

ESTIMATION OF THE COMPOSITE LAYER

Two formulas reflecting the differences among the effects of individual land-use measures are generated through statistical analysis. The first formula is estimated from the model of land-use measures only, and the second formula is from the model with the Seattle variable:

Model 1: π =

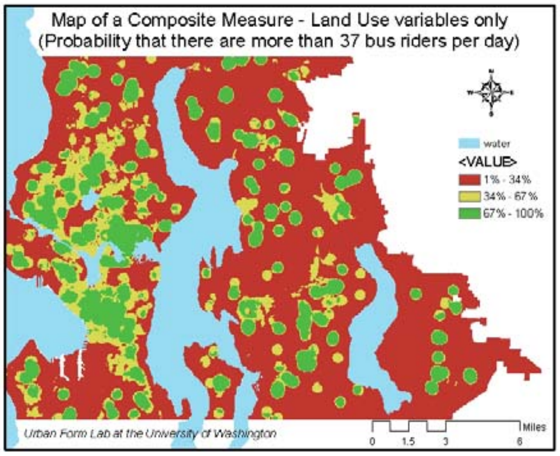
$$\frac{e^{0.002(sch\_traff)+0.0001(ret\_traff)+0.506(P\_Parking)+0.311(blk\_size)+0.416(emp\_den)+0.662(res\_den)+0.471(NC2)+0.324(slope)-5.181}}{1+e^{0.002(sch\_traff)+0.0001(ret\_traff)+0.506(P\_Parking)+0.311(blk\_size)+0.416(emp\_den)+0.662(res\_den)+0.471(NC2)+0.324(slope)-5.181}}$$

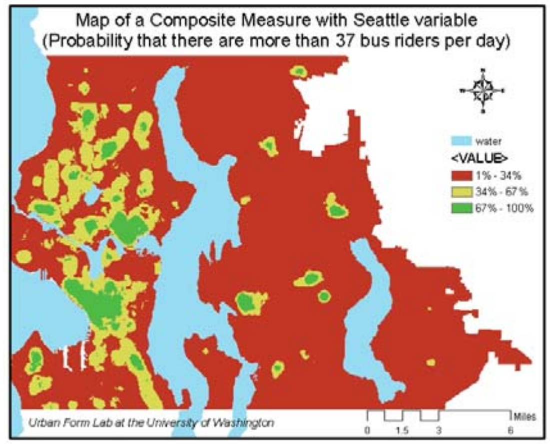
Model 2: π =

$$\frac{e^{0.002(sch\_traff)+0.0001(ret\_traff)+0.506(P\_Parking)+0.311(blk\_size)+0.416(emp\_den)+0.662(res\_den)+0.471(NC2)+0.324(slope)-5.181}}{1+e^{0.002(sch\_traff)+0.0001(ret\_traff)+0.506(P\_Parking)+0.311(blk\_size)+0.416(emp\_den)+0.662(res\_den)+0.471(NC2)+0.324(slope)-5.181}}$$

where π = the probability that a bus stop at a certain point has more than 37 bus-riders (0% < π <100%).

The GIS maps of two composite measures are produced with the formula (in Figure D-1). They illustrate the spatial distribution of the probability that there are more than 37 bus riders at a given location.





Model 1 Model 2

Figure D-1: Composite TELUMI layer.

Table D-5 summarizes the results of the modeling process and compares the values of composite measures from models 1 and 2.

Table D-5. Summary of King County areas with high, latent and low TE for all map layers.

		High TE	**Latent TE**	**Low TE**	**No data***	**Total**
1	Residential density (Res. units per acre)	13.0%	14.0%	65.0%	8.0%	100.0%
2	Employment density (Employees per acre)	3.3%	11.5%	64.0%	21.2%	100.0%
3	NC2**	13.3%	N/A	N/A	86.7%	100.0%
4	Shopping Traffic**	31.9%	N/A	N/A	68.1%	100.0%
5	School Traffic**	30.0%	N/A	N/A	70.0%	100.0%
6	Average block size in acres	5.0%	5.0%	88.0%	2.0%	100.0%
7	Percent of parking at grade**	0.3%	12.3%	66.3%	21.1%	100.0%
8	Slope (%)	15.0%	18.0%	67.0%	0.0%	100.0%
9	Affordable housing	22.0%	28.0%	50.0%	0.0%	100.0%
	Total 1-9					
	Composite 1	8.0%	9.0%	83.0%	0.0%	100.0%
	Composite 2	10.6%	3.4%	14.9%	71.1%	100.0%

CONCLUSIONS

The models show strong associations between the use of transit and the land use variables selected to develop the TELUMI. Bus ridership was selected as a measure of travel behavior that is well-accepted as a transportation-efficient mode of travel. Also, transit use data have the advantage of being disaggregated enough to capture the effects of land use on travel behavior, and to show differences in strength of association between land use variables. At the same time, bus ridership is strongly linked to commute trips. It would be desirable to run the models with travel data on all travel modes to gain insights on all travel patterns. However, comprehensive travel data available countywide have been shown to be too aggregated to examine the effects of land use on non-SOV travel. These data are also known to underestimate non-SOV travel, thus severely limiting the analysis of transportation options. In this light, bus use appears to be the most appropriate and feasible data to use for developing the TELUMI.