TRANSPORTATION PLANNING PERFORMANCE MEASURES

Final Report

SPR 357

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16. Abstract

Oregon transportation plans, including the statewide Oregon Transportation Plan, and current regional transportation plans for the Portland, Salem, Eugene, and Medford metropolitan areas, contain some policy areas that are not adequately addressed by performance measures. These include policies related to the following: balance and adaptability; economic vitality; safety and security; environmental justice; land use compatibility; and quality of life. This research, while acknowledging the importance of assessing current system performance, focuses on performance measures that can also employ model forecast data for evaluating future plan alternatives.

To address some of the deficiencies and to better address other plan policies, this research developed and tested six performance measures. The Urban Mobility Measures and Freight Delay Costs used performance measures developed by others and extended them for use in Oregon plans. The Transportation Cost Index represents a novel approach to measuring accessibility and to address, in part, issues related to balance, environmental justice, land use compatibility, and quality of life. The Percent of Market Basket Accessible by Non-auto Modes and the Auto Dependence Index measures are designed to address issues related to automobile reliance in the Oregon Transportation Planning Rule. The Road Network Concentration Index represents a novel approach to measuring transportation system security and efficiency. Other potential performance measures were considered but dropped because current models do not generate the appropriate data.

The results of testing and analysis indicate that the Urban Mobility Measures and the Freight Delay Costs could be implemented immediately in Oregon. The others could be implemented soon following further refinement. Further research is recommended into policies related to the following: balance, particularly regarding transportation investments; safety, focusing on the influence of long range planning decisions; reliability; and other aspects of economic vitality.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.67	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

NOTE: Volumes greater than 1000 L shall be in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSION TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	2.47	square yards	yd^2
ha	hectares	0.386	acres	ac
km^2	kilometers squared		square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit	°F

* SI is the symbol for the International System of Measurement

(12/96 jrl)

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TRANSPORTATION PLANNING PERFORMANCE MEASURES

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1.0 INTRODUCTION

Performance measurement is broadly defined as a process of assessing progress toward achieving predetermined goals. Measuring transportation plan performance entails assessing progress toward the plan's stated goals and objectives. A "good" measure simply and clearly indicates how well a goal or objective is being met, is unambiguously defined, is understandable and acceptable to plan stakeholders, allows for economical data collection and analysis, and is sensitive to differences among alternative transportation policies and investments.

Federal policies and state policies require the Oregon Department of Transportation (ODOT) and the metropolitan planning organizations (MPOs) to consider various transportation and land use alternatives. Transportation performance measures that are commonly used in Oregon to evaluate alternative plans and projects include per capita vehicle miles of travel, volume/capacity ratios, and auto occupancy. The current measures, however, do not address the full range of policies that currently guide Oregon transportation planning. For example, they do not provide meaningful indications of 1) how well the transportation system delivers multi-modal services; 2) the efficiency with which public resources are used to deliver transportation services; and 3) how public policies affect the delivery of those services.

One measure commonly used to judge the reliance of transportation systems on automobile travel is vehicle miles of travel (VMT) per capita. Its value comes from the implied relationship between the amount of automobile travel and the existence of alternative transportation modes and land use patterns which support their use. However, per capita VMT does not measure the effectiveness of delivering multi-modal transportation services. Per capita VMT will decline if nothing is done and congestion is simply allowed to increase. It is also difficult to separate the influence of public policy on VMT from other influences. For example, research has shown that the growth of VMT has been directly connected to the growth of personal incomes. Given that positive correlation, it could by hypothesized that Oregonians becoming less prosperous would cause a reduction in VMT. Even a precipitous spike in the price of oil could bring about VMT reduction and claimed "success."

It has been said that "What gets measured gets done." Hence it is important that multi-modal transportation and land use performance gets measured in the right way to accomplish public goals and objectives. Using the wrong performance measures can result in inadequately assessing transportation needs, failing to accommodate growth, misallocating transportation and land use investments, failing to consider important aspects of transportation performance (such as safety), and failing to meet legal requirements (e.g. state / federal air quality requirements).

Although much of the attention on multi-modal transportation and land use performance measures has focused on the metropolitan areas, they have much broader statewide value. The fundamental purpose of transportation is to provide opportunities for people and businesses to trade and otherwise interact with one another. This is as much an issue in the less developed areas of the state as in metropolitan areas. Good multi-modal performance measures will permit the evaluation of transportation performance in all regions of the state.

1.1 RESEARCH OBJECTIVES

The following objectives were identified for this study:

1) Identify Oregon transportation planning policies that currently lack adequate performance measures.

2) Identify, develop, and recommend multi-modal transportation performance measures that:
   a) Can be readily implemented by ODOT and Oregon MPOs in their planning processes, and can utilize current and planned forecasting tools;
   b) Address relevant local, state, and federal policies;
   c) Provide useful information to decision makers, help them discern among plan alternatives and investment options, and enable them to consider impacts on both the public in general and on various population segments;
   d) Allow performance to be measured as well as forecasted;
   e) Build upon recent research in transportation plan performance measurement; and
   f) Identify additional research opportunities.

3) Test the recommended performance measures using current MPO transportation planning models. Evaluate the results.

4) Prepare a final report and recommendations.

To accomplish these objectives, the project undertook five tasks:

<u>Task #1: Develop performance measures planning framework</u>

- Compile and summarize goals, policies, and objectives from Oregon state and MPO transportation plans
- Identify goals and policies currently lacking adequate performance measures
- Conduct transportation performance measure literature search and prepare database of performance measures, classified by policy area, data requirements, and other characteristics.

<u>Task #2: Select performance measures for detailed evaluation</u>

- Develop selection criteria
- Inventory State and MPO data and models
- Consult with TAC, OMSC PM Committee, and Expert Panel
- Summarize discussions and input, identify measures to evaluate
- Identify future research needs

<u>Task #3: Develop tools to test the selected performance measures</u>

- Develop application procedures, macros, and scripts to evaluate existing MPO scenarios in terms of the selected measures

Task #4: Calculate performance of prototype transportation planning scenarios

Task #5: Evaluate measures, prepare final report

1.2 ORGANIZATION OF THIS REPORT

This report is organized into five chapters – this one and the following four:

- Chapter 2 provides the framework for analyzing and selecting performance measures.
- Chapter 3 provides descriptions of the measures that were ultimately chosen.
- Chapter 4 discusses the methods used to calculate and test the performance measures and the results of those tests.
- Chapter 5 summarizes and evaluates the results of the performance analysis, and recommends additional research.

Appendix A at the end of this report contains tables and discussions summarizing the development of a performance measures planning framework.

Appendix B contains the commented computer programs that were used to calculate the measures.

Appendix C contains summaries of the Expert Panel responses and recommendations on performance measures to explore.

In addition to the appendices included in this report, additional documentation that includes the performance measure compendium table is available on CD from the Lane Council of Governments in Eugene, Oregon.

2.0 FRAMEWORK FOR ANALYZING AND SELECTING PERFORMANCE MEASURES

In transportation planning, the goals and objectives of a plan are typically guided by Federal and State policies and tailored to meet local needs. In Oregon, the Transportation Planning Rule (TPR) lays out requirements for all transportation plans (*Oregon Secretary of State 2002*). For projects with federal highway funds the Transportation Equity Act for the 21st Century legislation requires certain conditions to be met (*TEA-21 1998*). Consequently, most transportation plans share a similar set of policy themes or what we refer to in this report as policy areas.

Information from Oregon state and MPO plans and the National Cooperative Highway Research Program Report 446, *Guidebook for Performance-Based Transportation Planning*, served as a background for a multi-dimensional policy framework to be developed to describe the essential policy areas and the qualifying performance principles applicable to transportation planning in Oregon (*Cambridge Systematics 2000*). In addition, the Performance Measures sub-Committee (PMC) of the Oregon Modeling Steering Committee provided assistance in the development of this framework.

2.1 LITERATURE REVIEW

Recognizing that considerable work has been done with respect to transportation performance measures, a comprehensive literature review was undertaken. The research team reviewed the following documents:

- All Oregon MPO plans (*LCOG 2001; RVCOG 2002; SKATS 2002; Metro 2000*);
- TEA-21 planning elements (*TEA-21 1998*);
- The Oregon Transportation Planning Rule (*Oregon Secretary of State 2002*); and
- Oregon Transportation Plan components (*ODOT 1992; ODOT 1995; ODOT 1997; ODOT 1999; ODOT 2000; ODOT 2001*).

The transportation performance measures of the 2003 Oregon Benchmark Performance Report were also extracted (*Oregon Progress Board 2003*). For each of these documents that guide Oregon transportation planning, the stated goals, objectives and policies were assembled and were cross-referenced with measures currently in place to evaluate plan performance (see Appendix A, Tables A1.1 – A1.12).

Reaching beyond Oregon, the performance measures for the TTI Urban Mobility Study were compiled (*Texas Transportation Institute 2003*). The National Cooperative Highway Research

Program (NCHRP) Reports 398 and 446 were also acquired (*Lomax, et al. 1997; Cambridge Systematics 2000*). NCHRP Report 446 classified over 500 performance measures in one or more of the following 8 policy areas:

1. Accessibility
2. Mobility
3. Economic Development
4. Quality of Life
5. Environmental and Resource Conservation
6. Safety
7. Operational Efficiency
8. System Preservation

The performance measures from all other reports were added to this table to bring together a list with over 750 entries. (See Appendix A, Table A1.13.) (This table is also available on CD from the Lane Council of Governments.

2.2 POLICY FRAMEWORK

2.2.1 Input policy areas

Building upon the eight categories specified in NCHRP Report 446, twelve policy areas (hereafter referred to as Oregon Transportation Policy Areas, OTPA) were defined as shown in Table 2.1 to fit Oregon transportation planning.

Goals within each of these twelve policy areas can be either directly or indirectly affected by transportation planning decisions. That is, transportation systems can be the primary "Policy determinant" (P) (i.e., have a direct effect) or can play a predominately "Supporting role" (S) (i.e., have an indirect effect). For example, *Mobility* is directly influenced by transportation planning decisions -- the transportation system is the primary means for achieving the goals within this area. For other goals, such as in *Safety and Security*, there are components for which transportation is the primary determinant as well as non-transportation components, the most common of which is land use and urban design. For still other goals, such as *Quality of Life* or *Economic Vitality*, transportation plays only a supporting role.

Table 2.1: Oregon Transportation Policy Areas

Policy Area	Role*	Description or Aspects of….
Economic Vitality	S	• Diversified, Competitive Regional Economy • Long Term Economic Growth • New and Expanding Business Opportunities • Healthy, Efficient Markets • Plentiful Jobs, Suitable Workforce
Balanced Transportation System	P	• Strategic use of demand management, land use planning, systems management, and new investment to match transport system supply and demand • Appropriate allocation of resources • Investment in multiple travel modes • Transport investment synchronous with other public and private investment • Fair resolution of conflicts arising from competing goals and policies
Sustainability	S	• Preserve or improve environment • Conserve resources • Preserve or enhance value of public and private investments
Adaptability	S	• Avoiding over-reliance on one or more modes, routes, structures • Avoiding over-reliance on uncertain forecasts and plan outcomes • Resilience to system disturbances, natural and human-caused • Responsiveness to change, both planned and unplanned
Accessibility	P	• The ease of travel (traveler's perceived time, cost, comfort and safety) to participate in desired social and economic activities • The number, variety, and quality of activity opportunities that are available within the participant's time/cost travel budget.
Mobility	P	• The perceived speed of travel, pertaining primarily to motorized travel modes (related to ***Accessibility***)
Quality of Life	S	• Comfort (adequate food, clothing, shelter) and safety • Opportunities (economic, social, spiritual, recreational, educational, civic) • Sense of belonging; family, neighborhood, community • Quality of the natural and built environment • Prosperity and affordability
Environmental Justice	S	• Opportunities for all people, regardless of gender, age, disability, race, religion, economic status, car ownership, etc) • Consideration of the benefits afforded to and costs borne by all social, economic, geographic groups of people.
System Preservation	P	• Preserving public sector transportation infrastructure investment (related to ***Sustainability***)
Land Use Compatibility	S	• Coordinated land use and transportation planning • Concurrency (matching transportation services to the demand generated by new land development) • Land use supportive of transportation goals and policies, that makes efficient use of existing transportation systems, that doesn't overburden transport systems with new demand that cannot efficiently be met. • One component may be "Smart Growth" (mixed-uses, high densities, pedestrian and transit-supportive design)
Affordability	S	• From traveler's perspective: access to opportunities within his/her travel budget (related to ***Accessibility***) • From community perspective: transportation investment that is at least met by anticipated revenues (related to ***Sustainability***)
Safety and Security	S	• Minimizing risk of injury, death, or property loss through traffic accidents, disasters, and criminal acts (related to ***Quality of Life***) • Providing timely access to emergency services (related to ***Accessibility***)

* P = a primary role played by transportation planning decisions; S = a supportive role played by transportation planning decisions.

Using the OTPA framework summarized in Table 2.1, the performance measures of the NCHRP Reports and of the various Oregon plans were re-categorized (Appendix A, Table A1.13). The originally defined NCHRP policy area of "Economic Development" connoted transportation in support of land development. This was broadened to *Economic Vitality* in the OTPA framework, which includes both development and broader economic concerns. The NCHRP category "Operational Efficiency" was found to include both mobility-related and cost-related performance measures. The mobility-related measures were moved to the *Mobility* category and the "Operational Efficiency" category was expanded to *Affordability*, thereby including overall plan affordability. The category "Environmental and Resource Conservation" was captured by the broader category of *Sustainability* in the OTPA framework. Many of the remaining performance measures in the NCHRP Report were placed in the four additional OTPA categories of *Land Use Compatibility*, *Environmental Justice*, *Balance,* and *Adaptability*.

The performance measures distilled from the various Oregon plans were collected into one table and categorized using the OTPA framework (Appendix A, Table A1.14). Similar performance measures were grouped together. Some measures appeared multiple times based on their use in multiple plans. While the causal relationship with the policy area seemed tenuous for some measures, the association of a particular measure with a policy area indicated the presence of at least the intention of objectively measuring progress toward the goal.

2.2.2 Qualifying performance principles

In addition to the stated goals in each policy area, there are certain principles of "good planning" that are (either consciously or unconsciously) considered when planners and decision makers weigh the proposed projects of any plan. These principles address both ethical and pragmatic considerations, and typically include, for example, fairness and efficiency.

It became apparent during the development of the OTPA framework that there were a handful of planning principles which can be thought of as "qualifiers" or "key questions" to apply to the twelve policy areas described above. These principles are:

1. Fairness: does not disproportionately impact or benefit one group over another.

2. Efficiency: maximizes the achievement of policy objectives with a minimum expenditure of resources.

3. Opportunities and Choice: provides a satisfactory number of options; e.g., choice of not having to purchase a vehicle, choice of modes, choice of routes, access to a variety of desirable and affordable activities, goods, and services, etc.

4. Safety, Health and Well-being: promotes and does not impair public health, welfare, and safety.

5. Stewardship: protects and makes best use of public resources, environmental and financial.

6. Manage Uncertainty and Risk: ability of the plan to cope with many potential futures; avoidance of irrevocable commitment to one particular solution.

Each principle could be applied to all or a subset of policy areas depending on the project, and depending on the goals of the planners, the policymakers and the public. Table 2.2 demonstrates the matrix of possible combinations where each principle could/should be considered in all policy areas. Utilizing this framework, the information provided by one or more performance measures developed for a policy area is considered <u>in conjunction with</u> measures of the planning principles relevant to that policy area.

Table 2.2: Multi-dimensional framework describing Oregon transportation policies

	Policy Areas											
Principles of Good Planning	**Economic Vitality**	**Balance**	**Sustainability**	**Adaptability**	**Accessibility**	**Mobility**	**Quality of Life**	**Environmental Justice**	**System Preservation**	**Land Use Compatibility**	**Affordability**	**Safety and Security**
Fairness		✓			✓		✓	✓			✓	
Efficiency	✓	✓				✓			✓	✓		
Opportunities and Choices	✓	✓			✓	✓	✓				✓	
Safety, Health, and Well-Being		✓	✓				✓		✓			✓
Stewardship			✓				✓		✓			
Manage Uncertainty and Risk	✓	✓		✓								✓

Thus, an ideal performance measure (M) may be multi-dimensional in that it describes the state of a certain portion of the plan or project (usually as a change compared to a base case) while at the same time reflecting one or more decision-making principles. This framework can be represented as

$$\mathbf{M = M_1 \cdot F(x_1, x_2..)} \qquad \textbf{(2-1)}$$

For example, if the "number of people living within ¼ mile of a transit stop" (M_1) was selected as a measure of *Accessibility* to public transit service, then tracking the "income distribution" (x_1) of the potential patrons could reflect the *Fairness* of the plan, while the "cost per person per mile of travel by transit" (x_2) could indicate the *Affordability* of the project or plan. The overall performance measure, M, in this representation, is thus a function of multiple aspects or dimensions of the proposed plan/project. It is this complex assemblage of policy areas and planning principles for Oregon transportation plans for which a framework is sought.

This approach is presently not objectively manifest in most, if not all, Oregon plans, although, as suggested earlier, at least some of the principles are subjectively employed in the weighing of proposed alternatives.

2.2.3 Performance measure evaluation criteria

In addition to categorizing performance measures within the multi-dimensional framework, careful consideration was given when evaluating the viability of individual performance measures. Key questions when considering the usefulness of a performance measure were as follows:

- Can the measure be quantified, ordered, or expressed in terms of relative magnitude?
- Can the measure be calculated from observed data, and also estimated for the future, using forecasted variables?
- Does it measure a plan output or outcome that is clearly correlated with the goals and policies in question?
- Does it measure how well the goal, goal component, or supporting role is met?
- Can the measure be examined within the existing capabilities of current and planned travel models and data collection efforts?

To provide further insight into these evaluation criteria, the performance measures in the compendium of Appendix A, Table A1.13 were categorized *beyond* the policy area framework. Specifically, performance measures were further assigned categories of "data type" and "PM characteristics." A discussion of each of these categories follows.

2.2.4 Data type

This characterization of a performance measure indicates the source of the data used to evaluate the measure. The categories defined within data type are as follows:

- ***Land Use \ Economic \ Demographic \ Environmental*** data refer to observations of current or historical conditions. Typical sources include the Census, state employment data, land use parcel files, and air quality monitor data.

- ***Transport System*** data also document current or historical conditions, but specifically pertaining to the transportation system. Traffic counts, HPMS, transit passenger counts, speed\delay studies, weigh station data, and parking utilization studies are typical sources.

- ***Travel Models, Integrated Models, and Travel Behavior Surveys*** are grouped together. They seek to represent the transportation system using a complete description of travel behavior on the part of a representative sample of system users. Models have the added feature of using knowledge of past behavior to forecast travel response to alternative future conditions.

- ***Attitudinal Surveys*** are typically used to gather customer satisfaction data and user perceptions of transportation conditions.

2.2.5 Performance measure characteristics

Objective measures are quantifiable, and lend themselves to establishing ***benchmarks*** and standards. They can be used to compare different urban areas. Examples are fare box recovery ratios, volume/capacity ratios, VMT per capita, and non-motorized mode share. ***Relative*** measures can also be quantifiable, but the units of measurement do not lend themselves to benchmarking or cross-regional comparisons. Some measures of *Accessibility*, using destination choice log sums for example, are non-dimensional. They are useful for estimating changes over time, or for comparing two or more future alternatives, but may be difficult for the public to comprehend, even when translated to dollars or "utiles." Other relative measures may use attitudinal data and "fuzzy logic" analysis.

Forecastable performance measures utilize model output. The quality of the output depends upon the reliability of the model input data and the validity of the model itself.

Output performance measures quantify system changes that occur through implementation of the transportation plan. Examples include number of public meetings, miles of bikeway, transit service hours, road capacity, and acres zoned for nodal development. ***Outcome*** performance measures, on the other hand, quantify the effects of those system changes, frequently determined by the responses of people to the changes. Examples include attendance at public meetings, riders per bikeway mile, transit mode split, volume capacity ratios, and percent of new housing and employment captured in mixed-use nodes. User response measures often use sample behavioral data or travel models to describe system-wide conditions. A measure can be influenced by BOTH plan implementation and user response. "Boarding Rides per Revenue Hour," for example, is affected by both the number of riders (user response) and the number of service hours provided (plan implementation).

A number of the *Accessibility* measures quantify the ***combined effects of land use and transportation.*** Number of jobs within 30 minutes by bus, for example, combines employment, a land use variable, and travel time by bus, a transportation variable. Other typical model-based measures may sum the product of attraction zone employment and multi-modal travel costs (e.g., the destination choice logsum value) for each production zone. Some of the measures applicable to *Balance, Quality of Life, Adaptability,* and *Environmental Justice* will similarly measure the combined effects.

2.3 ADEQUACY IN MEASURING PERFORMANCE

2.3.1 Current transportation planning performance measure deficiencies in Oregon

Table A1.13 contains more than 750 transportation performance measures, of which 175 were compiled from the Oregon plans (Table A1.14). A key issue is whether there is a clear causal relationship between policy goal and performance measure. For example, if within the policy area of *Balance*, the goal is "Increase transit patronage," then a performance measure like "annual transit trips" is better than "transit mode share," and both are far better than "VMT/capita." Thus, although a policy area may nominally have a large number of performance measures, many are found to be only obliquely related to the policy area purportedly under review. Identified deficiencies are noted in Appendix A, Table A-1.15.

Several policy areas were found to be reasonably well-covered in the Oregon plans. We propose to continue to use many of the performance measures currently popular in Oregon, or currently under development for other projects. For example, there are several popular measures of

Accessibility, such as number of opportunities available to zonal households within *t* minutes by mode *m* or comparative *Accessibility* measures using the destination choice model "inclusive value," a component of the econometric model that captures, to some extent, both the travel time and cost of accessing opportunities, and the number and quality of those opportunities. However, many of the accessibility measures were developed for internal use within the travel models themselves, and are not suitable or adequate for conveying how accessible a neighborhood is to policy makers and the public.

Similarly, there are numerous measures of *Mobility* currently in use, including volume-capacity-type level-of-service (LOS) standards found in the Oregon Highway Plan and most metropolitan plans. However, these measures, too, are aimed primarily at planners and engineers, rather than policy makers and the general public. The annual Urban Mobility Report (UMR) produced by the Texas Transportation Institute utilizes comparative measures of urban mobility that seem to resonate with the general public. Some of those measures have been further refined as part of ODOT's *Operations Performance Measures* project. The UMR measures have thus far been used for analysis of current conditions and historic trends. One challenge would be to develop a methodology to extend the UMR measures into future forecasts and evaluation of long-range plan scenarios.

Some policy areas had either few performance measures or had measures that did not address all aspects of the goals. Some of these policy areas such as *Balance* may have many performance measures, but these performance measures were found to be inadequate in that they did not capture the essence of the policy. Among those policy areas that were not adequately addressed, members of the Technical Advisory Committee (TAC) and the PMC expressed particular interest in the following:

2.3.1.1 Balance and Adaptability

First and foremost, this project should consider *Balance* in light of requirements of Oregon's Transportation Planning Rule (TPR). The TPR requires that state and local transportation plans cannot have an over-reliance on any one mode. The TPR calls for a reduction in per-capita VMT, but does not really include objective measures of *reliance* or dependence. For example, VMT measures motor vehicle *use*, but a measure of automobile *dependence* might entail the availability and attractiveness of alternative modes for accessing certain activities, perhaps with consideration to the activity type, the traveler's socio-economic characteristics, the time of day or week, or the cost of travel relative to the automobile. This is an interesting challenge, and potentially the most important contribution this project can make within the context of Oregon transportation planning.

Oregon plans contain numerous *Mobility*-related LOS standards for motor vehicles, but no LOS standards for transit, pedestrian, and bicycle modes. There are a handful of alternative mode LOS standards found in the literature. Alternative-mode LOS measures typically relate to aspects of coverage, frequency, safety and convenience, rather than to travel time and speed. As such, they tend to overlap the *Accessibility* policy area, although a comparison of modal accessibilities within an area would be a measure of *Balance*. There is a current investigation of multimodal levels of service for urban arterials (NCHRP Project 3-70) that will consider the effects of each mode upon the others. *Balance* might be thought of in terms of the change in multimodal accessibility that occurs as the cost of a mode changes or as a mode becomes unavailable. A relatively low elasticity of accessibility with respect to such a change would imply a well-balanced system.

Balance is a critical element of transportation investment. We have investment in preservation versus new projects, for example, or investment that responds to forecasted highway demand versus responding to policy directives to reduce demand or to shift demand to other modes. Typically, a plan is deemed "balanced" in this sense, when it is acceptable to a majority of the adopting officials, but we would like to explore ways to objectively measure balanced transportation investment.

Balance could also be thought of in terms of providing comparable accessibility for various population groups, which overlaps the *Environmental Justice* policy area. Some other potential aspects of *Balanc*e are the degree to which private development and public infrastructure investment is coordinated and mutually supportive; the balanced use of demand management, land use planning, systems management, and new investment to match transport system supply and demand; and the balanced resolution of partly conflicting plan policies, such as between competing environmental and economic goals. *Balance* could also be thought of in terms of providing comparable accessibility for various population groups, which overlaps the *Environmental Justice* policy area.

2.3.1.2 Economic Vitality

Several TAC members felt that despite the fact that transportation plays only a supporting role in *Economic Vitality,* it is important to be able to gauge how well it performs that role. Our research has found measures that try to capture the contribution of transportation systems to things such as freight mobility, business access to customers and labor force, household access to goods and services, and worker access to jobs.

While transportation-related economic analysis has typically focused on costs and user benefits of specific projects, Cambridge Systematics has reported the use of the Highway Economic Requirements System (HERS) in combination with the REMI macroeconomic model to estimate the effects of program-level transportation investments on regional economic growth (*Cambridge Systematics 2003*). The HERS model was modified to separate the direct economic benefits (reduced travel time, operating costs, and accident costs) accrued for personal travel from those related to business travel. A reduction in business costs then leads to macroeconomic benefits measured by increases in personal income for residents of the region, increased employment, and increased gross regional product. Oregon could explore the feasibility of combining metropolitan land use and transportation model output with economic components of the Statewide Model for a similar assessment.

Central to this discussion will be the effects of traffic congestion on economic vitality, and the distinction of congestion that may have benign (or even beneficial) effects from that which increases production costs, reduces access to markets, and interferes with commerce.

2.3.1.3 Safety and Security

There is significant interest in Safety-Conscious Planning at the federal level. We routinely monitor vehicular crashes by type and severity in existing transportation networks, but we do not typically conduct an in-depth evaluation of safety in long range plans. Planning-level crash-prediction models consider such variables as exposure (VMT) by facility type (functional class, lanes, speed, and LOS), from which we can evaluate the safety consequences of adding new facilities, of improving hazardous facilities that currently have greater-than-expected crash rates, or of reducing travel demand. Similarly, we can explore the use of models to evaluate the safety ramifications of bicycle and pedestrian system elements that reduce exposure and conflicts with vehicular traffic. We can also explore the automation and integration of crash prediction models with regional travel forecasting models so we can readily evaluate the safety of entire networks.

Of course, there are a number of important traffic safety variables (e.g., driver education, law enforcement, road and intersection engineering) that would not be feasible to consider at the planning level, and which might not be addressed by plan policies in any case. There are other seldom-considered safety variables in long range plans, however, that might prove to be very interesting. For example, our land use and demographic models often enable small-area forecasts of school-age children and senior drivers. This may lead to planned improvements in the pedestrian system in areas with more children or additional transit services in areas with an aging population, either of which might enhance the safety effectiveness of the projects relative to the “average” effectiveness.

Many aspects of both safety and security are operational, and thus not part of the typical long-range planning process, but transport models and regional GIS systems can certainly assess how the planned land uses and network structure affect vulnerability to floods, earthquakes, and terrorist threats. We can also evaluate the adequacy of networks for access to emergency services and for quickly evacuating portions of the metro area. Exposure of transit riders to crime could be evaluated in terms of walk distances and wait times, if a relationship between exposure and crime incidence were clearly established.

2.3.1.4 Environmental Justice

Environmental justice has also been a major concern at the federal level, but Oregon plans do not typically include measures to assess disproportionality in the distribution of transportation costs and benefits. We could, for example, combine model and GIS data to measure the variation in accessibility and mobility by socio-economic group, or the variation in exposure to traffic noise and air pollution. The latest Oregon trip-based MPO models also segment each model stage by income group. Thus, for example, we could track highway users by income at the network link level and forecast the effects of road pricing on different income groups.

2.3.1.5 Land Use Compatibility

The TPR calls for integrated land use / transportation plans, but there are no objective measures of plan integration. Efficiency measures, such as average trip length, and many of the *Accessibility* measures capture land use effects, but do not really measure the degree of compatibility or integration. We could explore simple measures comparing population and employment densities with street and intersection densities or with transit route densities and service frequencies. Potential measures could perhaps identify underserved areas, where development has outstripped transportation services and underdeveloped areas, where current and planned transport services could support more development than currently planned. Potential measures could also gauge the capacity of transport services relative to other services, such as sewer, water, and schools.

2.3.1.6 Quality of Life

Transportation's supporting role is covered in several other policy areas (*Accessibility, Sustainability, Environmental Justice, Safety*, etc). However, some aspects of transportation's influence on *Quality of Life* are not captured in the other policy areas. For example, they don't address the transport system's influence on urban form and legibility or on neighborhood cohesiveness; its contribution to urban vitality; providing opportunities to "get out and about" and interact with others and with the environment, with travel itself as the primary activity; the emerging focus on health aspects of walking and biking; or the aesthetics of transport systems and the traveling experience. We found very little in the literature that suggests how to measure the influence of transportation systems on *Quality of Life*.

This information was presented to an expert panel for the purpose of exploring performance measures within these policy areas. Chapter 3 details what policy areas and performance measures ultimately resulted from those discussions.

2.4 DATA AVAILABILITY

2.4.1 Data requirements

Travel models in Oregon have many common requirements. Data may be needed directly for model development and calibration, or it may be used indirectly to compute values that are subsequently used directly in the model. Data classes consist of the following:

(1) Spatial boundaries
  a. Transportation analysis zones (TAZ) and districts
  b. Regional boundary
  c. Urban growth boundaries and city limits

(2) Characteristics and spatial geometry of the travel network
  a. location, lanes, intersections
  b. pedestrian walkways and bikeways

c. transit routes, stops, transfer locations
d. parking inventory (park and ride lots, garages, etc.)
e. functional classification, posted speeds
f. intersection controls

(3) Travel behavior data: a common household travel survey is used within Oregon delineating trips by origin/destination, mode and time of day
a. trips from households internal to the region,
b. trips external to the region: entering, exiting, passing though

(4) Socioeconomic characteristics of households
a. household demography
b. household economics

(5) Land use data
a. housing unit type by parcel for base year, by TAZ for future year
b. employment by type: by location for base year, by TAZ for future year
c. other trip generating/attracting land uses – schools, parks, libraries, etc.
d. vacant parcels

(6) Planning data
a. comprehensive land use plans
b. development constraints – environmental and political
b. regional population and trends (current and projected)
c. regional employment and trends (current and projected)

(7) Calibration and other analytic data
a. Traffic counts
b. Traffic volume versus speed
c. Peak periods and peaking factors

While the model structures may be similar between MPOs, the details of each model are specific to the area, based on the travel behavior of the local public, the transportation options available, and the land uses and distribution within the region. In general, the "travel demand model" is comprised of a set of modules which span a mixture of data structures, including GIS databases and models, EXCEL-based models, and EMME/2 travel forecasting models.

Because of the need to use models for both present day and future year analyses, various sub-models within the travel model package may be constrained to using relationships that can be evaluated for any time period. This need drives both the model form and the aggregation of data. For example, while GIS databases maintain current land use data at the parcel level, forecasts of future land use are typically made only at a coarser spatial scale. The "transportation analysis zone" is the common spatial unit into which areal data are condensed.

Table 2.3 summarizes data utilized in travel modeling by the Central Lane MPO, Salem/Keizer MPO, Rogue Valley MPO, and Portland Metro.

Table 2.3: Input data commonly used in travel demand modeling

Variable	Subcategories	Geography	Sources
Land use allocation models			
Base Year Dwelling units	Single family, Duplex, Multi-family, Mobile Home; Group Quarters, Percent occupied/vacant	GIS by parcel; aggregated to TAZ	GIS regional information systems; Building permit data; US Census
Base Year Employment	Retail, Government, Service, Other. Also used: Temporary/Group, Construction, Financial/Insurance/Real Estate, Transportation/Communications/Utilities, Wholesale, Federal, State and Local Education, State and Local Govt., Other Durable Manufacturing, Other Non-durable manufacturing, Food, Lumber and Wood products, Agriculture, Mining. Also used: within 20 minutes of bus travel	GIS by location and SIC/NAICS, aggregated to TAZ	County control totals from Oregon Dept of Economic Analysis; ES202 employment files from Oregon Employment Department; GIS regional information systems
Planned Use, Plan Designation, Zoning, Current Use, Parcel Size	Land use type, Nodal Development Overlay	GIS by parcel	Comprehensive plan, Zoning Map, Assessor's Data, GIS regional information systems
Development Constraints	Wetlands, steep slopes, floodways, Utility Easements, UGB boundary, etc.	GIS by theme	GIS regional information systems
Future Regional Totals, Population and Employment	Region		PSU Center for Population Research, OEA Countywide totals
School and College enrollment	Elementary, Middle, High Schools, Community College, University	School District Boundaries, TAZ's	School Districts, Colleges
Potential Redevelopment areas, pipeline projects	Residential, Commercial, Industrial, Education, Government	Parcel	City
Transportation Models			
Auto Network	Geometric characteristics, functional class, number of lanes, posted speeds, limited intersection data, (typically, control type and turn prohibitions) , and possibly, parking presence; access management;	Typically, Freeways, Arterials, and Collectors only. Centroid Connectors depicting local street access to arterial network.	City, County, State, Federal transportation agencies; GIS center line files, RTP
Roadway Capacity	Estimated vehicles per hour at saturation flow LOS E/F	Freeway segment or arterial Intersection approach, applied to network links.	Estimated from known characteristics (e.g., functional class, access conditions, median type) and assumed signal g/c splits.

Variable	Subcategories	Geography	Sources
Transit networks	Type of service, Bus, LRT, BRT	By route and route segment	Regional Transit Agency, RTP
Non-motorized Network	On-street walk and bike access, off-street multi-use paths, connectors to transit stops		GIS data, RTP
Base Year Travel network proximity characteristics	As needed: e.g. intersection density; % of TAZ within ¼ mi of transit line		GIS or Model Software
Other parameters required: Auto operating cost Transit fare No. of transit transfers per trip			Transit Agency National Sources
Base Year Households and Population	1-person, 2-person, 3-person, 4+ person Households	TAZ	Estimated from occupied Dwelling Units by structure type, based upon Census data.
HH size; Income; Age of Head of Household,		Census tract, urbanized area; TAZ	Public User Microdata Sample (PUMS) Data; US Census 1A, 3A
HH workers		TAZ	Census Transportation Planning Package (CTPP)
HH auto ownership		TAZ	Census Transportation Planning Package (CTPP)
Person-Trip Production and Attraction Rates	Home-Based Work, School, College, Shopping, Other; Non-Home-Based Work, Non-Work Also: Recreation	TAZ and External Trip End Totals; Zone-to-Zone	HH activity Survey (’94, ’95)
Person Trips by Mode of Travel and Purpose	Purposes above, 1-person, 2-person, and 3- person auto, walk-access transit and park & ride, bicycle, and pedestrian modes. Also: rail	TAZ and External Trip End Totals; Zone-to-Zone	HH activity Survey (’94, ’95)
Person-Trip distances	Purposes above	Indiv trips, district and regional avgs	
Traffic Counts	AM peak, PM peak	Point location	HPMS, City, County, State
Volume-delay functions		Road area type and functional class	Local speed study or standard curves from non-local sources
Area Characteristics	CBD, Parking Charges, Parking Restrictions, Mixed-Use Node or T.O.D.,	TAZ	GIS Data, local plans

2.4.2 Model results

Regional travel models provide estimates of various types of travel impacts:

(1) Trip volume distribution on the network by length, purpose, mode, time of day;
(2) Travel time, speed, and delay under congested conditions;
(3) Preferred and alternative routes of travel under congested conditions or network disruption;
(4) Characteristics of trips within or traversing selected areas (groupings of TAZs) or selected corridors (groupings of network segments); and
(5) Costs perceived by travelers in moving from one TAZ to another.

Table 2.4 provides a sampling of model results.

Table 2.4: Typical output data available from models

Variable	Subcategories	Geography
Person Trips	By Purpose, Mode of Travel, and Time of Day	Network and Transit Route Segments
Vehicle Trips	Purposes above, plus Commercial Vehicles, Thru-trip autos, Thru-trip trucks	TAZ and External Trip End Totals; Zone-to-Zone
Transit Trips	Weekday, Peak Period	Route, Segment, Mode of Access (walk, auto)
Auto Volumes	Average Weekday, AMPK 1-hr and 2-hr, PMPK 1-hr and 2-hr, Mid-day, Night	Network Links: Freeways, Arterials, and Collectors
Travel Time and Delay	By Mode of Travel and Time of Day by other segmentation such as in-vehicle time, wait time, etc.	Zone-to-Zone and Intrazonal Estimates in Matrices, Road Segment and Corridor on Network
Travel Costs	By mode of Travel and Time of Day	Zone-to-Zone and Intrazonal Trips
Non Motorized Trips	Walk and Bike Modes	
Volume-Capacity and Level of Service	By Time of Day	Network Links
Network characteristics	e.g., Lane miles of roadway; miles of off-road bikeways, VMT,	Network segments

This research used data from two travel models in Oregon, the Eugene-Springfield metropolitan area model and the Medford metropolitan area model (RVMPO model). The Eugene-Springfield metropolitan model was used to calculate measures based on modeled estimates of traffic volumes. This model has been completely calibrated and validated and therefore produces reasonable estimates of traffic volumes. The Medford area model was used to calculate measures based on modeled estimates of travel flows and travel costs between portions of the metropolitan area. This model was chosen because it implements the new JEMnR model structure that is well suited for computing a number of the chosen measures.

JEMnR stands for "Joint Estimated Model in R." It is the implementation in the R programming language of a common MPO travel demand model structure developed by the MPOs in Oregon and ODOT. Metro, the MPO for the Portland area, developed the structure and estimated the model equations from pooled MPO travel behavior data. ODOT implemented this model in the R programming language. Using JEMnR to calculate performance measures has several advantages resulting from the model's structure and its implementation in R.

The JEMnR model is a four-step disaggregate discrete choice model which accounts for factors that most influence the travel decisions of different types of households with regard to:

- The number and type of trips made (trip generation);
- The destinations of trips (trip distribution);
- The choice of transportation mode (e.g. car, bus, walk); and,
- The choice of route (trip assignment).

The disaggregate nature of the model facilitates the assessment of transportation costs and benefits by different types of households. For example, it allows the transportation costs of households in different income groups to be assessed. The discrete choice nature of the model provides a set of statistically estimated equations (utilities) that quantify the importance of different factors such as travel time and operating cost to household travel decisions. A consistent set of discrete choice models are used for both trip distribution and mode choice. The travel utilities calculated by these models can easily be converted into monetary or time equivalents.

Other advantages result from the way that JEMnR was implemented using the R programming language. JEMnR models save all of the data from intermediate model calculations. These include all of the destination choice and mode choice utilities that may be used to calculate travel costs. The use of the R programming language also facilitates the reuse of portions of the JEMnR model code in programs to calculate the performance measures. These calculations and the production of output graphics can be readily added to JEMnR model runs.

Unfortunately, calibration and validation of the Medford metropolitan area model could not be completed in time for completing of this research. Work progressed far enough along to allow all the measures to be computed, but results are not as accurate as would be expected from a fully calibrated and validated model. Although the model was not wholely ready, the advantages of testing and implementing measures that could use the JEMnR model and be readily connected to the model outweighed the disadvantages of testing on an incomplete model.

3.0 SELECTED PERFORMANCE MEASURES

3.1 SELECTION PROCESS

The results of the literature review were presented to the TAC and the Performance Measures Committee of the Oregon Modeling Steering Committee. Their recommendations were used in the preparation of a Briefing Memorandum, which discussed policy categories that currently lack sufficient performance measures in Oregon transportation plans. The Expert Panel was asked to provide ideas pertaining to these and other plan policies and objectives. The panel cited some important characteristics of a useful measure:

- Context;
- Comparable over time;
- Comparable over regions;
- Applicable to subareas and corridors;
- Both forecastable and measurable measures are needed;
- Can be rolled-up to broader aggregations;
- Understandable link to the policies or goals;
- Winnowed from a large set of potential measures to an essential set – there may be many performance measures for internal use, but only a few essential ones communicated to policy makers and the public;
- Matched to the audience – agency, decision-makers, public;
- Matched to the intention of the policy.

The panel also noted that:

- At least some of the measures chosen should be directly measurable as well as forecastable.
- The annual Urban Mobility Report documentation can provide useful insights into how congestion can be conveyed to the public.
- We should avoid "average" measures, which lose meaning when aggregated over an entire area.
    - *Accessibility* measures are important, should be referenced to a number of dimensions (social-economic group, geographic area, time of day, etc.), and should be communicated in a meaningful way (not in terms of "utiles," etc). The panel was intrigued with the idea of measuring accessibility to a market basket of activities and choices.
        1. Measure cost of accessibility over time or change in the market basket over time.
        2. Issue of whether there should be one basket for all or different baskets for different population groups.

- Reliability of the transportation system is important, but still difficult to forecast.
- There are many aspects to *Economic Vitality*, including mobility, accessibility, and freight costs. Some of these effects may be beyond the scope of MPO models. The idea of consumer surplus can be useful for evaluating transport system costs and benefits.
- It is important to monitor safety and to quantify the societal costs of crashes, but the panel acknowledged that it is still difficult to forecast crashes.
- Transportation system security measures typically deal with recovery from, not prevention of, catastrophes; but the panel did express interest in measures of network redundancy, which reduces vulnerability.

3.2 DATA AND IMPLEMENTATION ISSUES

Selection of performance measures for implementation in this research focused on Oregon transportation planning and the measures that would be useful for evaluating alternative plan scenarios. This constraint thus narrowed the range of measures to be considered. Each measure had to be calculable using forecasted land use and transportation output. The forecasted land use variables had to be sufficiently disaggregate (by household demographic, employment sector, and geographic location) to support the calculations. Similarly, the forecasted transportation variables had to be sufficiently detailed (by trip purpose, mode of travel, time of day, speed, volume, etc).

Several of the performance measures recommended by the Expert Review Panel relied solely upon observed data, some of which could also be used to validate model forecasts, but which were not strictly forecastable themselves. The researchers endorsed the use of those measures, but this current research focus was on measures that could also utilize forecasted information. Other measures simply lacked the appropriate modeling tools at this time, but could be considered in the future. These are listed below, with the limitations perceived:

- **Track population and employment over time by TAZ and other small functional areas**

  Type of measure: Land Use Compatibility
  This measure, which may utilize annual American Community Survey and State Employment data, provides impetus for updating the model base year when necessary, to validate land use model forecasts, and to gauge the effectiveness of land use policies. It is not, however, useful for evaluating plan scenarios, where land uses and development densities are typically specified exogenously. (An exception can be argued for fully integrated land use models, where TAZ allocations over time can vary as a result of other land use and transportation inputs.)

- **Number of traffic-related crashes / fatalities per unit of population / VMT / time period**

  Type of measure: Safety
  This is a vitally important measure of transportation system safety in the eyes of the public and policy makers. It is very difficult, however, to forecast crashes and fatalities in a meaningful way. Travel models can provide exposure-related data such as forecasted entering volumes by intersection type or forecasted link volumes by functional class and

level of service. However, the number of crashes and fatalities are also a function of other variables that are not typically included in model forecasts, such as engineering design of roads and intersections, level of traffic law enforcement, weather conditions, incidence of reckless driver or pedestrian behavior, and other random or non-forecastable variables. (See recommendations for future research.)

- **Transportation system reliability**

  Type of measure: Reliability
  This is very important to the public's perception of freight, transit, and road system performance. It can be calculated from observed travel time data from trucks, buses, and highway users. It can also be approximated using TTI's older travel delay-based methods. However, the current MPO modeling tools employ "static" traffic assignments, which do not forecast future changes in travel time variability. (See recommendations for future research.)

- **Effects of transportation on regional and state competitiveness**

  Type of measure: Economic Vitality
  Analysts using the Oregon II statewide model will be able to investigate this by quantifying the transportation component of production and export costs, but MPO forecasting tools do not have the economic component to carry out this analysis locally. (See also, recommendations for future research.)

3.3 OVERVIEW OF SELECTED PERFORMANCE MEASURES

The remaining information in this chapter provides a general description of the performance measures selected, in addition to what policy area(s) they address. Also included are brief discussions to address why the measures were chosen and what they were intended to demonstrate. Finally, specifications for analyzing each measure are included.

3.3.1 Measure 1: Urban Mobility

Policy Areas Addressed: Mobility, Economic Vitality

Description:

This is a family of performance measures have been developed by the Texas Transportation Institute and included as part of the annual Urban Mobility Report (UMR) for U.S. urban areas. Each measure uses traffic estimates and congested speeds, which can be obtained either from model results or from observed data, as reported annually by the Highway Performance Monitoring System (HPMS). Accordingly, they are appropriate for setting interim standards and benchmarks, for ongoing monitoring of the transportation system as the plan is implemented, and for validating model forecasts.

Discussion:

This project will extend the use of UMR measures into the realm of travel forecast modeling in Oregon. A similar project is currently being undertaken by the Texas DOT in cooperation with the Texas MPOs. The annual UMR has received a great deal of coverage in the local and national media. Several of the transportation system performance measures reported in the UMR have resonated with the public, as well as with local policy-makers. By using directly comparable measures in travel forecasts, we hope to establish stronger linkages between the UMR and Oregon transportation planning.

While the UMR indicates past mobility trends for each urban area, the model-driven measures will inform policy makers how their short-range and long-range planning decisions are predicted to alter those trends. The use of measures from the UMR also facilitates comparisons that are meaningful to the public. For example, the statement might be made that "In 2025, Eugene's peak period travel delay is expected to be comparable to that of present-day Portland." This conveys a meaningful message to the public.

These measures leverage a great deal of research and development, and much work has already gone into the development of appropriate data resources. For Oregon's MPO areas, the Base Year model calculations of these performance measures can be directly compared and calibrated to those that were published in the UMR for that particular base year and calculated from HPMS data. The modeled measures will have the flexibility of either being calculated from aggregate model output comparable to the HPMS data, or from more detailed output covering more functional classes and time periods.

Specification:

Detailed specifications are omitted here. Our intent was to follow the methodology described in the 2004 Urban Mobility Report (*Texas Transportation Institute 2003*).

> **Travel Delay:** This is the amount of additional time spent in travel, relative to free-flow conditions. It has two components. The recurring component includes delays due to congestion, and the non-recurring component includes delays due to occurrences such as traffic incidents and bad weather.
>
> **Travel Time Index:** This is the ratio of peak period travel time to free-flow conditions and represents the percentage of additional time needed for making the trip in the peak period.
>
> **Buffer (Reliability) Index:** This is a measure of network reliability and is an estimate of the additional time that a traveler needs to budget during peak-period travel, to be assured of arriving on time with a 95 percent confidence level.
>
> **Annual Cost of Congestion:** This is calculated from the travel delay estimate. It has three components: passenger vehicle delay costs, freight vehicle delay costs, and the cost of additional fuel consumed due to slower and uneven travel speeds.

3.3.2 Measure 2: Transportation Cost Index (TCI)

Policy Areas Addressed: Accessibility, Quality of Life, Balance, Land Use Compatibility

Description:

This is an accessibility measure that is analogous to the Consumer Price Index (CPI). The CPI measures the relative price for acquiring a reference market basket of goods and services. It may be used to compare living costs in different areas and changes over time. The TCI measures the relative cost of accessing a market basket of travel destinations. It may be used to compare accessibility by trip purpose, travel mode, income group, geographic area and time period. Travel demand models provide information that may be used to define the travel market basket and to calculate transportation costs.

Discussion:

The TCI is primarily intended to be a measure of accessibility and the effects of the transportation / land use system on the quality of life. It can also serve as an indicator of transportation / land use system compatibility and of balance. The primary purpose of the transportation system, from the standpoint of the individual household, is to provide affordable access to the goods, services, and daily activities that the household desires, and which often play an important role in how household members perceive their quality of life. Like the CPI, which may be used to indicate relative change in the cost of the goods and services themselves, the TCI may be used to indicate changes in the costs to access goods and services. The TCI may be used to measure how transportation affordability varies across an urban area, how it changes over time, and how it is affected by various land use and transportation system alternatives.

Areas having excessively high TCI's in future year scenarios are indicative of problems with land use / transport system compatibility and balance. Extreme traffic congestion, combined with limited alternatives for accessing the "market basket" will result in reduced quality of life, with the household having to either endure higher costs or accept a more limited number of choices. Such situations might be addressed in a variety of ways, including land use changes, investment in alternative modes, transportation system management (TSM) measures, and additional roadway capacity, any of which could reduce the TCI. An overall regional TCI can be computed for each alternative solution to indicate relative effectiveness.

Specification:

The TCI may be computed for different forms of travel demand models, but the specifications presented below are for use with the JEMnR model. The specifications could be readily adapted to other dissagregate discrete choice travel demand models.

A. Define a market basket of travel destinations

The goal of identifying a market basket of travel opportunities is to identify a set of destinations that provide a good set of choices for meeting daily living needs. The process of identifying this market basket involves three steps:

1. Identify the categories of travel for which market baskets of travel destinations are to be defined.
2. Identify a market area that will serve as the reference for quantifying travel destinations
3. Calculate the number of travel destinations in the reference market area.

The travel categories are defined based on their definition in the model used for calculating the measure. For this study they include work, shopping, recreation and other non-school trips made from the home.

The second step involves identifying a market area that will serve as the reference for quantifying the market basket of travel destinations. The reference market area is a TAZ within the urban area and a set of zones located around the TAZ that represent a large number of destinations. The reference TAZ may be identified through the use of expert judgment or through a structured analytical process. Several processes were tested in the study.

The final step is to identify the total quantity of market attractions located within the market area for each trip purpose. Disaggregate discrete choice models provide the information needed to measure the relative attractiveness of places in the urban area to different categories of households. The cumulative attractiveness of destinations within the reference market area may be measured using components of the destination choice model. This is the reference market basket.

B. Calculate travel costs to access the market basket

Once the travel destination market basket has been defined for each trip purpose, the average cost to access each market basket is calculated for each TAZ and income group in the model area. The information for calculating these costs comes from “access utilities” calculated for the JEMnR destination choice model. The access utilities measure the perceived “costs” of traveling between TAZs by trip purpose, income group and travel mode. The model-derived costs are converted into monetary units and are aggregated across travel modes and averaged across the market place for the TAZ

Since the cost that is to be averaged varies by travel mode, it is necessary to combine the mode costs into one representative cost to be averaged across each TAZ market place.

The average cost to access the market basket from each TAZ is computed as a weighted average of the travel costs from that TAZ to each other TAZ in the market place containing the market basket of destinations for that TAZ. The weighting factor in calculating the average is the proportion of the market basket that is located within each TAZ in the market place. The market place for each TAZ is identified as the set of TAZs that contain the market basket of destinations and may be accessed at the lowest cost from the target TAZ.

C. Compute Travel Cost Indices

TCI values for each cost array are computed by dividing the values for each TAZ by the values for the reference TAZ. This produces TCI values by TAZ and income, by TAZ and trip purpose, and by TAZ for all incomes and purposes.

While the study only computed TCI values for one time period within one metropolitan area, TCI values could be used to make other comparisons as well. For example, the comparison of present year and future year average travel costs for an urban area would indicate the amount of increase or decrease in accessibility. Following are some other examples of comparisons that are possible:

- Future to present urban area average;
- Future to present urban area average by transport mode;
- Future to present urban area average by income group;
- Present transport mode average to urban area average;
- Present income group average to urban area average; and
- Present TAZ average to urban area average.

TAZ comparisons can be presented in maps and other graphical forms.

3.3.3 Measure 3: Percent of Travel Market-Basket Accessible by Non-Auto Modes

Policy Area Addressed: Reduce Automobile Dependence (Oregon TPR)

Description:

This measure identifies the proportions of the travel opportunity market baskets identified for Measure 2 for each TAZ that are determined to be accessible by non-auto travel modes. It measures the amount that the transportation and land use system fosters automobile dependence. This measure focuses upon transportation choices rather than behavior. It is primarily influenced by land use, but is also influenced by non-motorized network connectivity, and by transit system coverage and service frequencies.

Discussion:

This is intended to be a more direct measure of automobile dependence than the TPR's current VMT/capita standard. It is superior to the current VMT measure as an indicator of automobile dependence for the following reasons:

- It is not affected by factors unrelated to land use and transportation policies such as the price of fuel, or the amount of travel generated by various economic conditions, both of which can dramatically influence VMT.
- It is not affected by increased carpooling (which reduces VMT, but not auto dependency)
- Unlike VMT, it will show a benefit from deteriorating automobile levels-of-service ONLY if there are viable non-automobile options.

Specification:

This measure is calculated using the market baskets and market areas calculated for Measure 2. In addition, the following is done to calculate the measure:

1. Thresholds for determining which areas are accessible by non-auto modes are determined.
2. For each trip purpose, income group and TAZ, the zones that make up the market place for the TAZ are identified in the same way that they are identified for the purpose of computing average travel costs. Then the those zones divided into the ones that are practical to travel to by at least one non-auto mode and the zones that are impractical to reach by all non-auto modes.
3. The market opportunities for all zones that are accessible to the TAZ by non-auto modes are summed, as are the market opportunities for all of the TAZs in the market place.
4. The sum of the market opportunities in the non-auto accessible zones is divided by the total market opportunities in the market place of the TAZ to determine the percentage of the market basket that is accessible by non-auto modes.

The result of these calculations is an array of percentages by TAZ, income group and trip purpose. The percentages are aggregated by income group, purpose, and geographic area using the same methods used for aggregating the TCI.

3.3.4 Measure 4: Auto-Dependence Index

Policy Areas Addressed: Balance, Reduce Automobile Dependence (Oregon TPR)

Description:

The Auto Dependence Index (ADI) compares the Transportation Cost Indices for auto and non-auto modes to indicate the degree of auto-dependence that the land use and transportation system fosters. Like Measure 3, the ADI is a measure of dependence, not behavior. It differs from Measure 3 in one important aspect, however. It is affected by changes in transport costs. For example, higher fuel prices and deteriorating highway levels-of-service would increase the automobile TCI, and, especially where the most attractive non-auto mode is not affected by fuel costs or congestion, would lower the ADI.

Discussion:

The ADI measures other aspects of balance. It indicates where travel costs by auto and non-auto modes are out of balance. A value greater than one indicates that the land use and transportation system fosters auto-dependence, because auto travel is less costly than travel by other modes. Larger ADI values indicate greater auto-dependence.

Specification:

The measure is calculated according to a procedure very similar to the procedure for calculating the TCI. The average cost to access the travel opportunity market basket is calculated for automobiles and for non-auto modes in the same manner with one exception. The travel cost for non-auto modes between any pair of TAZs uses the cost of the non-auto travel mode that costs the least. As with the TCI, the average travel costs are computed for each trip purpose and income group. The results of these calculations are two arrays of average costs by TAZ, income group and trip purpose; one for auto costs and one for non-auto costs. Dividing the non-auto cost array by the auto cost array produces the ADI values for each combination of TAZ, income and purpose. The ADI values are aggregated by income group, purpose, and geographic area using the same methods used for aggregating the TCI.

3.3.5 Measure 5: Freight Delay Costs

Policy Area Addressed: Economic Vitality

Description:

This measure is similar to the freight congestion cost component of Measure 1 but is intended for application to a freight model.

Specification:

For the Oregon 2 statewide model, and for MPOs with a truck or commodity flow model, hourly delay costs are developed for each vehicle type and / or commodity class. Model estimates of delay include recurring delay, as calculated directly from the model or using TTI methodology, non-recurring delay using TTI factors, and delay due to truck restrictions on the arterial network, as estimated from the model. The latter is derived from a matrix-based comparison of the shortest congested time path on the entire arterial network with that of the restricted network. Hourly delay costs include vehicle operating costs, driver costs, and average costs of commodity delay, for each freight vehicle class, if obtainable.

3.3.6 Measure 6: Road Network Concentration Index

Policy Areas Addressed: Security, Balance

Description:

This is a measure of the degree to which travel is distributed over the regional arterial network. It is a measure of both system vulnerability and balance. The less evenly traffic is spread over the system, the less balanced it is and the more vulnerable the system is to traffic disruptions. For example, an incident on a very heavily traveled link could cause an inordinate amount of system delay.

Specification:

This measure is computed from travel model data, but could also be computed from actual traffic counts and inventories (such as the HPMS data used by the Texas Transportation Institute for the Urban Mobility Report). For each link in the road network, the traffic volume on the link is tabulated as are the number of lanes. The traffic load on any link is the ratio of the traffic volume on the link to the link lanes. The data is split into tabulations for each roadway functional class. The Road Network Concentration Index (RNCI) is computed from these tabulations.

The RNCI is similar to the Gini coefficient, a measure used in economics to measure distributional inequality such as income inequality. As with the Gini coefficient, the RNCI measures equality on a scale of 0 to 1. An index of 0 means perfect equality of traffic loads. An index of 1 means perfect inequality of traffic loads.

The computation of the RNCI can be most easily understood with a graphical example (Figure 3.1). Plotting the cumulative sum of traffic loads (lane volumes) on all links in ascending order produces an upward bending graph, illustrated by the solid black line in Figure 3.1. This is called a Lorenz curve. If traffic loads were distributed perfectly equally among all links, the curve would be a straight line with a slope of 1, as shown by the dashed line in the figure. The RNCI (Gini coefficient) is calculated as the ratio of the area between the Lorenz curve and the line of perfect equality (grey area in the figure) and the total area under the line of perfect equality (hatched area in the figure). If traffic loads are very unequally distributed, then the Lorenz curve would bend sharply and the area designated as "A" in the diagram would be a large portion of the area under the diagonal and the RNCI would be close to one. If traffic loads are close to equally distributed, area "A" becomes very small and the RNCI would be close to zero.

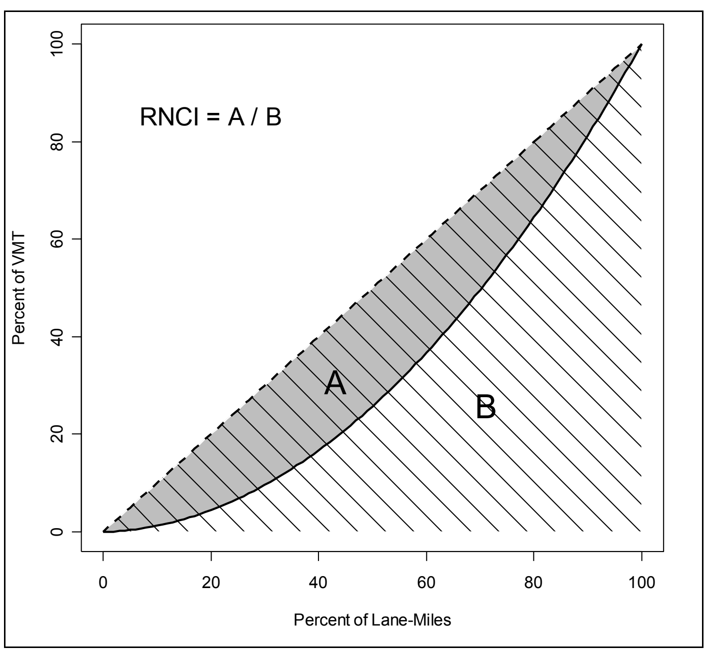

Figure 3.1: Illustration of RNCI

4.0 CALCULATION AND TESTING OF PERFORMANCE MEASURES

This section reviews the methods used to calculate the selected performance measures and the results of the calculations. In several instances, several different calculation methods were tested. These are reported on and successes and failures are noted. While the section covers the calculation methods thoroughly, it does not address all of the details. These are documented in programs written in the R language to implement the calculations and included in Appendix B.

4.1 URBAN MOBILITY

Urban mobility measures were calculated using the detailed Eugene network data rather than the generalized procedures used by the Texas Transportation Institute for its Urban Mobility Study (UMS) . The UMS procedures use generalized speed relationships for freeways and other principal arterials that depend on counts of average daily traffic and roadway lane-miles. Based primarily on these data, the UMS estimates the duration of congestion travel periods and the average speeds occurring during those periods. No estimates of speeds are made for roads other than freeways and other principal arterials. Travel models allow more complete estimation of traffic congestion since they address all roads of collector classification or above. In addition, the method used in travel models to estimate travel speeds is more specific than the UMS method. Furthermore, the UMS speed methodology was developed for freeways and other principal arterials and may not be transferrable to other functionally classed roads.

The mobility measures identified in the specifications are travel delay, travel time index, buffer index, and annual cost of congestion. The Buffer Index (BI) was not computed for this test. As described earlier, this index measures the variations in travel times. It is based on evaluation of travel speed variations recorded by continuous real-time measurement systems on freeways and principal arterials. The Texas Transportation Institute has developed some factors to apply to the Travel Time Index (TTI) to calculate the BI, based on comparisons between computed TTI values and BI values (computed from real-time data) for urban areas with real-time measurement systems. In this study, however, real-time travel speed data were not available, so a base-year BI and TTI factors could not be computed. The Portland metro area, which has rich travel speed database, would be a logical test area for the BI.

The measures were tested using both daily traffic assignment results, and those for the morning and evening peak 2-hour time periods. Daily models simplify volume delay relationships to match daily traffic assignments to average daily traffic counts. While the modeled daily link volumes are comparable to the HPMS data from which the UMR calculations are done, the link travel speed and delay calculated from such an approach is not as accurate as those calculated from an hourly traffic model. As an additional sensitivity check, the mobility measures were also computed for a 2002 network that had a key regional link removed – the Ferry Street Bridge over the Willamette River.

4.1.1 Travel delay

Travel delay is the extra time spent traveling in congestion. The calculation of delay, therefore, is a function of the reference speed chosen to represent what travelers should expect. The Texas Transportation Institute has chosen 60 MPH as the reference speed for freeways and 35 MPH as the reference speed for other principal arterials. These are speeds that are close to free-flow speed, the speed when travelers are unimpeded by other travelers. The expert panel recommended that delay also be calculated relative to the somewhat lower speeds associated with higher vehicle densities and more efficient vehicle flow rates. For this study, a flow rate of 87% of link capacity (approximately LOS 'D') was chosen. This reflects moderate congestion.

The travel delay and other measures were computed using free-flow speed as a reference and also using a reference speed at moderate congestion levels. The difference between travel time at that speed and the travel time in congestion may be a more realistic reflection of what travelers perceive to be travel delay due to congestion.

Annual travel delay per person was calculated for these two conditions using the two reference speeds for the two network scenarios. Delay due to recurring congestion and total delay due to recurring and incident-related congestion were both calculated. The Texas Transportation Institute only computes delay on freeways, expressways and other principal arterials. A comparison is done of just freeways and other principal arterials as well as all roads.

The results of the analysis are contained in Tables 4.1 and 4.2. Following are some observations:

1. All of the measures show substantial differences in delay between the scenarios with and those without the Ferry Street Bridge.

2. A substantial amount of delay (25% to 55%, depending on how it is calculated) occurs on roadways other than freeways and other principal arterials.

3. There are very large differences in delay calculated using a moderate reference speed versus a free-flow reference speed. Both results are different than the 5 hours of total annual per capita delay on freeways and principal arterials reported in the Texas Transportation Institute's UMR for Eugene in 2003. The peak-hour model-based estimate using the free flow speed – 8.6 hours – appears to be the best approximation of the UMR estimate.

4. Peak period assignments produce delay results more comparable to the UMR than Daily assignments. The UMR calculated a Roadway Congestion Index of .91 for Eugene, which indicates that very little congestion occurs outside of the morning and evening peak hours. The UMR calculations assume that only about one third of average daily traffic is even exposed to potentially congested conditions, and only a portion of that actually encounters congestion. The UMR assumes that Eugene traffic may be exposed to congestion for a total 5.8 hours per day. The table below assumes a total of 4 hours of congested conditions per day. Further research is recommended on calibrating the reference flow conditions from a disaggregate model analysis to match the aggregate HPMS-based delay estimates derived by the Texas Transportation Institute's UMR.

Table 4.1: Annual hours of delay per person using daily assignments

Delay Type	Reference Flow Type	With Ferry St. Bridge All	With Ferry St. Bridge Freeway & Principal Arterial	Without Ferry St. Bridge All	Without Ferry St. Bridge Freeway & Principal Arterial
Recurring	Free-Flow	16.8	8.0	20.1	10.9
	Mod-Flow	0.9	0.4	2.7	1.9
Total	Free-Flow	43.8	23.9	53.8	33.0
	Mod-Flow	2.8	1.3	8.5	6.2

Table 4.2: Annual hours of delay per person using peak 2-hour assignments

Delay Type	Reference Flow Type	With Ferry St. Bridge All	With Ferry St. Bridge Freeway & Principal Arterial	Without Ferry St. Bridge All	Without Ferry St. Bridge Freeway & Principal Arterial
Recurring	Free-Flow	5.4	3.0	6.3	3.7
	Mod-Flow	0.4	0.3	1.0	0.7
Total	Free-Flow	13.7	8.6	16.4	10.9
	Mod-Flow	1.2	0.9	3.0	2.4

4.1.2 Travel Time Index

The Travel Time Index (TTI) is a measure of average travel rates on the road network. (A travel rate is the reciprocal of a travel speed.) The TTI takes into account the effects of both recurring congestion and incident-caused congestion on average travel rates. As with delay, the TTI is dependent on the choice of the reference flow conditions. It was calculated for both a free-flow and moderate flow reference. TTI values were calculated for both scenarios (with and without the Ferry Street Bridge) and for the whole network and just the freeways and principal arterials. Tables 4.3 and 4.4 show the results.

Table 4.3: Travel Time Index using daily assignments

Reference Flow Type	With Ferry St. Bridge All	With Ferry St. Bridge Freeway & Principal Arterial	Without Ferry St. Bridge All	Without Ferry St. Bridge Freeway & Principal Arterial
Free-Flow	1.33	1.41	1.40	1.53
Mod-Flow	1.18	1.24	1.22	1.31

Table 4.4: Travel Time Index using peak 2-hour assignments

Reference Flow Type	With Ferry St. Bridge All	With Ferry St. Bridge Freeway & Principal Arterial	Without Ferry St. Bridge All	Without Ferry St. Bridge Freeway & Principal Arterial
Free-Flow	1.13	1.15	1.15	1.18
Mod-Flow	1.01	1.01	1.02	1.02

Following are some observations about the results:

1. The 2003 TTI value for freeways and principal arterials, as reported in the Urban Mobility Report for Eugene in 2003, was 1.11. Once again, it appears that that the value computed for using the peak period assignments only – 1.15 – comes closest to the UMR value. The disaggregate method was used here. Limiting the calculation to freeways and principal arterials increases the TTI value. Since the TTI is most often explained as showing how much longer it would take to travel during peak conditions versus off-peak conditions, limiting the TTI to freeways and principal arterials may overstate the effect of congestion on travel since a significant portion of trips occurs on other road types.

2. There is not as much difference in the TTI values for the scenarios with and without the Ferry Street Bridge as there is in the delay values. That may be a result of traffic rerouting to roads that may be relatively uncongested but more circuitous. The TTI measure does not depend on the trip length, whereas the delay measure does.

4.1.3 Annual cost of congestion

Congestion costs include the cost of person-hours lost to travel delay, the cost of additional fuel wasted in congested travel, and the cost of freight delay. Annual congestion costs were calculated using the UMR methodology and assumptions (http://mobility.tamu.edu/ums/report/methodology.stm). For these calculations, only the peak period assignments were used. Table 4.5 shows the results.

Table 4.5: Annual cost of congestion using peak 2-hour assignments

Annual Delay Cost	With Ferry St. Bridge		Without Ferry St. Bridge	
	Free-Flow	LOS "D"	Free-Flow	LOS "D"
Passenger Delay	$16,811,000	$1,374,000	$19,633,000	$3,054,000
Wasted Pass. Fuel	$3,791,000	$310,000	$4,392,000	$683,000
Freight Delay	$5,880,000	$389,000	$6,999,000	$992,000
Total	$26,482,000	$2,073,000	$31,024,000	$4,729,000

The value computed ($26.5 million) is somewhat higher than the value computed by the UMR ($20 million). This may be due in part to the inclusion of all network links, including minor arterials and collectors, were used in the calculation. The UMR calculations only include freeways and other principal arterials.

4.2 TRANSPORTATION COST INDEX (TCI)

The Transportation Cost Index (TCI) along with two related measures, percentage of the market available to non-auto modes, and auto dependence matrix, were calculated using the JEMnR model for the Rogue Valley Metropolitan Planning Organization (RVMPO) model now under development. Figure 4.1 is a map showing the RVMPO model area and its location in Oregon. The boundaries of the 744 transporation analysis zones (TAZs) into which the model area is subdivided are shown. The map also shows the two largest cities in the area, Medford and Ashland.

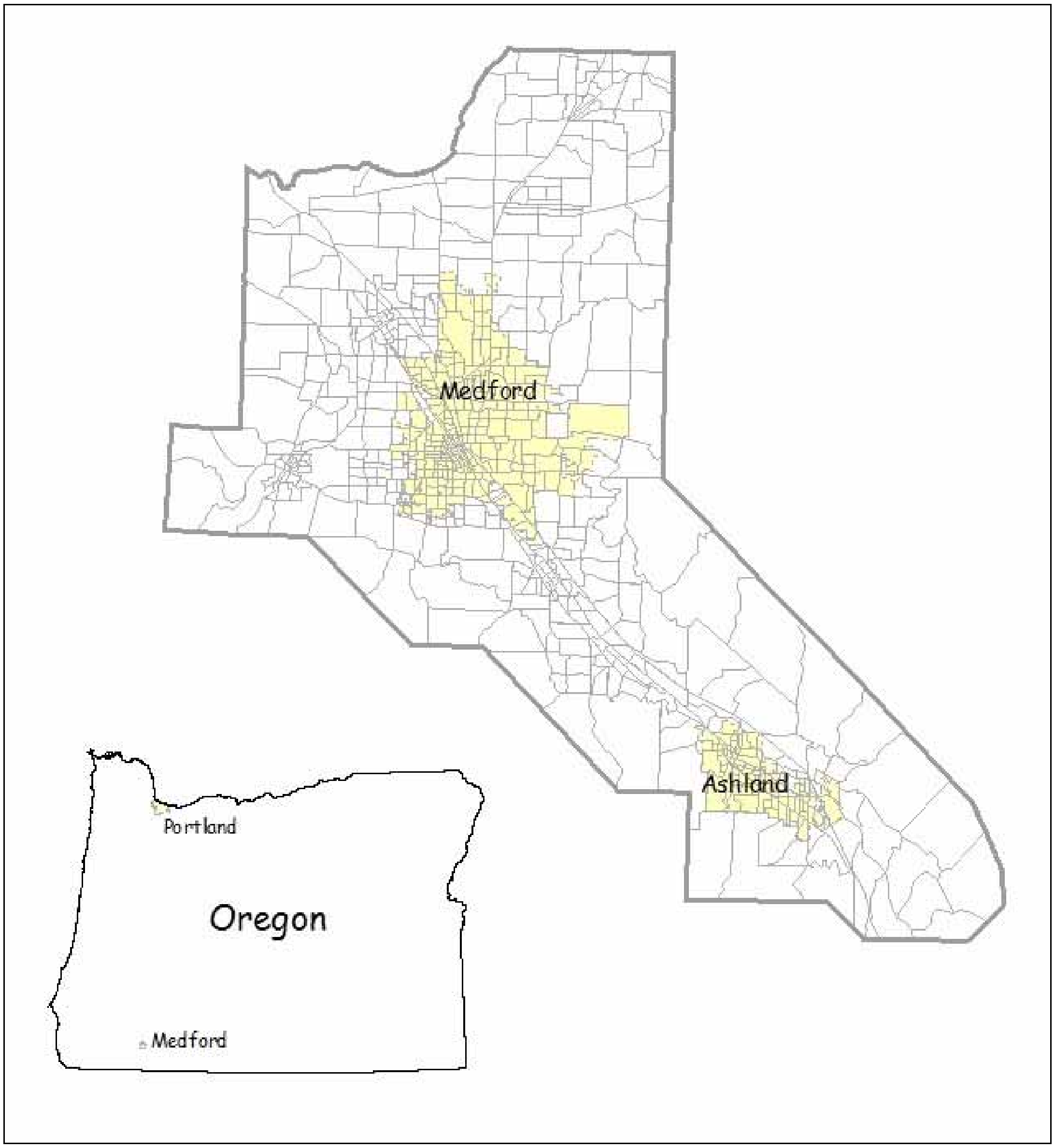

Figure 4.1: Rogue Valley MPO model area

Although calibration and validation of the RVMPO model are not complete, the model was used because its JEMnR model structure facilitates the calculation of performance measures. In addition, the development of the performance measurement software to use the JEMnR model will enable the research results to be deployed more rapidly. Because the model has not been calibrated and validated, however, the study results should not be used to judge transportation or land use performance of the RVMPO area. Instead, the results should be evaluated for reasonability, whether they accomplish the measurement objectives, whether they show a good range of sensitivity to conditions.

The Transportation Cost Index (TCI) was calculated for four trip purposes and three income groups. The four trip purposes were:

- Trips between home and work, also known as home-based work (hbw) trips;
- Trips between home and shopping destinations, also known as home-based shop (hbs) trips;
- Trips between home and recreation destinations, also known as home-based recreation (hbr) trips; and,
- Trips between home and other non-school destinations, also known as home-based other (hbo) trips.

To simplify the calculations and their interpretation, measures were not computed for trips from home to schools or colleges or for trips between non-home destinations. Only home-based trips were considered because the method developed to average measures by income, purpose and geographic area uses the household trip-making rates in each TAZ as the weighting factor. A different method would be needed for aggregating non-home-based trips which do not start or end at home. School trips were not considered because a completely different method is used in the JEMnR model to allocate these trips whose origins and destinations are prescribed by school service area boundaries. College trips were not studied, because the concept of a college market basket within an urban area is not applicable in most circumstances. Extending the TCI measure to include these other trip purposes is a subject for future research.

The method for calculating the TCI involves three main steps:

1. Identifying reference market areas and market baskets;
2. Calculating average travel costs to access the reference market baskets from each TAZ;
3. Calculating TCI values from the average travel costs.

Each of these steps is described in detail below.

4.2.1 Identifying reference market areas and market baskets

The first step in computing the TCI involves identifying a reference market area and reference market baskets. More than one reference market basket is identified because the mix of locations people wish to travel to varies by trip purpose and with their income. Trip purpose affects the market basket because the types of destinations that attract one type of trips (e.g. shopping) are different than the destinations that attract another type of trips (e.g. recreation). Household income affects the choice of reference market basket because purchases of goods and services vary by household income.

It may be argued that varying the market baskets with income introduces bias to income-based comparisons. A low income household will have lower market access costs than a high income household living in the same TAZ and using the same transportation mode because it has smaller market baskets due to its smaller income. In other words, the market access costs for lower income households are constrained by their more limited opportunities. If they had the opportunities of higher income households, their market baskets would be more expansive. On the other hand, the market baskets of some lower income households such as the elderly may be more reflective of their desires. This research tests the measures using market baskets that vary with income, but more research should be done to evaluate this approach and the alternative.

Three steps are involved in computing reference market baskets. They are: identifying a reference TAZ, identifying reference market areas, and summing travel destinations within the identified market areas. These are described in detail below.

The reference TAZ can be identified through a process that uses expert judgment and consensus, or it can be identified using an analytical process. This study tested several analytical processes. It would be worthwhile in application to test a process that combines analysis with expert judgment and community consensus. The analysis can be used to provide some initial ratings. This can be followed by community discussions to bring other considerations into discussions and to decide on a reference TAZ that the community supports.

The reference TAZ can have two functions. One function is to serve as a geographic reference for comparing market access costs. The reference TAZ provides a connection to a real place that is familiar to the community.

The other function the reference TAZ may serve is as a focus for defining the reference market baskets. The patterns of trip making and land use around the reference TAZ can be used to identify market places for each trip purpose and income; and then the destinations in those market places can be summed to calculate reference market baskets. This was originally envisioned to be an important role for the reference TAZ, but subsequent testing revealed problems with this approach. These are discussed below.

All of the processes used to identify a reference TAZ rely on components of the JEMnR destination choice model to identify market areas and calculate the corresponding market baskets. The destination choice model estimates the probabilities that trips will be made between each pair of TAZs in the model area based on two primary considerations, the ease of traveling between the TAZs and the sizes of trip attractors within each TAZ. The portion of the destination choice model which quantifies the ease of travel between TAZs is used to identify market areas. The magnitude of trip attractors is used to calculate market destinations.

The ease of travel by mode and income group for each trip purpose is calculated from "access utilities" produced by the JEMnR model. These utilities are calculated using equations that include factors such as travel time and operating cost that most affect the perceived difficulty of traveling between TAZs. Following is an example of the access utility for driving alone to work from home:

$$U_{DriveAloneWork} = -0.035(PeakFac * IVPeakTime + OffPeakFac * IVOffPeakTime) - 0.099 * WalkTime - 0.58 * OpCost \quad \textbf{(4-1)}$$

where

PeakFac = proportion of travel occurring at peak times
OffPeakFac = proportion of travel occurring at off-peak times
IVPeakTime = minutes of in-vehicle travel time for driving alone during the peak
IVOffPeakTime = minutes of in-vehicle travel time for driving alone during the off-peak
WalkTime = the walking time to get to and from the automobile
OpCost = the operating cost in dollars for the trip

The access utilities are combined into a composite value for all modes by calculating the log of the sum of the exponentiated utilities for each mode.

$$\ln(\sum_m e^{U_m}) \quad \textbf{(4-2)}$$

where

$m \in M$, the set of all travel modes.

These log sum values are used in the process of identifying of market places.The magnitude of trip attractors is calculated using the "size terms" of the destination choice model utilities. The size terms measure the perceived attractiveness of TAZs to trips of different types. They are functions primarily of the numbers of jobs and households in a TAZ, but may include other factors. Following is an example of the equation for calculating the size term for home-based recreation trips:

$$emp + 1.175 * hhs + 7.614 * parks \quad \textbf{(4-3)}$$

where

emp = number of employees
hhs = number of households
parks = park land in acres

Once a market place has been identified for a TAZ, income group and trip purpose, the market basket can be calculated by adding up the size terms for all the TAZs in the market place for the trip purpose.

The process proceeds in several steps and starts with the calculation and storage of the size terms of the destination choice model utilities. The JEMnR code computes the size terms as part of the destination choice model but does not save them to disk. The destination choice model program code was copied and modified to do this. Once the size terms have been calculated, the procedure iterates through each trip purpose, each income group, and each TAZ. Potential market baskets are identified for each TAZ so that they may be compared to identify the reference TAZ.

Two different methods were tested for identifying the potential market area of a TAZ. In both methods, the TAZ is considered the focus of a market area and that TAZ and remaining TAZs are placed in order according to their log sum values in descending order. Then a threshold is used to identify the set of TAZs that is to be included in the market area of the focus TAZ. The method originally specified for this study calculates a cumulative sum of trips attracted to the 1
TAZs from the focus TAZ and sets the cutoff at a specified percentage of the total trips coming from the focus TAZ. Several cutoffs were tested. The set of TAZs making up market area J for trip purpose p, income group i, and TAZ k is defined for this method as:

$$J_{pik} = \{ j : \sum_j trips_{pikj} / \sum_t trips_{pikt} \approx cutoff \text{ and } \sum_j logsum_{pikj} = \max(\sum_j logsum_{pikj}) \} \quad \textbf{(4-4)}$$

where

$t \in T$, the set of all TAZs in the model area

$cutoff$ = the proportion of total trips chosen as the threshold for defining the market area

$trips_{pikj}$ = the number of trips by income group i for purpose p between TAZ k and TAZ j

$logsum_{pikj}$ = the log sum of the access utilities for travel by income group i for purpose p between TAZ k and TAZ j

The second method establishes a log sum threshold for determining which TAZs are to be 2
included in the market area for the focus TAZ. This threshold was chosen by examining ordered plots of log sum values for all TAZs and each trip purpose (Figure 4.2). The average trends for all zones have inflection points where log sum values are about 1. Log sums increase rapidly to the left of the inflection points and decline gradually to the right. This value was chosen as the threshold for determining the market area by the second method. The set of TAZs making up market area J for trip purpose p, income group i, and TAZ k is defined for this method as:

$$J_{pik} = \{ j : logsum_{pikj} \geq 1 \} \quad \textbf{(4-5)}$$

For both methods, the potential market basket is computed by summing all of the size terms within the identified market area. The result of this process is an array of market basket totals by TAZ, trip purpose and income group. The equation for calculating the market basket MB for a particular income group i, trip purpose p, and TAZ k is:

$$MB_{pik} = \sum_j size_{pij} \quad \textbf{(4-6)}$$

where

$j \in J$

$size_{pij}$ is the value of the size term for purpose p, income group i, and zone j

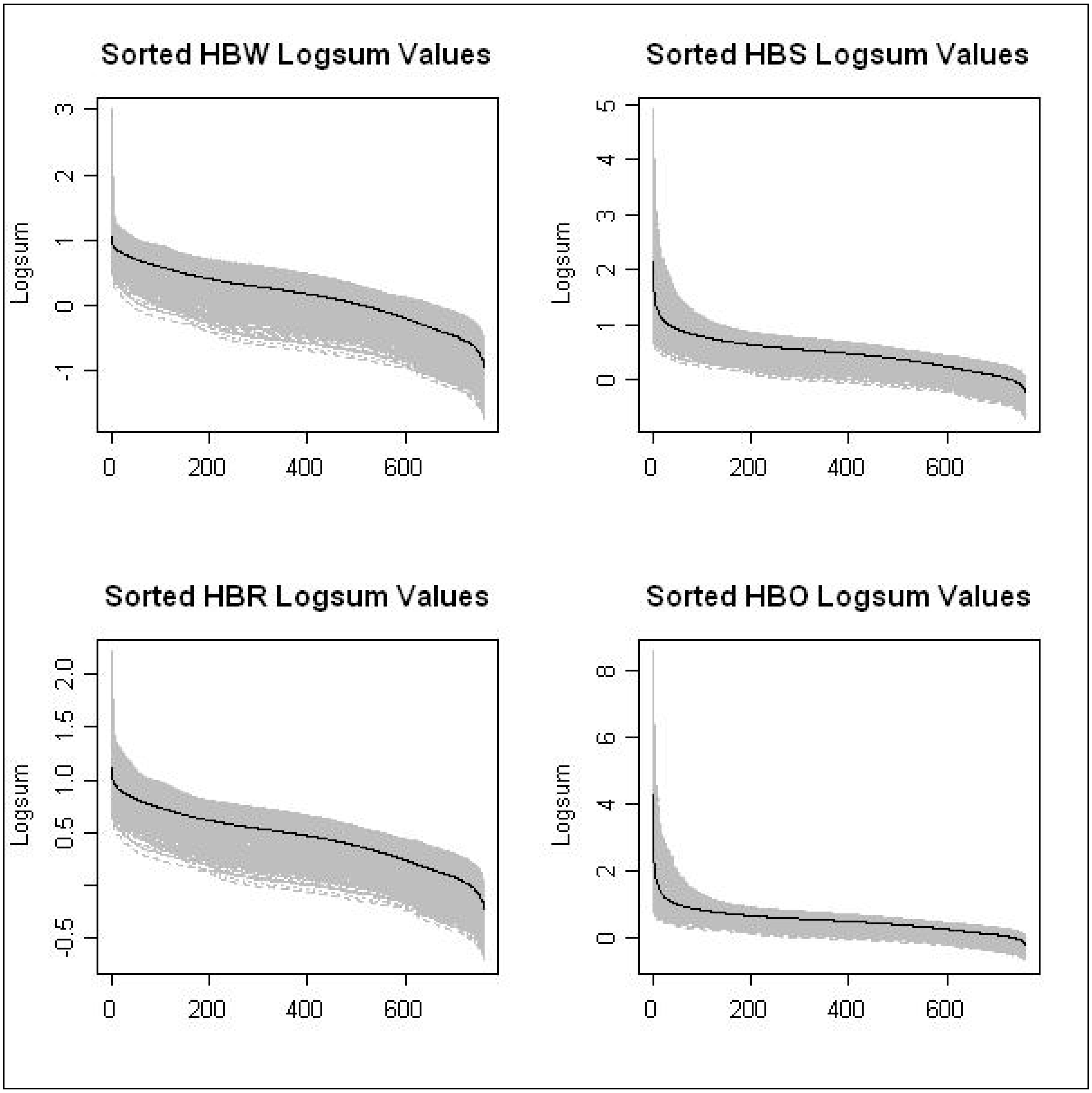

Figure 4.2: Sorted access log sums for all TAZs by trip purpose

The reference TAZ is identified by comparing the market basket totals for each TAZ by trip purpose and income to the maximum values for all TAZs by trip purpose and income. Scores by trip purpose and income group are calculated for each TAZ by dividing the TAZ values by the maximum values. These scores are then added to calculate an overall score. The TAZ with the highest overall score is chosen as the reference zone. Since there are 4 trip purposes and 3 income groups, the maximum possible score is 12.

$$score_k = \sum_{pi} score_{pik} \qquad \textbf{(4-7)}$$

where

$$score_{pik} = MB_{pik} / \max_k (MB_{pik})$$

The two methods for determining market areas identify different reference TAZs. The application of the first method with a trip percentage threshold of 75% identified a TAZ located in a small city on the outskirts of Medford. The application of the second method identified a TAZ in the center of Medford. The first method's choice of a more peripheral zone was puzzling. At first it was thought that this choice was due to the 75% threshold so that the market area represented regional accessibility. Further testing with a variety of lower thresholds resulted in similar results that the reference TAZ was one on the outskirts of the Medford area rather than in a more central location. Thus it was not a matter of regional or local accessibility.

Subsequent evaluation revealed that this method did not work as intended because a trip threshold measures accessibility in terms of traveler trip patterns instead of in terms of trip costs. Without a trip cost constraint, the area that is included in the market can vary greatly. Fringe TAZs can be expected to have a larger number of zones to account for 75% of their trips. Consequently, market areas defined for fringe zones can contain a larger number of attractions than market areas defined for TAZs that are more centrally located.

The second method produces better results. It identifies a reference TAZ that is more centrally located. Without additional constraints, however, it may identify a TAZ that has few or no households in it. It may also identify a TAZ that does not have all modes of transportation available. The method was modified to add these constraints. Figure 4.3 shows the scoring results for this method.

The log of the scores are mapped in Figure 4.3 rather than the scores themselves to improve the discrimination between zones that have low scores. The map shows the relative scores of all TAZs in the model area. The reference zone is located in the central area of Medford. It is surrounded by a fairly large area in Medford that also has relatively high scores. Portions of Ashland also have similar scores. The histogram below the map shows the proportions of households located in each of the mapped categories.

Both methods for identifying the reference TAZ also calculate market baskets. As originally envisioned, the market baskets calculated for the reference TAZ would be the reference market baskets. A practical limitation was found with this approach. The sizes of the market baskets identified vary considerably and the market basket for the reference TAZ can be very idiosyncratic. One way this shows up is in large variations in the sizes of the market baskets of different income groups depending on which zone is chosen as the reference. The most likely causes of this problem are:

- The very uneven distribution of land uses;
- The geographical aggregation of data into TAZs that magnifies the unevenness of land use distributions; and,
- The use of a crisp threshold to identify market areas magnifies the differences even more.

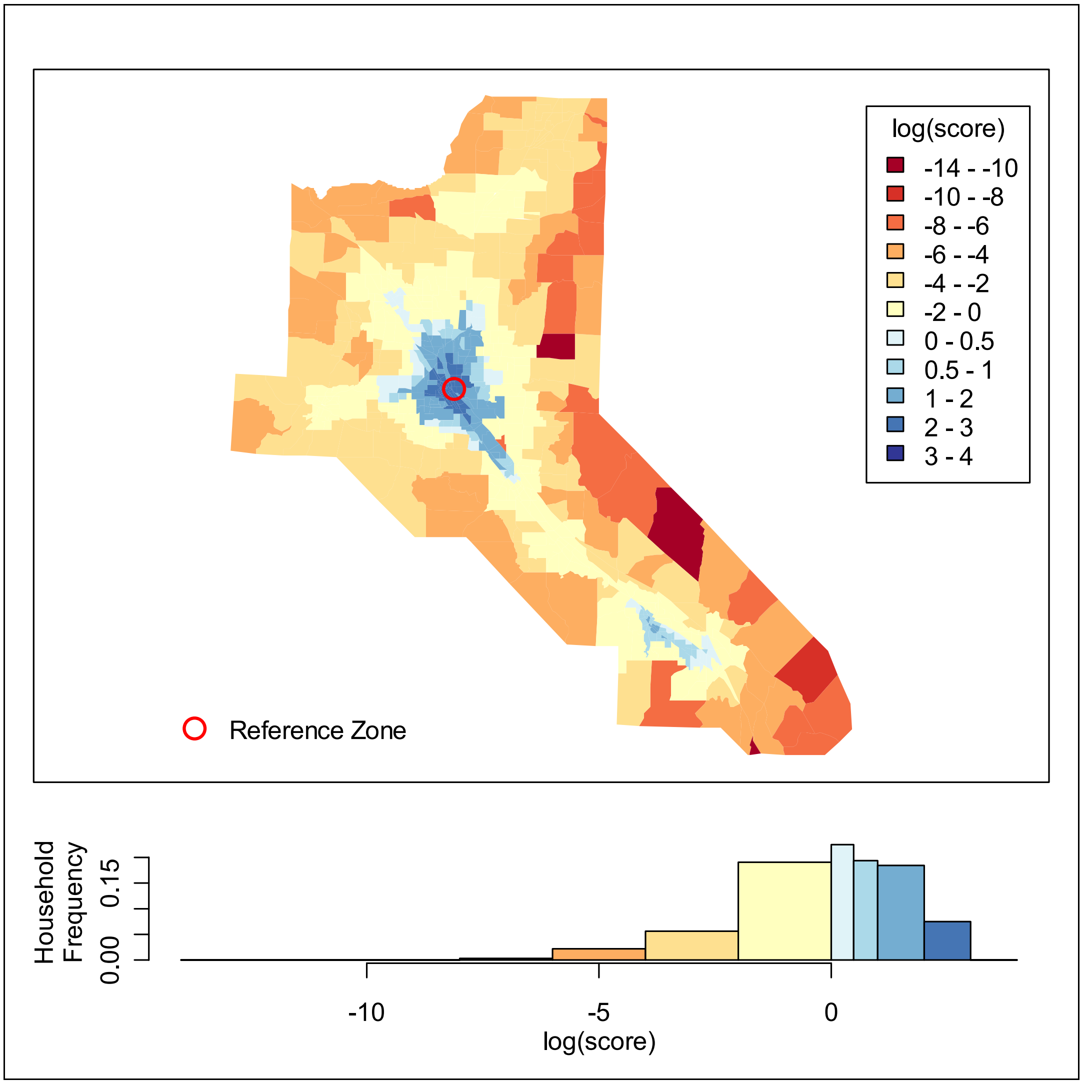

Figure 4.3: Map and histogram of attraction scores

An alternate approach was developed to overcome this limitation. This is simply to average by income group and trip purpose the market baskets identified using the trip-based approach.

$$MB_{pi} = \underset{k}{\mathrm{mean}}(MB_{pik}) \qquad \textbf{(4-8)}$$

The TCI and related performance measures calculated in this study use market baskets based on a 50% trip threshold. This approach averages out the variability between zones and reduces the variation between income groups. This approach also overcomes another limitation of the second method used to identify the reference TAZ. It is difficult, if not impossible, to describe a market basket defined by using a threshold log sum value in common sense terms. The alternative approach overcomes this limitation nicely. The market baskets defined for the study represent the mix of destinations needed to satisfy a majority of travel needs. !!!

4.2.2 Calculating travel costs to access the market basket

Average costs to access the reference market baskets are calculated for each TAZ. The costs are calculated from the JEMnR access utilities which measure the perceived ease of travel between every pair of TAZs for each trip purpose, income group and mode of travel. The utilities are calculated from linear equations that were statistically estimated from household travel behavior surveys. The terms of the equations are factors that affect people's perceptions of the ease of travel. The coefficients for the terms indicate the strength of each factor. Some examples of factors included in the utility equations are:

- The time spent traveling in a vehicle,
- The time to walk to get to the vehicle (e.g. walk time to a bus stop),
- The time spent waiting, and
- The money cost of the trip (i.e. operating cost).

Since the utilities are calculated as a combination of different factors, they are dimensionless quantities that are not intuitively easy to understand. They can, however, be easily converted into understandable units by dividing them by the coefficient of one of the factors. They may be converted into dollar cost equivalents by dividing by the coefficient for operating cost. For example, the utility calculated using Equation (4-1) would be converted into dollar equivalents by dividing by -0.58. These dollar equivalents of the utilities are the basis for calculating the average cost to access the reference market baskets.

One question that arises from this conversion of utilities to cost equivalents is whether to use one cost coefficient for all income groups, or to use the income group specific coefficients. Variation in the cost coefficients by income group reflect the relative importance of cost and time considerations to travel decisions. Cost is a bigger consideration and time a smaller consideration for lower income households than for middle and upper income households. This is a significant question because an important objective of the performance measures is to support equity analysis. The choice of whether to use income-dependent coefficients greatly affects the comparisons of market access costs between income groups.

The multiple cost coefficient approach results in measures showing substantial differences for low and high income households. The average market basket access costs for higher income households are substantially higher than the low income averages for households living in the same zone and using the same travel mode. The difference is mostly due to the difference in the cost coefficients. The high income coefficient is about 60% of the lower income coefficient. The difference in the sizes of the market baskets is small in comparison. The disparities produced by the multiple cost coefficient approach raise several questions pertinent to equity analysis:

1. Does it make sense for two households differing only in their incomes (location and travel mode being the same) to have greatly different market access costs?

2. Since higher income households have greater means to meet their needs, does it make sense to have a measure that shows them to be disadvantaged?

3. The market access costs for lower income households are calculated to be lower for this income group because the cost coefficients for this group are higher. Does it make sense that the greater sensitivity of lower income households to cost, because of their lower incomes, should be reflected in lower estimates of market access costs?

4. The time coefficients are the same for all income groups. Therefore, the average time equivalents for market access for different income groups would not vary if all else is equal. Does it make sense to have measures that vary by income group when they are expressed in cost equivalents, but not vary when expressed in time equivalents?

The conclusions drawn for this research was that using different cost coefficients did not make sense. Thus the cost coefficients for middle income households were used in calculations for all households in this study. Other researchers may wish to explore this issue further.

The average cost to access the market basket for any TAZ can be computed as a weighted average of the travel costs from that TAZ to each other TAZ in the market place containing the market basket of destinations for that TAZ. The weighting factor in calculating the average is the proportion of the market basket that is located within each TAZ in the market place. Thus the average cost *AC* to access the market basket for income group *i* and purpose *p* from zone *k* is calculated as follows:

$$AC_{pik} = \sum_j (EC_{pikj} * size_{pij}) / \sum_j size_{pij} \qquad \textbf{(4-9)}$$

where

$j \in J$, the market place containing the market basket

EC_{pikj} is the equivalent cost for traveling between TAZ *k* and TAZ *j* by all modes (see below) by income group *i* for purpose *p*

$size_{pij}$ is the size term for income group *i* for purpose *p* in TAZ *j*

Since the cost that is to be averaged varies by travel mode, it is also necessary to combine the mode costs into one representative cost to be averaged. Three approaches for doing this were tested. The "Average" approach is to compute a weighted average cost where the travel cost between each pair of TAZs by each travel mode is weighted by the proportion of travel between those TAZs by each travel mode. One result of this approach is that average costs will be higher where slower, and hence more costly, modes of travel (e.g. bus) are available. Thus the average cost *AveCost* for traveling between two TAZs *k* and *j* by a household of income group *i* for purpose *p* is calculated as follows:

$$AveCost_{pikj} = \sum_m (MC_{pikmj} * MP_{pikjm}) \qquad \textbf{(4-10)}$$

$$MC_{pikjm} = U_{pikjm} / CC_{pi}$$

$$MP_{pikjm} = \exp(U_{pikjm}) / \sum_{m} \exp(U_{pikjm})$$

where

MC_{pikjm} is the cost for traveling by mode *m* between TAZs *k* and *j* for purpose *p* by income group *i*

U_{pikjm} is the utility for traveling by mode m between TAZs *k* and *j* for purpose *p* by income group *i*

CC_{pi} is the cost coefficient for purpose *p* and income group *i*

MP_{pikjm} is the probability that mode *m* is used by income group *i* for trip of purpose *p* between TAZs *k* and *j*

The "Minimum" approach is to choose the travel cost of the mode that has the minimum travel cost for each pair of TAZs. A disadvantage of this approach is that because auto travel is usually much faster than other travel modes, the result will be a measure of auto accessibility. The minimum cost *MinCost* for traveling between two TAZs *k* and *j* by a household of income group *i* for purpose *p* is calculated as follows:

$$MinCost_{pikj} = \min_{m}(MC_{pikjm}) \qquad \textbf{(4-11)}$$

where

MC_{pikjm} is as defined in Equation (4-10)

The "Composite" approach is to compute a cost from a composite of the access utilities for the travel modes. This is done in the standard traveling modeling approach by calculating the log of the sum of the exponentiated utilities. Unlike the first approach, this approach decreases the overall travel cost with more travel modes. It can be thought of as a measure of travel opportunities rather than travel cost. The composite cost *CompCost* for traveling between two TAZs *k* and *j* by a household of income group *i* for purpose *p* is calculated as follows:

$$CompCost_{pikjm} = logsum_{pikj} \qquad \textbf{(4-12)}$$

The average cost to access the travel opportunity market basket is calculated in the following steps:

1. For each trip purpose and income group, load the access utilities calculated by the JEMnR model. The utility values vary by TAZ pair and mode.
2. The modal average costs, minimum modal costs, and composite modal costs are calculated.

3. For each of the modal costs calculated in step 2, the average cost to access the market basket is computed for each TAZ as follows:
   a. A market place for the TAZ is identified by placing the destination TAZs in order of increasing travel cost, calculating a cumulative sum of market destinations in that order, and identifying the zones whose cumulative sum equals the market basket of destinations.
   b. The average cost for the market place is computed by averaging the travel costs to the market place TAZs weighted by the proportions of the total market place destinations located in each TAZ.

The results of these steps are three arrays of average costs to access the travel opportunity market basket by TAZ, income group, and trip purpose. TAZ averages by income group, by purpose, and by all income groups and purposes are computed as follows:

1. For each trip purpose, the JEMnR model array of trips generated is loaded. This array stores the number of trips generated in each TAZ by each household category. The array is summed across all dimensions except for the TAZ and income dimensions, resulting in a matrix of trips generated by TAZ and income group for each trip purpose. These matrices are combined into one array of trips by TAZ, income and purpose.
2. From the array generated in step 1 arrays of proportions of trips by income group, proportions of trips by purpose and proportions of overall trips are calculated.
3. The arrays generated in step 2 are used along with the three cost arrays to calculate average costs by TAZ and income group, by TAZ and trip purpose, and by TAZ for all income groups and purposes.

$$AC_{pk} = \sum_{i} (AC_{pik} * trips_{pik}) / \sum_{i} trips_{pik} \qquad \textbf{(4-13)}$$

$$AC_{ik} = \sum_{p} (AC_{pik} * trips_{pik}) / \sum_{p} trips_{pik} \qquad \textbf{(4-14)}$$

where

AC_{pik} is as defined in Equation (4-9)

$trips_{pik}$ is the number of trips produced by income group i for purpose p in TAZ k

A similar process is followed to aggregate average travel costs to larger geographic units such as cities and metropolitan areas. In this process, the proportions of trips occurring among the zones within each larger geographic area are computed. These proportions are used to calculate weighted averages of travel costs for the larger geographic areas. The average cost *AC* to access the market basket for all TAZs *k* in district *d* for purpose *p* and income group *i* is calculated as follows:

$$AC_{pid} = \sum_{k \in d} (AC_{pik} * trips_{pik}) / \sum_{k \in d} trips_{pik} \qquad \textbf{(4-15)}$$

Figure 4.4 shows the frequency distributions of households by average travel costs for each combination of trip purpose and income. These figures demonstrate that reasonable results are calculated by this method. In addition, the results show that the measure is sensitive to differences in trip purposes and income groupings. Work trips have the largest market baskets, and this shows up in the largest variation in the market costs for these trips. Work trip costs are similar for the different income groups, but lower income households have higher market access costs for other types of trips.

Figure 4.5 show the corresponding geographical distributions of TAZ values. Several patterns are readily apparent. The larger size of the work market basket shows up in a stronger gradient of costs from central to fringe TAZs. Lower income households have similar market access costs as middle and higher income households in central areas, but greater costs in fringe TAZs. This may indicate the concentration of employment in central areas.

There is a greater geographic disparity among income groups in the non-work trip categories. These are apparent over a wider geographic area including more central areas. Finally, the additive effect of additional modes of travel on average costs is apparent. The core area of Medford (where the reference zone is located) has lower values than areas that immediately surround it. Also, the public transit corridors connecting Medford and surrounding cities (notably Ashland) show lower values than nearby TAZs.

The other methods for aggregating costs have different results. The effects of these differences are demonstrated for the TCI below.

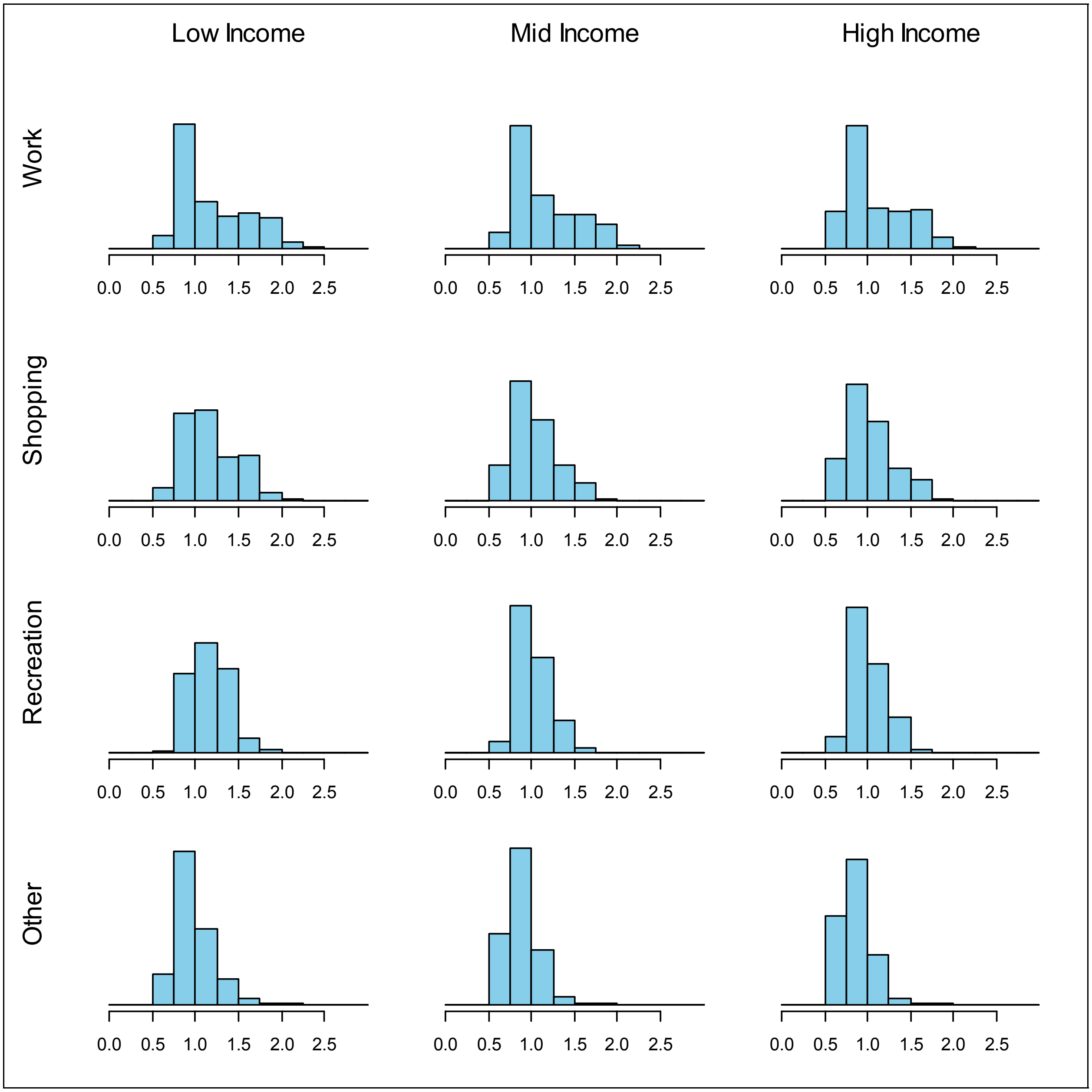

Figure 4.4: Household frequency distributions of average market cost in dollars by trip purpose and income

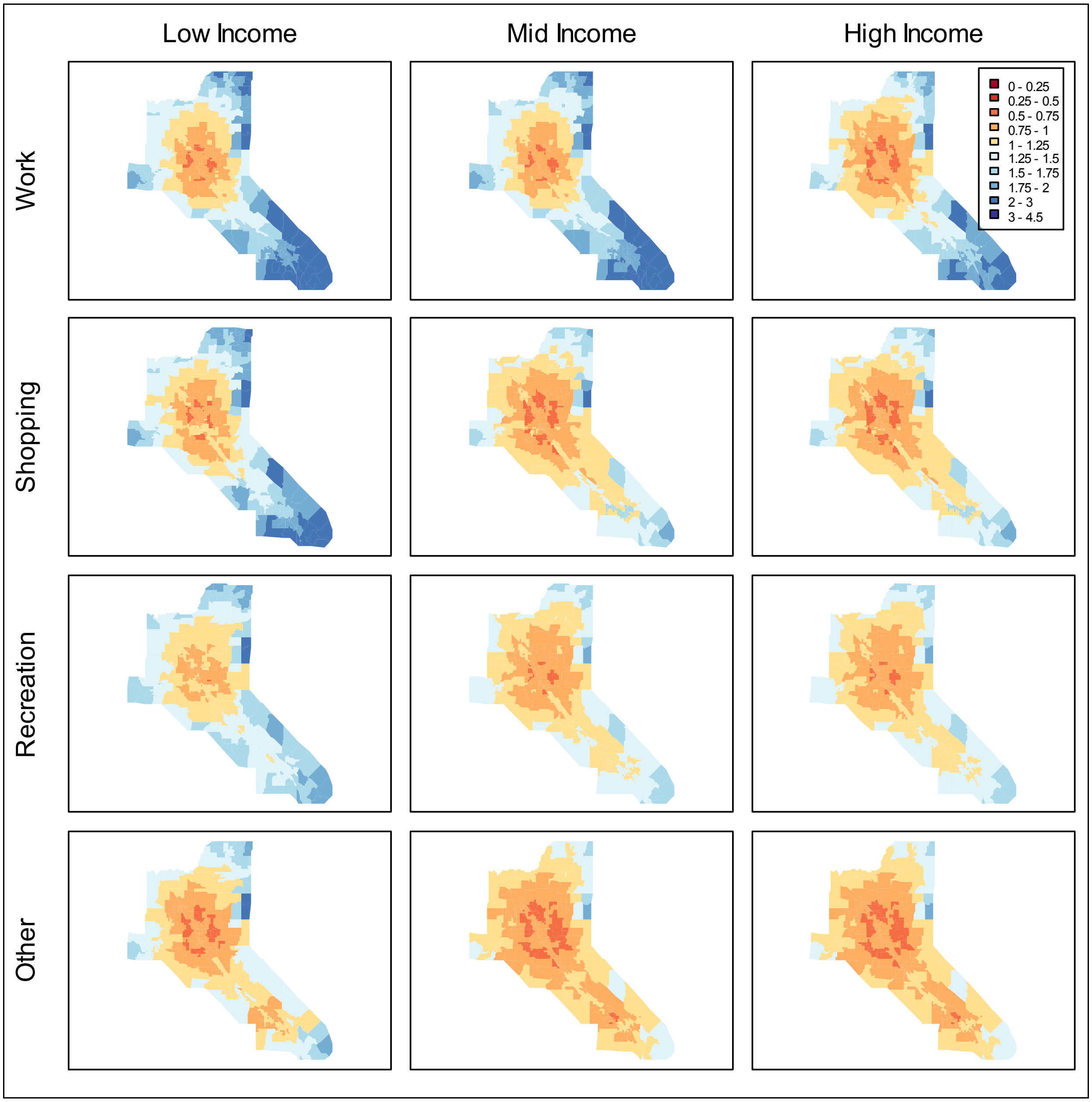

Figure 4.5: Geographic distributions of average market cost in dollars by trip purpose and income

4.2.3 Calculating the TCI

The results of computing market access costs are three arrays, one for each method of aggregating costs across transport modes. Each array contains the average market access costs by TAZ, income group and trip purpose. TCI values are computed from each cost array by dividing the values for each TAZ by the values for the reference TAZ by income group and trip purpose. This produces TCI values by TAZ, income group and trip purpose for each mode aggregation method. TCI values aggregated by income, or purpose, or geographic area may be calculated from the corresponding aggregated market access costs. The TCI for income group *i* and purpose *p* in TAZ *k* is calculated as follows:

$$TCI_{pik} = AC_{pik} \, / \, AC_{pir} \qquad \textbf{(4-16)}$$

where

AC_{pik} is as defined in Equation (4-9)

$AC_{pir} = AC_{pik}$ when k is the reference TAZ

Figures 4.6 and 4.7 show household frequency distributions of TCI values. Figure 4.6 compares distributions by income category and the three mode aggregation methods. Figure 4.7 compares distributions by trip purpose and mode aggregation method.

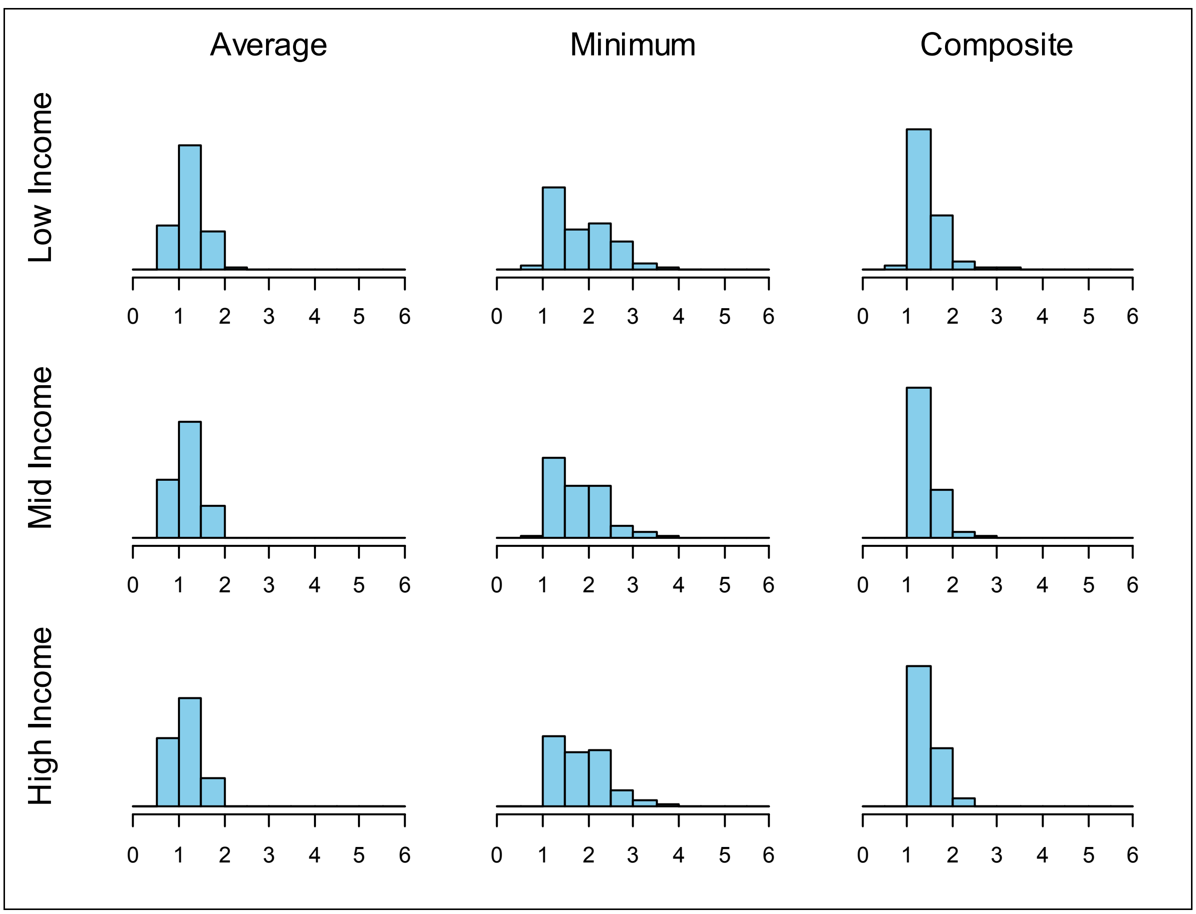

Figure 4.6: Household frequency distribution of TCI by income and mode aggregation method

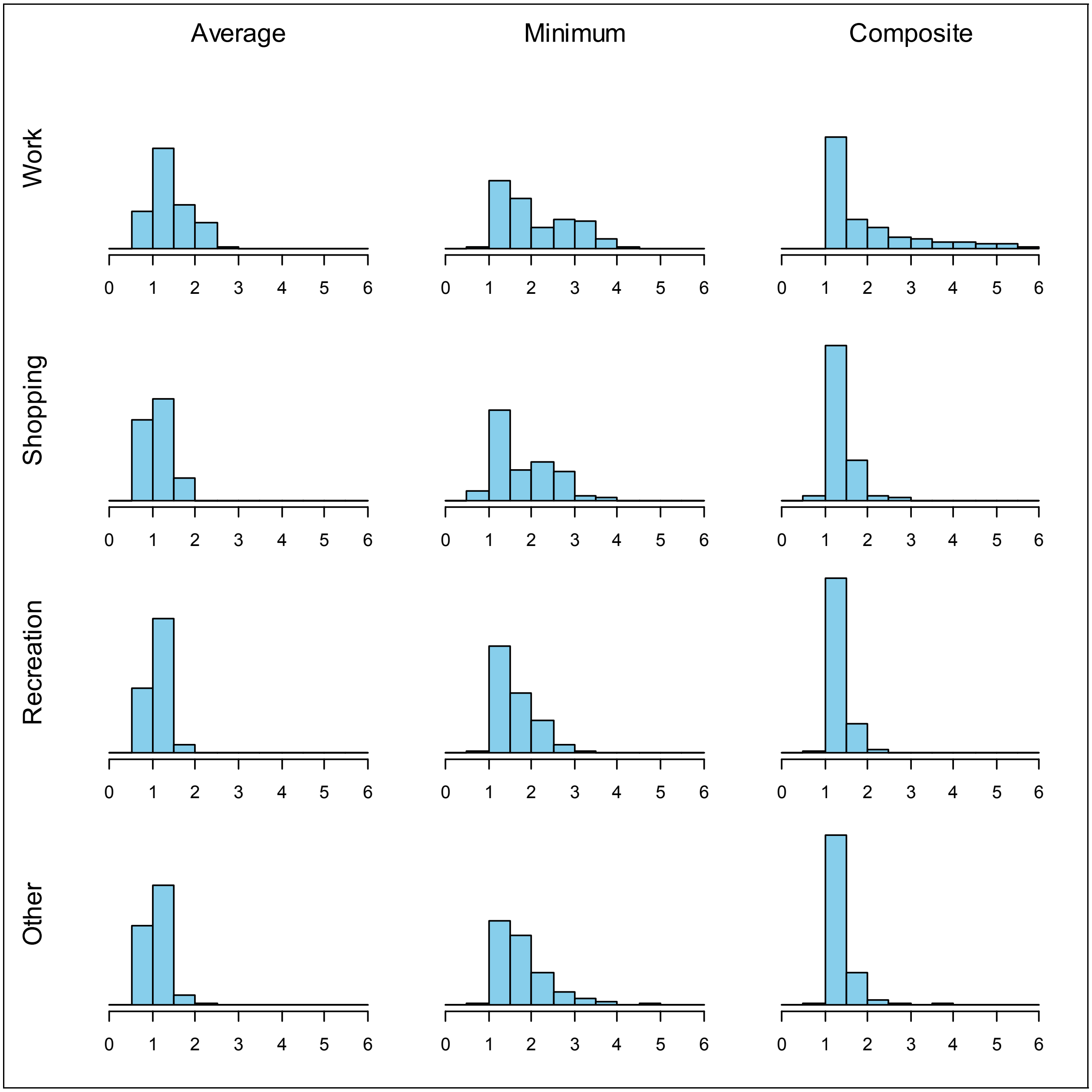

Figure 4.7: Household frequency distribution of TCI by trip purpose and mode aggregation method

The Average Cost method produces TCI values for a substantial number of zones that are lower than the reference zone values. The Minimum Cost and Composite Cost methods identify very few zones with TCI values less than one. This is because the average mode cost for the reference zone is increased by the presence and use of slower (and hence higher cost) transport modes. This is not the case with the Minimum and Composite cost methods in which additional transportation modes do not penalize the cost basis for computing the TCI. The Minimum and Composite Cost methods also produce a wider dispersion of values than the Average Cost method. The lesser dispersion of TCI values calculated using the Average method is at least partially the result of the cost penalty the reference TAZ faces by having more transportation modes available.

Figures 4.8 and 4.9 show the corresponding geographic distributions of TCI values for the various cost aggregation methods. The differences in dispersion patterns are readily apparent. Note that the color scale accentuates differences in smaller values. All of the methods show strong geographic variations.

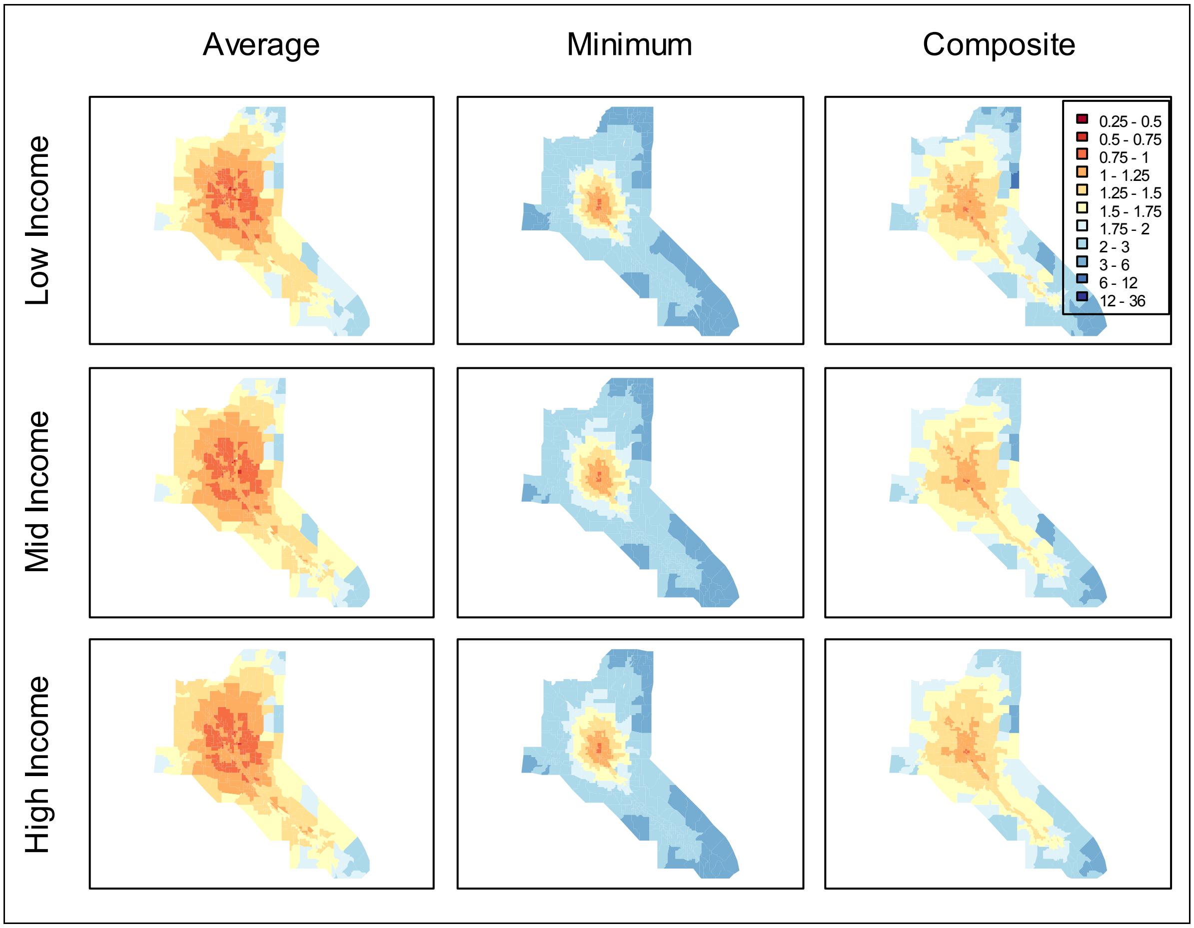

Figure 4.8: Geographic distribution of TCI by income and mode aggregation method

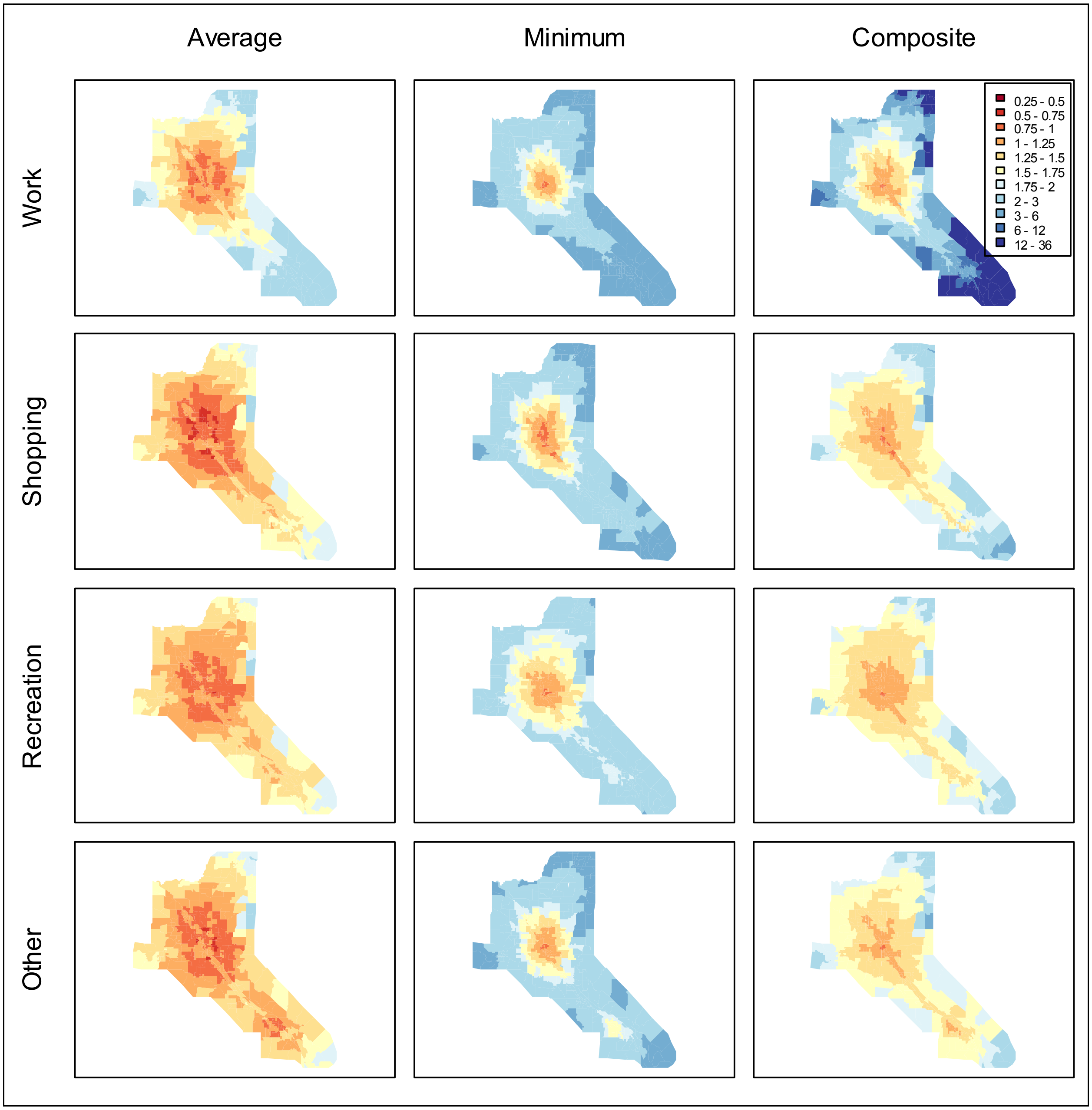

Figure 4.9: Geographic distribution of TCI by trip purpose and mode aggregation method

The maps, particularly those shown in Figure 4.9, illustrate why it may be useful to have several different approaches to calculating the TCI. Each method handles the interactions between transportation modes and land use in different ways. Because the Minimum Cost method uses auto mode costs for all areas, it primarily shows the effects of land use distributions and the road network on market access costs. The Average Cost and Composite Cost methods show the interactions of modes and land use. The Average cost method shows the addition of modes as increasing average costs. The Composite Cost method shows the addition of modes as increasing opportunities. A significant advantage of the Average Cost method is that it is more understandable and the effects of improving transportation services are more predictable. More research needs to be done on how each measure is affected by changes in the transportation system.

TCI values may be readily aggregated to larger geographic areas such as cities and metropolitan areas using the trip-based method described above. Figure 4.10 compares the average TCI values for the cities located within the RVMPO area for the three different methods of aggregating costs across modes.

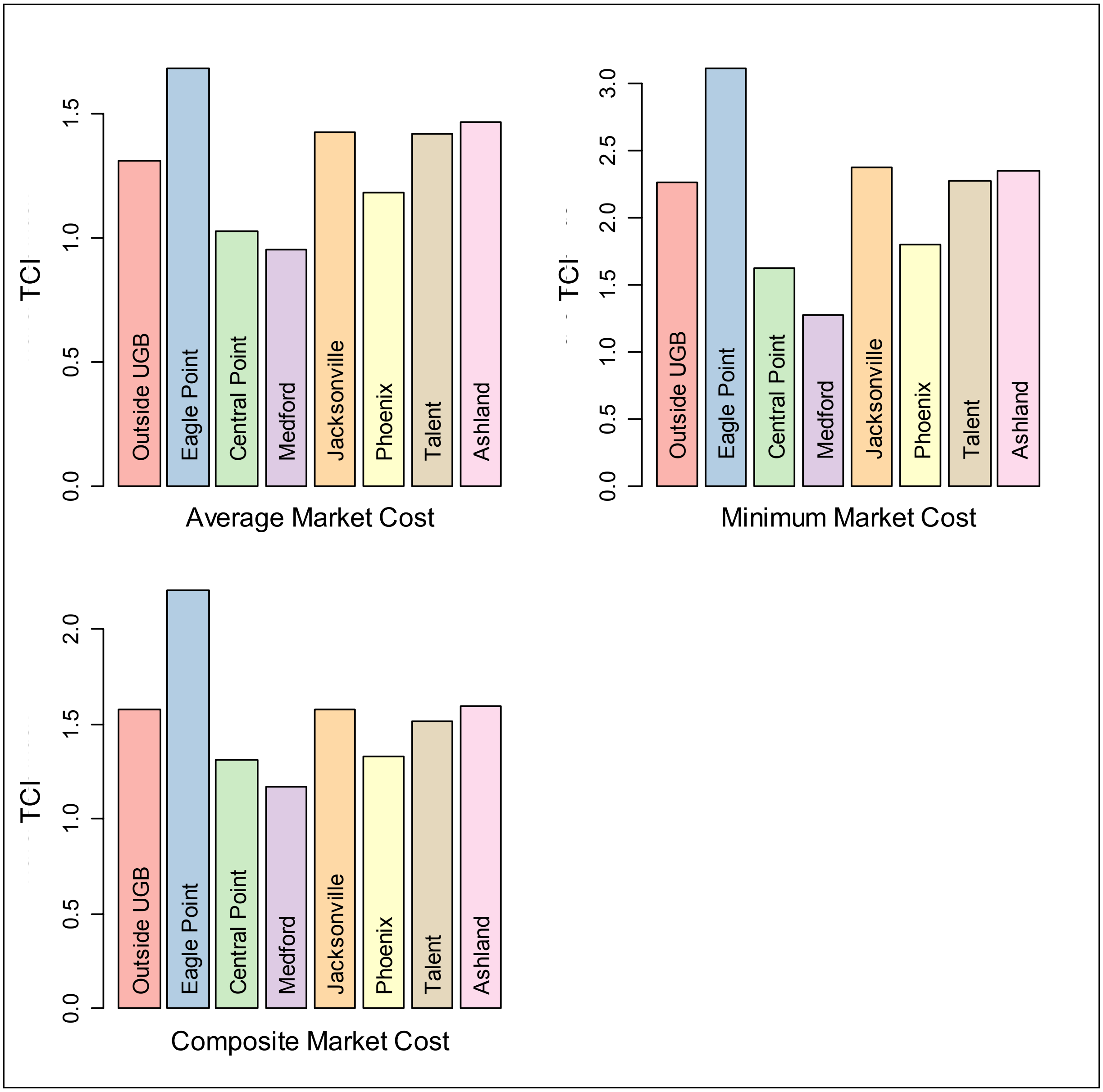

Figure 4.10: Urban area TCI values by mode aggregation type

Figure 4.10 shows that meaningful urban area averages may be calculated by this method. The TCI values vary by cost aggregation method, but the rankings among cities are similar. The minimum market cost method produces the greatest variation. The average market cost method results in a TCI average for Medford of less than 1.0.

4.3 PERCENT OF MARKET PLACE ACCESSIBLE BY NON-AUTO MODES

This measure depends on the definition of thresholds for determining the practicality of getting from one TAZ to another by a non-auto mode of transportation. The JEMnR model incorporates four non-auto travel modes: bus with walk access, bus with park and ride access, bicycling, and walking. In this study, a non-auto mode of travel is determined to be practical if the travel time for that mode is less than 30 minutes or if the travel time for the mode is not more than 30 minutes greater than the auto travel time for the corresponding trip. These thresholds represent the researchers' preliminary judgments about what reasonable thresholds might be like and how they affect the measure. Additional research needs to be done to provide a stronger basis for thresholds. For example, household survey data might be examined for relationships between travel and activity times to identify maximum practical travel times for different activities. This might provide a basis for establishing defensible thresholds.

Based on this definition of practicality, matrices were constructed for each of the non-auto travel modes which identified all the pairs of origin and destination zones for which the mode is a practical alternative. These matrices were combined into one array identifying practical non-auto travel by origin zone, destination zone and non-auto mode.

The array of practical non-auto travel alternatives is used to calculate the percentage of the market place that is accessible by non-auto modes. As with the TCI calculation, this is calculated on a zone-by-zone basis for each trip purpose and income group with the market place being calculated in the same way as well. The array of practical non-auto travel is used to identify which of the market place TAZs are accessible by one or more non-auto modes. The attractions in the accessible zones are measured as for the TCI and are summed. This quantity is divided by the sum of attractions in the market place to yield the measure. The result of these calculations is an array of percentages by TAZ, income group and trip purpose. The percentages may be aggregated by income group, purpose, and geographic area using the same methods as for aggregating the TCI. The accessible market percentage *AMP* for an income group *i*, purpose *p* and TAZ *k* is calculated as follows:

$$AMP_{pik} = 100 * \sum_{j \in A} size_{pij} / \sum_{j} size_{pij} \qquad \textbf{(4-17)}$$

where

$$A = \{ j : j \in J \ \ and \ \ j \in practical\ zones \}$$

Figure 4.11 shows frequency distributions of households according to the accessible market percentages for each combination of income group and trip purpose. Figure 4.12 maps the TAZ values. The histograms and maps show a concentration of TAZs and households that have complete or near complete market place coverage by non-auto modes. These households and TAZs are located in Medford. Non-auto market coverage is least extensive for work trips. It is most extensive for "other" trips. High levels of non-auto market coverage are present thoughout the RVMPO for this trip purpose. There is little variation among income groups.

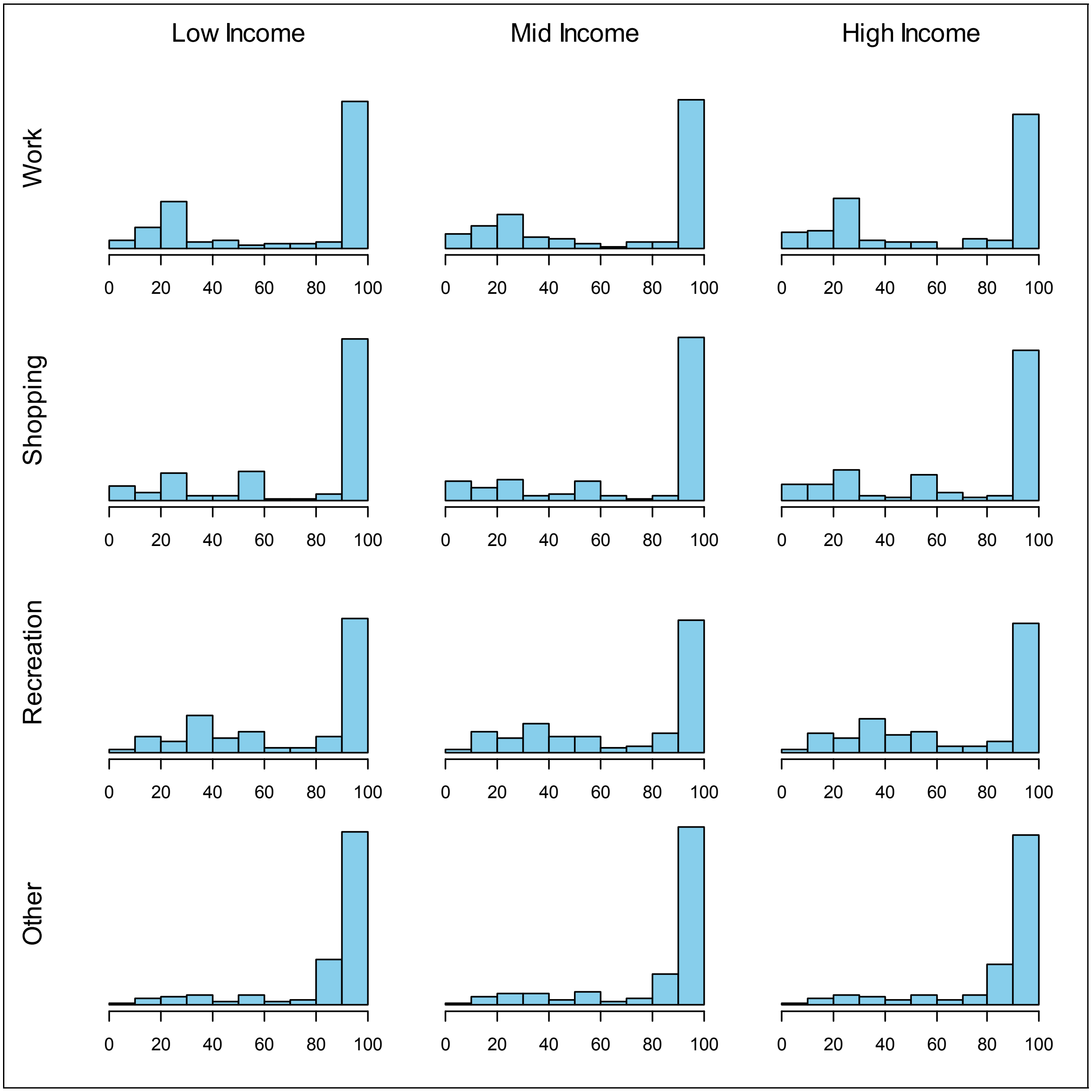

Figure 4.11: Household frequency distribution of non-auto market coverage by trip purpose and income

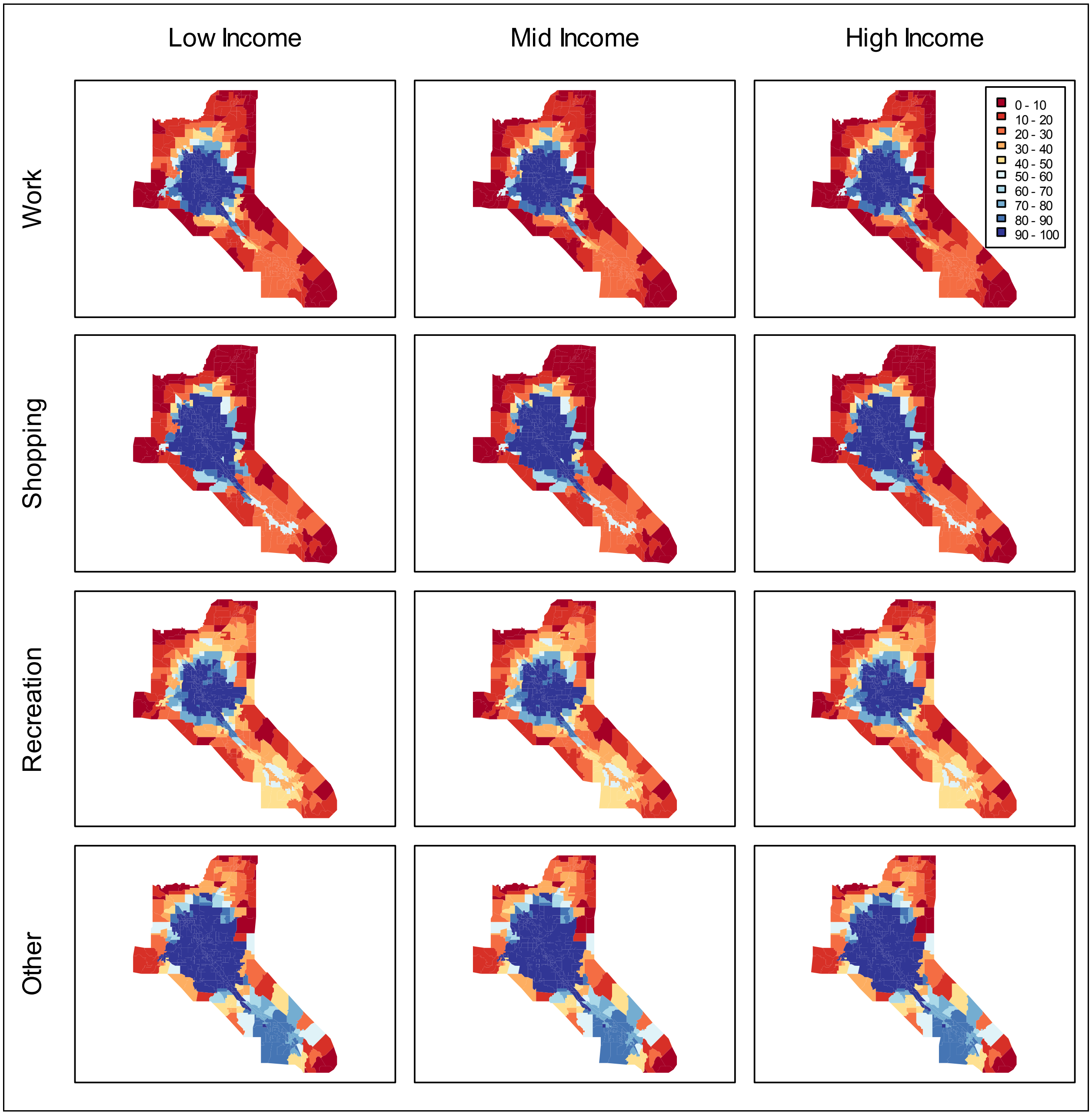

Figure 4.12: Geographic distribution of non-auto market coverage by trip purpose and income

As with the TCI, this measure can be easily aggregated by larger geographic areas. Figure 4.13 compares the percentages by urban areas within the RVMPO area.

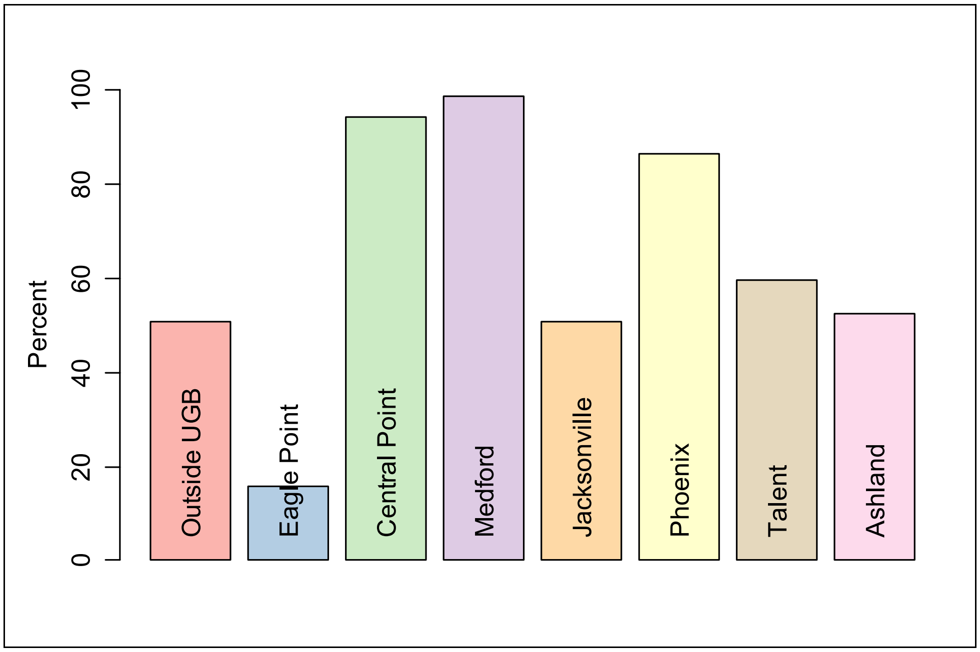

Figure 4.13: Non-auto market coverage by urban area

4.4 AUTO–DEPENDENCE INDEX – RATIO OF NON-AUTO COST TO AUTO COST

The methods used to calculate this measure are very similar to the methods used to calculate the TCI. Market places and average market access costs are calculated in the same way. For this measure, however, market access costs are calculated for auto and non-auto modes. Since several non-auto modes are available having different costs, it is necessary to develop an aggregation method. The method chosen for the study is to take the cost of the least costly non-auto mode.

Two arrays of costs are computed; one for average auto costs by TAZ, income group and trip purpose and one for average non-auto costs by TAZ, income group and trip purpose. Dividing the non-auto cost array by the auto cost array produces the ADI values for each combination of TAZ, income and purpose. The ADI values are aggregated by income group, purpose, and geographic area using the same methods used for aggregating the TCI.

The Auto-dependence Index is another way to compare the degree of auto-dependency of different parts of an urban area. It is calculated using similar procedures as the other measures. The ADI for income group i, trip purpose p and TAZ k is calculated as follows:

$$ADI_{pik} = ACAuto_{pik} / ACNonAuto_{pik} \quad \textbf{(4-18)}$$

where

$ACAuto_{pik}$ is calculated as in Equations (4-9) and (4-10) but only for auto travel modes
$ACNonAuto_{pik}$ is calculated as in Equations (4-9) and (4-10) but only for non-auto travel modes.

Figure 4.14 shows household frequency distributions of the ADI by income group and trip purpose. These histograms are revealing in a number of ways. First, the values show that it is much more costly to access the market place by non-auto modes than by auto modes. Few households have non-auto market access costs which are less than 25 times the auto market access costs. For many households, non-auto costs are several hundred times higher than auto costs.

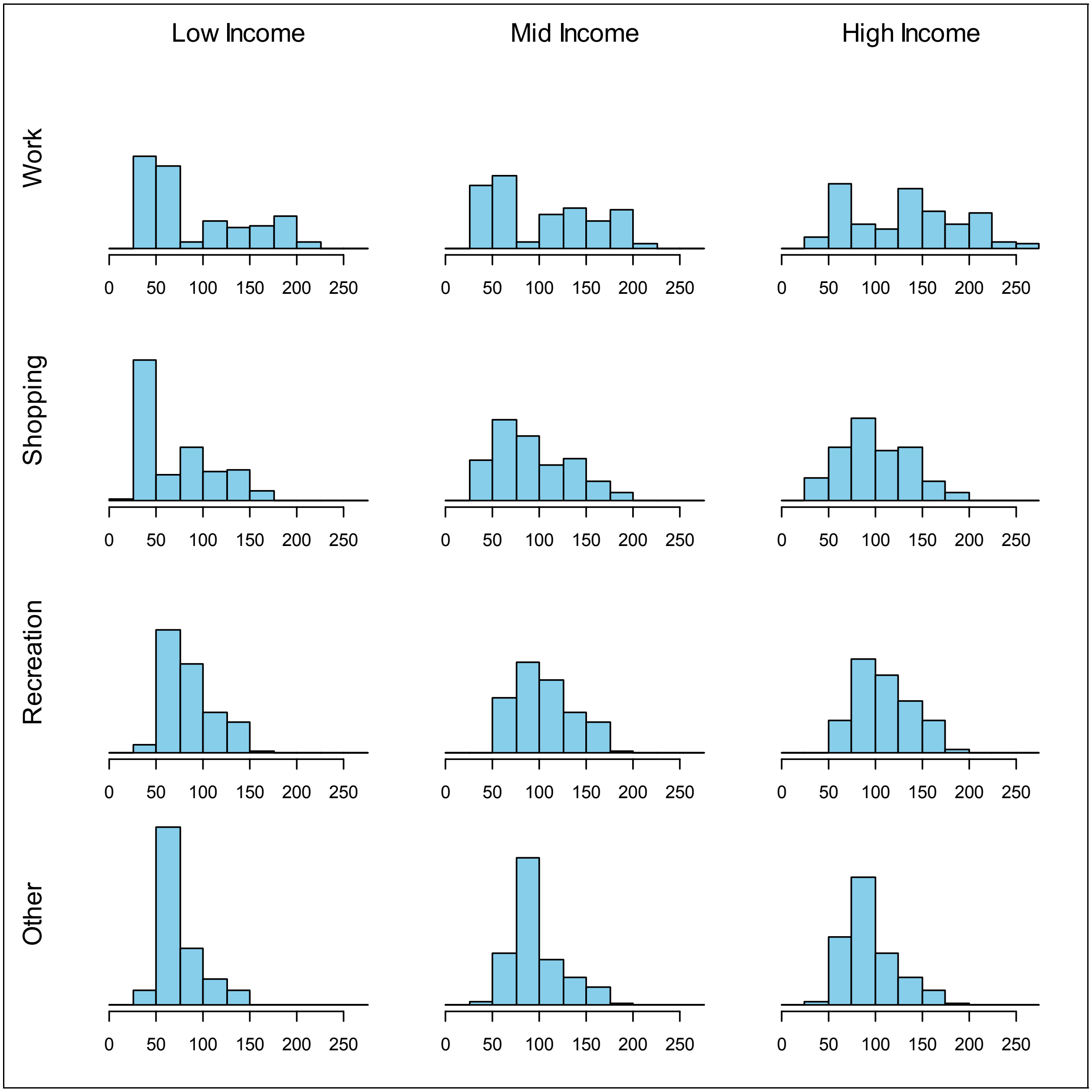

Figure 4.14: Household frequency distribution of ADI by trip purpose and income

Figure 4.15 shows the geographic distributions of ADI values by trip purpose. The location of the public transportation system is clearly shown by the pattern of ADI values. There is a strong gradient of values for work trips because of the large sizes of work trip market baskets. The smaller sizes of market baskets for other types of trips results in lower ADI values and weaker values gradients.

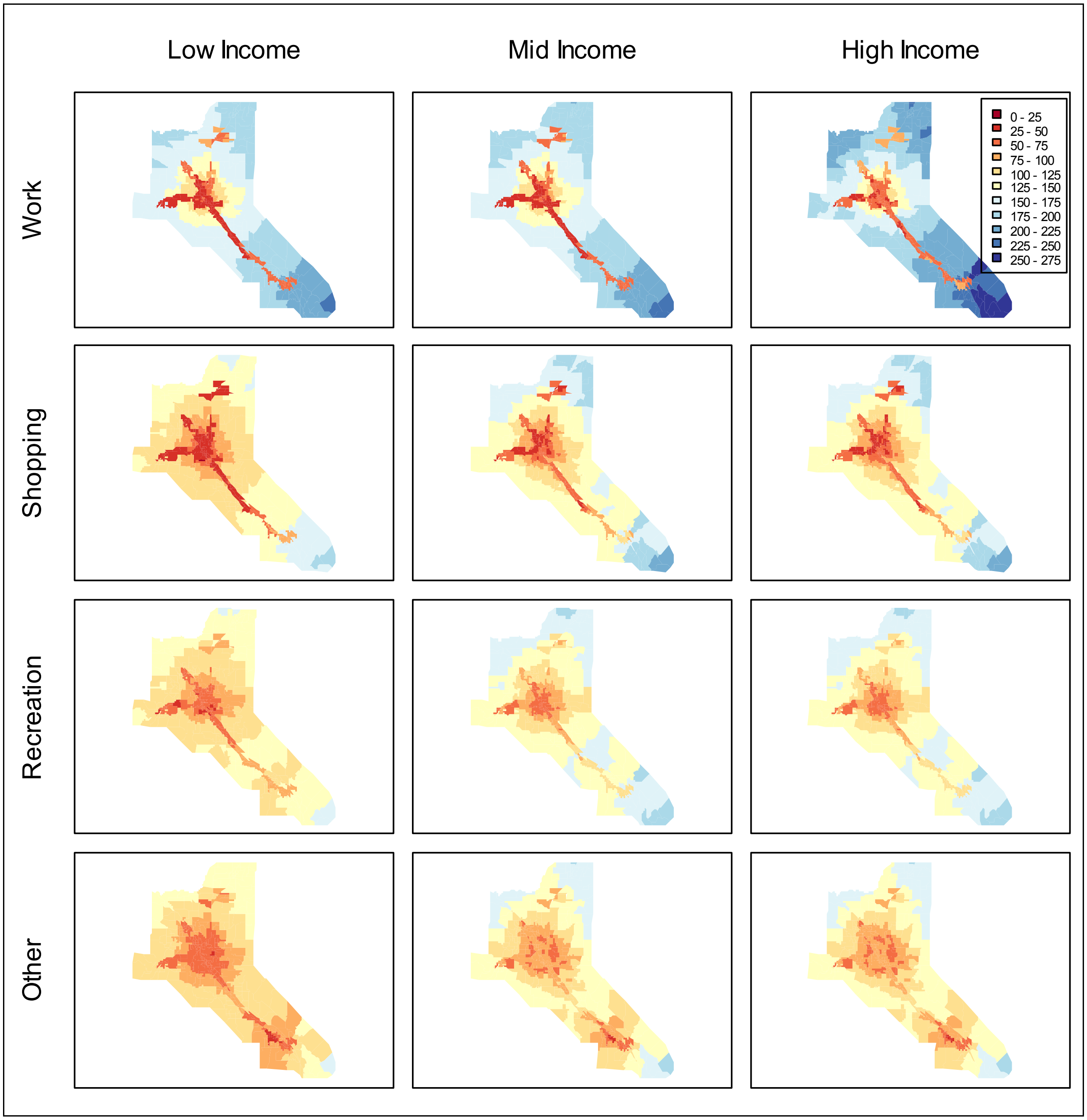

Figure 4.15: Geographic distribution of ADI by trip purpose and income

ADI values for low income households are lower than for middle and high income households. One reason this occurs is that a higher proportion of lower income households live in higher density areas where public transportation is more available. Another cause is indicated by the non-work trip maps in Figure 4.15. ADI values in many places are lower for low income household than for middle and high income households. This may the result of smaller market baskets of lower income households.

Figure 4.16 shows ADI values aggregated by urban area. Except for Eagle Point and non-urban areas, the differences in ADI values between urban areas are smaller than the differences in the TCI and percentage of non-auto market coverage.

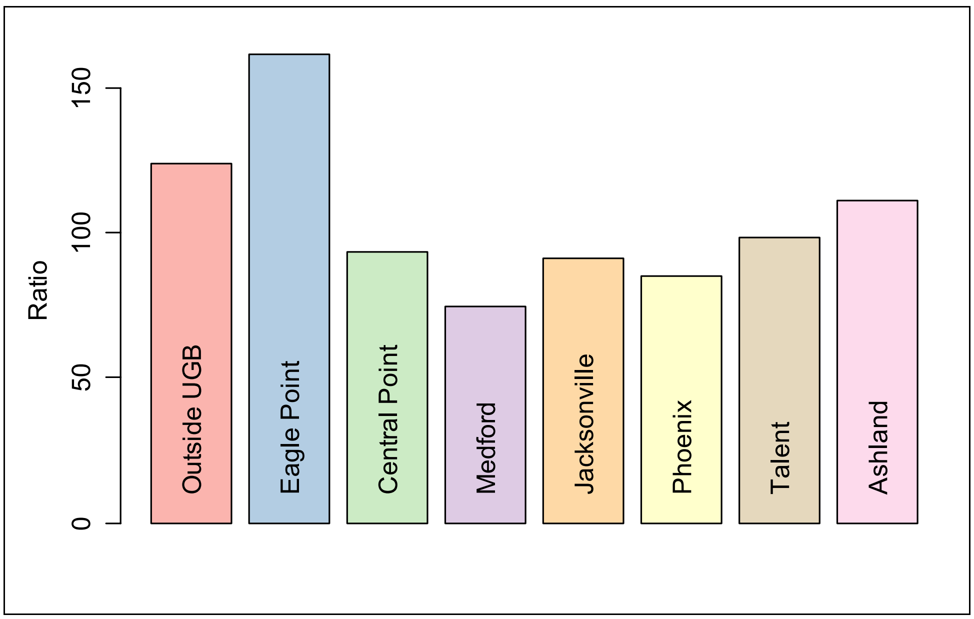

Figure 4.16: Auto Dependence Index by urban area

4.5 FREIGHT DELAY COSTS

Annual freight delay costs were obtained for two Eugene scenarios (Table 4.6). The methodology used was designed to be compatible with that of the UMR. However, where the UMR assumes that 5% of VMT comprises truck traffic, the Eugene model incorporates a synthetic internal truck component. This, combined with an external truck component, based upon data from a 1994 cordon intercept survey, enables tracking of truck trips on each network link. Recurring truck delay was calculated relative to both free-flow conditions and LOS “D”. Non-recurring delay was calculated using UMR freeway and arterial incident delay ratios, and then UMR annualization factors and costs were applied.

Table 4.6: Annual freight delay costs

Estimated Annual Freight Delay Cost (2002)	With Ferry Street Bridge		Without Ferry Street Bridge	
Reference flow	Free-Flow	LOS "D"	Free-Flow	LOS "D"
	$5,880,000	$389,000	$6,999,000	$992,000

Several refinements could be made to this methodology. First, a commercial vehicle model estimated from local data could be used to segment trucks into freight vehicles and service vehicles, each with its appropriate cost factor. Second, a commodity flow model could segment freight vehicles by commodity type and delay value. Third, while the Eugene network included no route restrictions, other regions may restrict certain truck movements in accordance with local policies, weight restrictions, clearances, and other factors. In such cases, the costs associated with route diversions could be included in the overall network delay costs.

4.6 ROADWAY NETWORK CONCENTRATION INDEX

The Roadway Network Concentration Index (RNCI) measures the degree to which travel is unevenly distributed over the regional road network. It is similar to the Gini coefficient, a measure used in economics to measure distributional inequality such as income inequality. As with the Gini coefficient, the RNCI measures equality on a scale of 0 to 1. An index of 0 means perfect equality of traffic loads. An index of 1 means perfect inequality of traffic loads.

This measure was calculated for several sets of Eugene model network data. The measure was tested for two comparisons. The first was a comparison of the traffic flows on the road network as is and on the road network with an important link removed – the Ferry Street Bridge over the Willamette River. The removal of the Ferry Street Bridge link diverts traffic to other river crossings. This should show up as higher RNCI values.

The second comparison was between different parts of the Eugene model network. These portions of the network differ in the amount of road connectivity. It was expected that the portion of the network with higher connectivity should have less traffic concentration and this should show up as lower RNCI values.

The RNCI was calculated for each roadway type: Freeway, Principal Arterial, Major Arterial, Minor Arterial, Major Collector, Neighborhood Collector, and Freeway Ramp. The calculation method is as follows:

1. Data is extracted for the roadway type.
2. Links are put in ascending order by their ratios of average daily traffic to number of lanes.
3. The cumulative sum of ADT/lane is calculated for links in this order.
4. A cumulative proportion is calculated by dividing the cumulative sum by the total sum. The result is an ordered vector of proportions of total lane volume in descending order.
5. A vector of equal length is calculated that is a cumulative sum of an equal proportion of travel per lane all links.

6. The RNCI is computed by comparing the sum of the cumulative proportion of link volumes to the cumulative sum of equally proportioned link volumes according the following formula:

$$RNCI = (\sum_l PctEqVol_l - \sum_l PctLaneVol_l) / \sum_l PctLaneVol_l \qquad \textbf{(4-17)}$$

   where

   $PctEqVol_l$ is the vector of cumulative proportions of evenly distributed volumes by link
   $PctLaneVol_l$ is the vector of the cumulative proportions of the traffic data.

A method of computing a composite RNCI value for all road types was tested. The only difference in this method from what is described above is that ADT is divided by road capacity rather than the number of lanes.

4.6.1 Results of comparing RNCI for alternative network configurations

Figures 4.17 through 4.23 show the results of testing the effects of removing a major roadway link on RNCI values. Following are some observations about the results:

1. Traffic volumes are more evenly spread across major road links than across minor road links. This is to be expected since minor roads provide the collection and distribution function and this is highly dependent on the distribution of land uses. This difference among roadway types makes the computation of a RNCI across types problematical because variation between the types can obscure variation between alternatives.
2. Among almost all of the roadway types, the differences in RNCI between networks are as expected. The removal of the Ferry Street Bridge increases the concentration of travel on the road network. The biggest differences occur on major road links: 11% for freeways, 18% for principal arterials.
3. Only on neighborhood collectors did the RNCI decrease with the removal of the Ferry Street Bridge link. The percentage difference was small (2%). Neighborhood collectors and other minor roads are the most difficult to model accurately. Given this and the small difference, the counter directional results are probably not important.

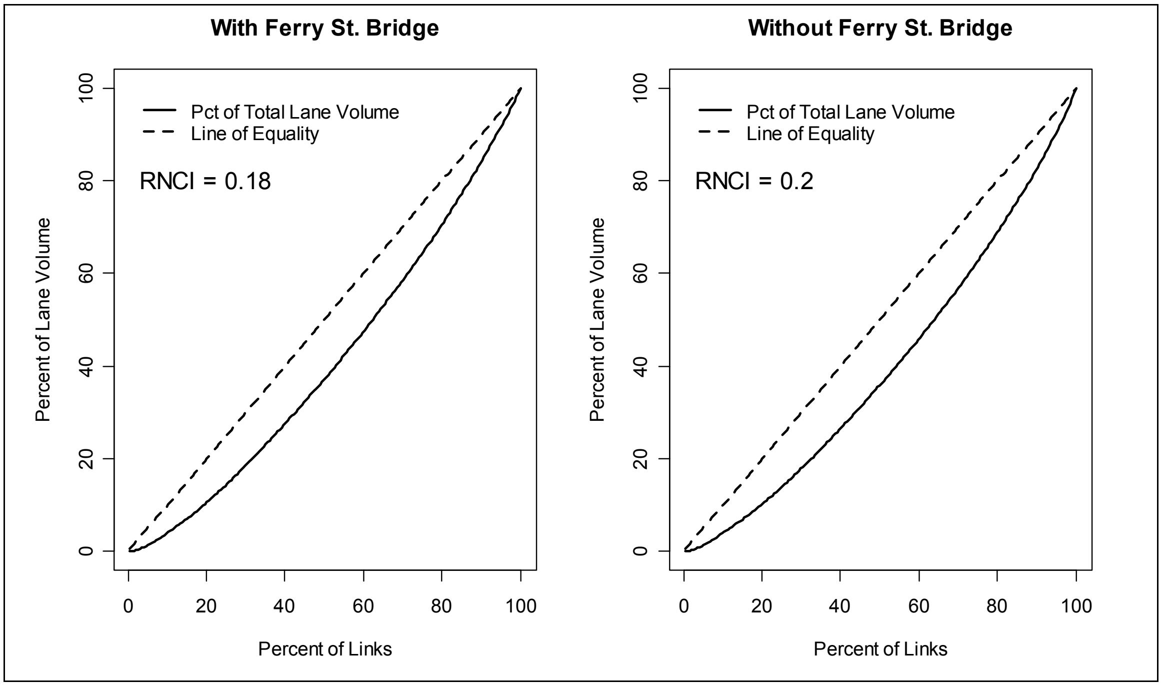

Figure 4.17: Freeway RNCI with and without Ferry Street Bridge

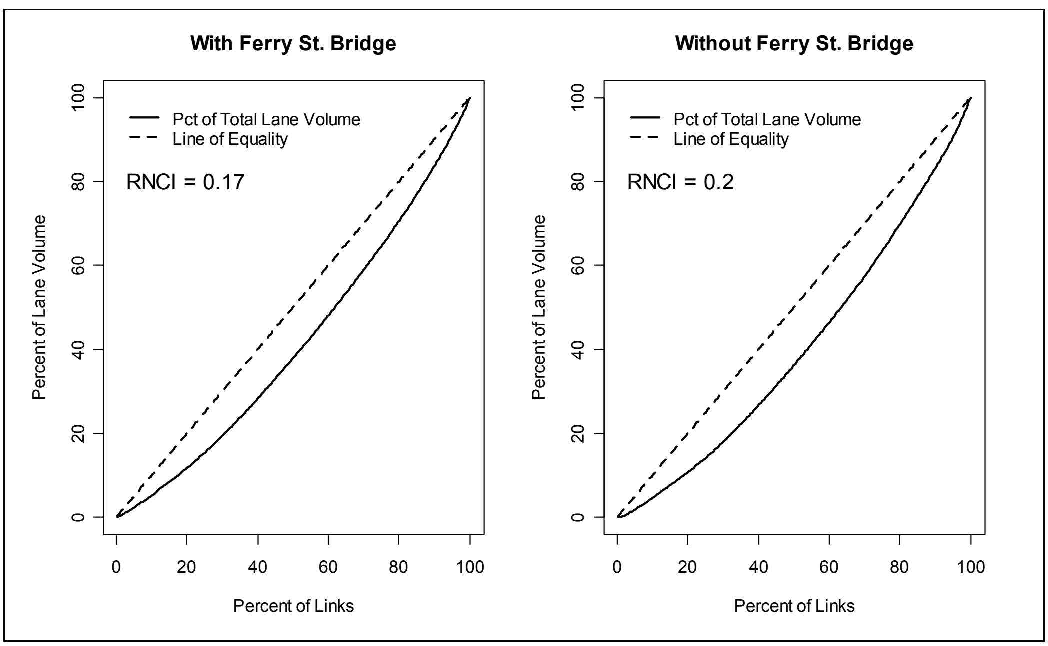

Figure 4.18: Principal arterial RNCI with and without Ferry Street Bridge

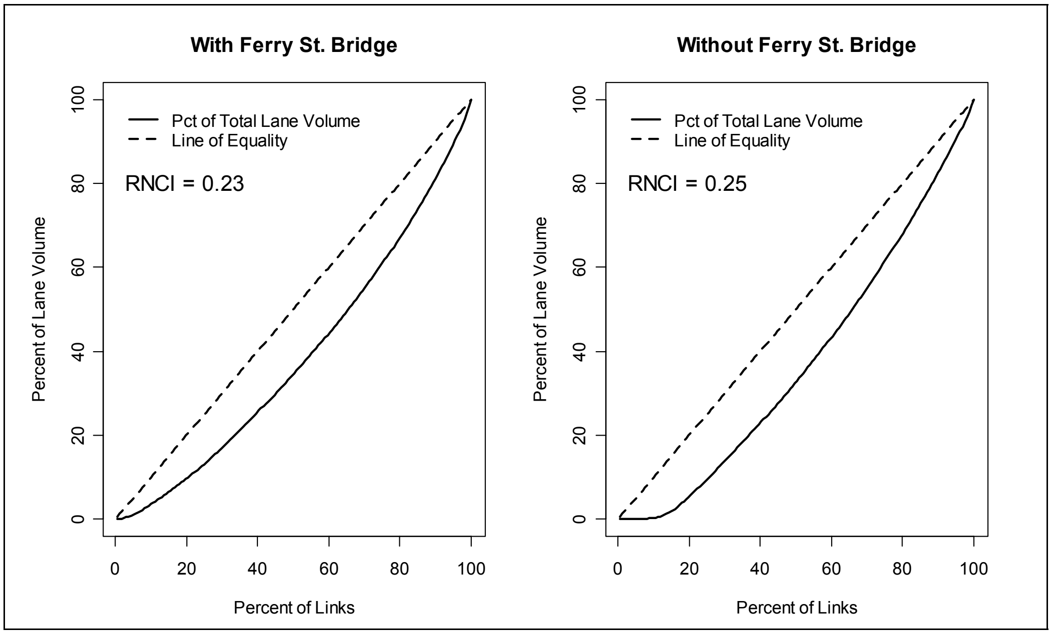

Figure 4.19: Major arterial RNCI with and without Ferry Street Bridge

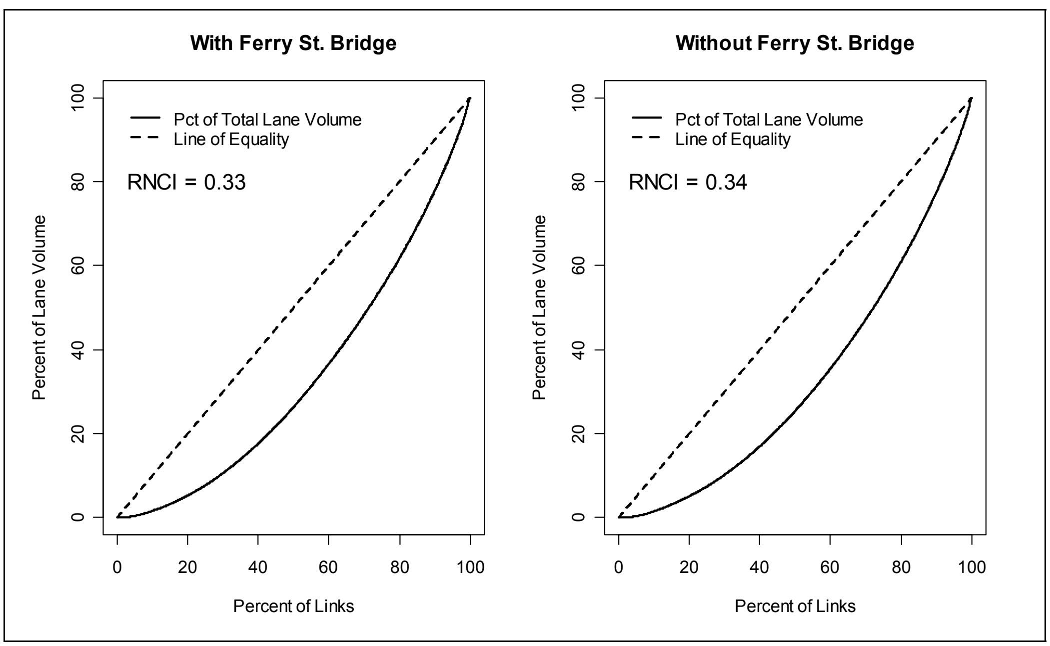

Figure 4.20: Minor arterial RNCI with and without Ferry Street Bridge

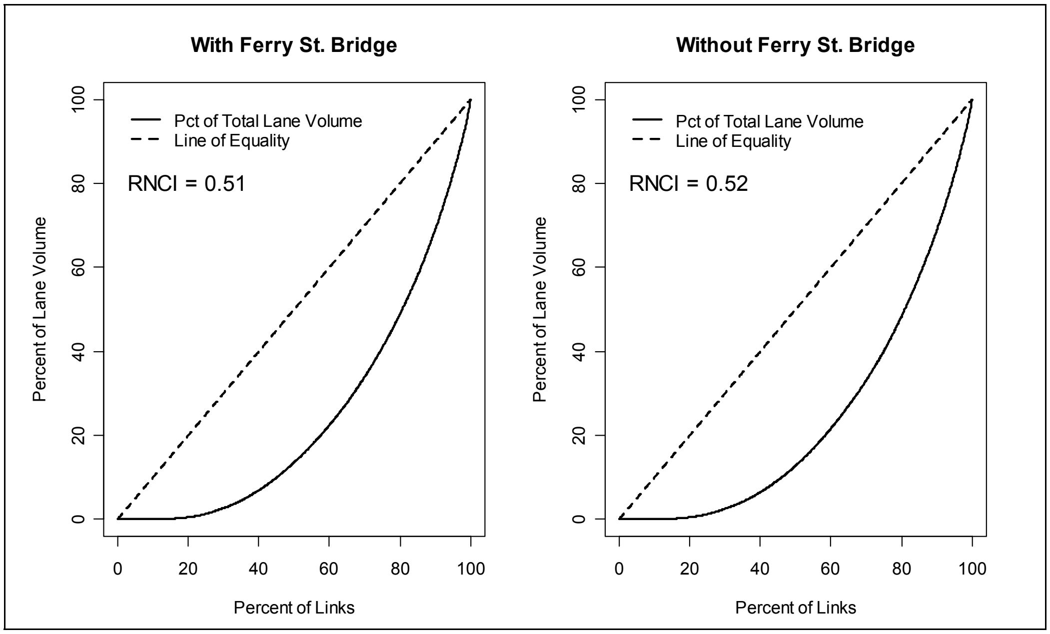

Figure 4.21: Major collector RNCI with and without Ferry Street Bridge

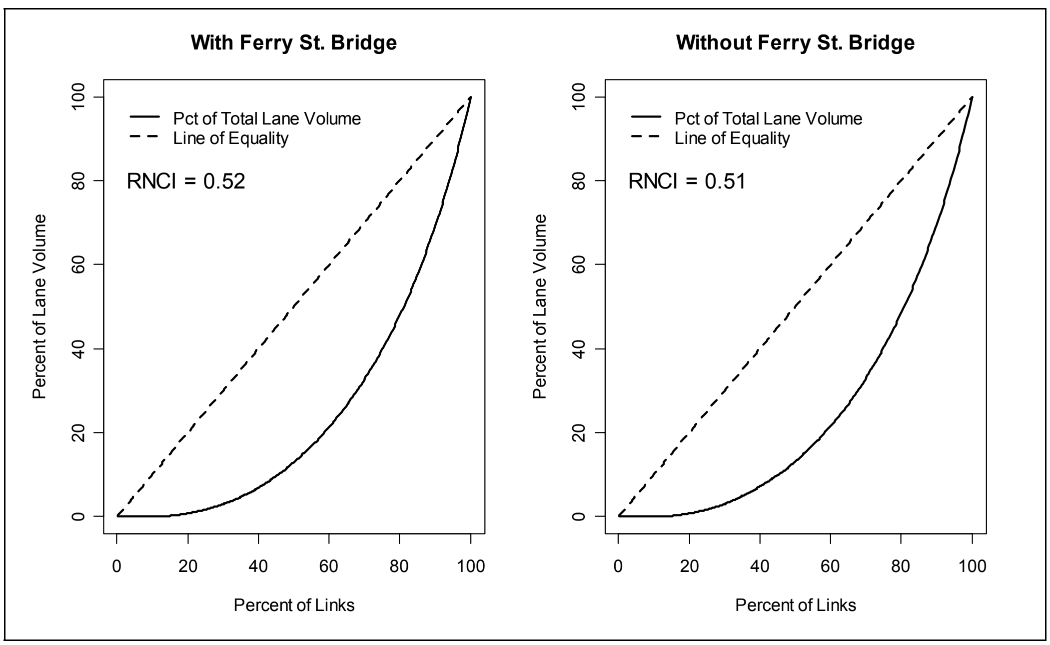

Figure 4.22: Neighborhood collector RNCI with and without Ferry Street Bridge

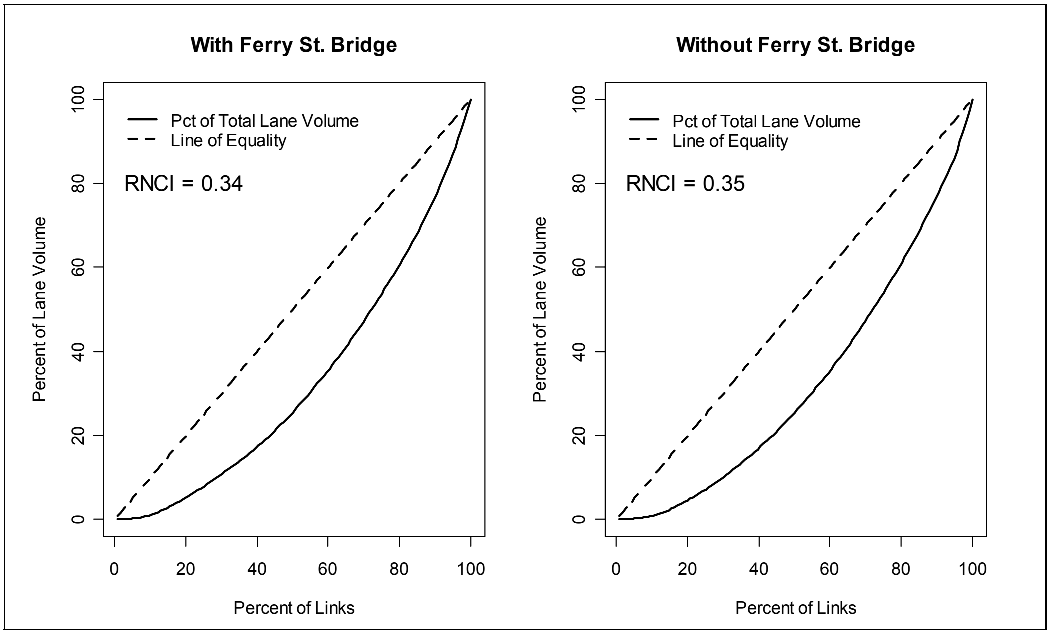

Figure 4.23: Freeway ramp RNCI with and without Ferry Street Bridge

4.6.2 Results of comparing RNCI for different portions of a network

Figures 4.24 through 4.28 show the results of comparing RNCI values for two different portions of the Eugene road network. These portions differ in the amount of road connectivity. The higher connectivity portion is characterized by a grid street system. The lower connectivity portion is characterized by a more discontinuous road network. The graphs compare the RNCI by roadway type. Comparisons for freeways and freeway ramps are not included because the higher connectivity portion does not contain these roadway types. Following are observations about the results:

1. There are larger RNCI differences in this comparison than in the previous comparison. For example, the RNCI for principal arterials in the lower connectivity network are 38% greater than in the higher connectivity network. The RNCI for neighborhood collectors in the lower connectivity network is 16% greater.

2. For all but one roadway type, the difference in RNCI is as one would expect. However, there is a large difference in the opposite direction than expected in the case of major arterials.

The counter-directional result for major arterials is important to address. It might point out difficulties for comparing different portions of a road network. In the earlier comparison, all the road network links are the same except for the few links that are changed. In this comparison, the set of links being compared is different. The measurements depend on the characteristics of the link samples and how the sample was determined. The samples will vary according to the basis of comparison (connectivity in this case) but also on some other factors. The presence of other factors affecting the sample will muddy the comparisons. Following are a couple of factors that could affect the results:

1. Traffic flows between portions of the network so the traffic loads on one portion of the network are dependent on traffic loads on other portions of the network. In other words, an imbalance of flows in one area may be due to an imbalance of flows feeding into and out of the area.

2. Road type classifications may not be consistent across a metropolitan area. Roadway classes are generalized and the classification process has political ramifications. Therefore, classifications can vary between cities and even neighborhoods. The portions of the network compared in this case are influenced by different classification approaches.

3. Partitioning the network can result in small samples of links in particular classifications. The results for these may not be representative of the results that would occur if the road network were more extensive and more of these links were present.

Although there are problems to be addressed, the RNCI appears to offer potential for comparing between different portions of a network in order to evaluate fundamental network attributes like connectivity. Further research and testing should be done to determine how networks should be partitioned to address these problems.

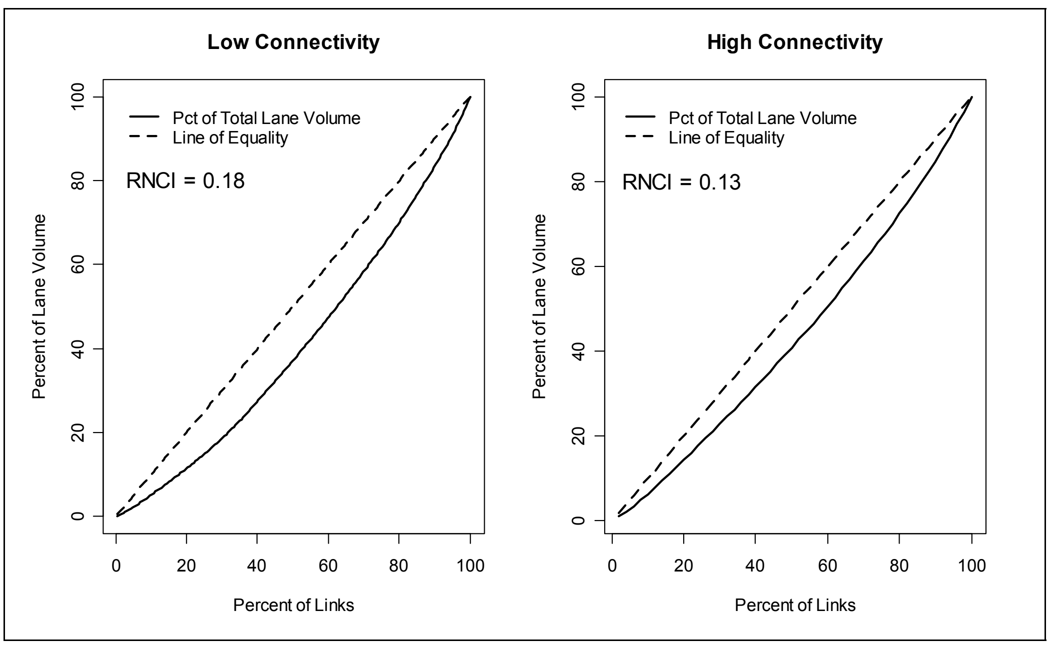

Figure 4.24: Principal arterial RNCI for different portions of the network

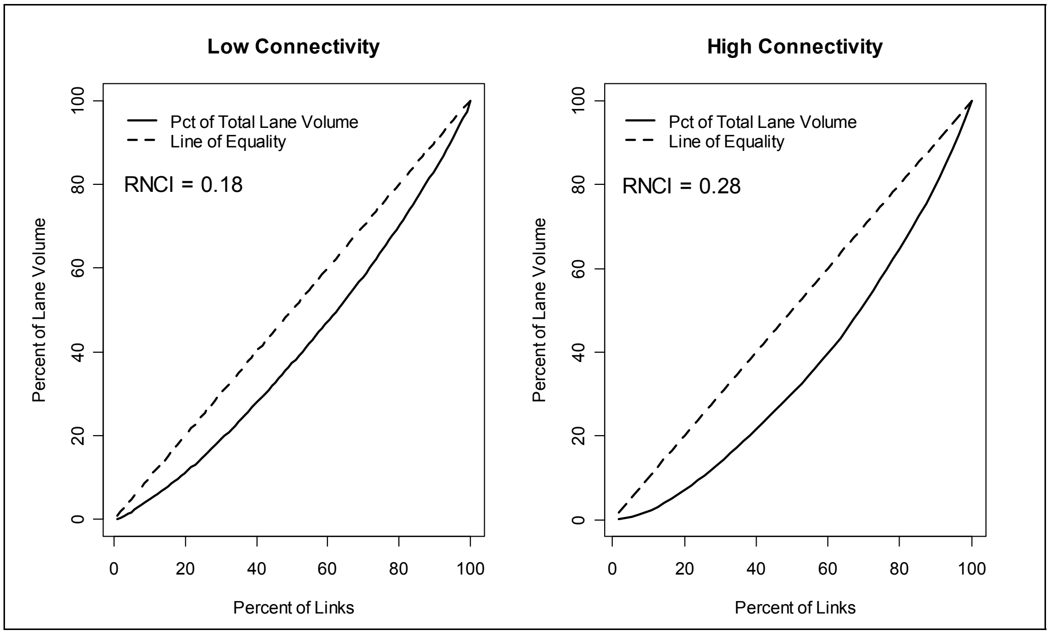

Figure 4.25: Major arterial RNCI for different portions of the network

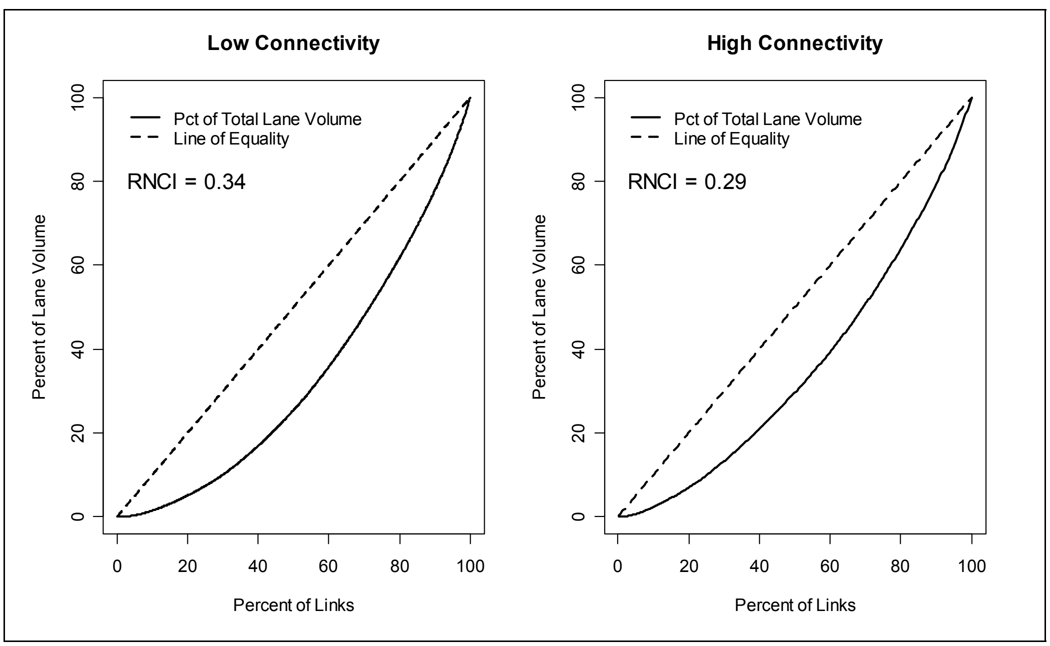

Figure 4.26: Minor arterial RNCI for different portions of the network

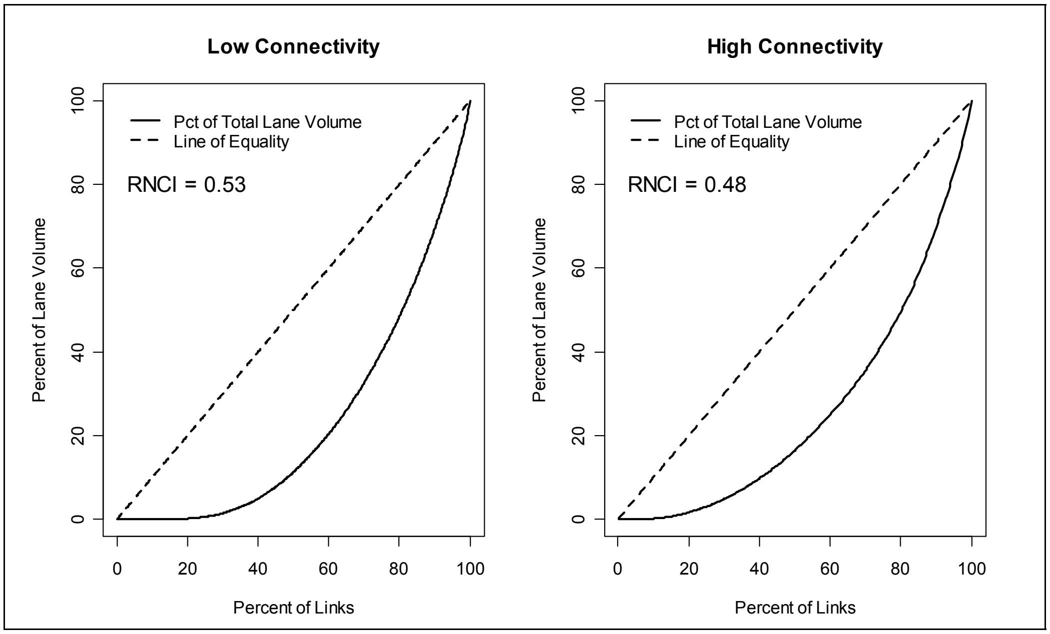

Figure 4.27: Major collector RNCI for different portions of the network

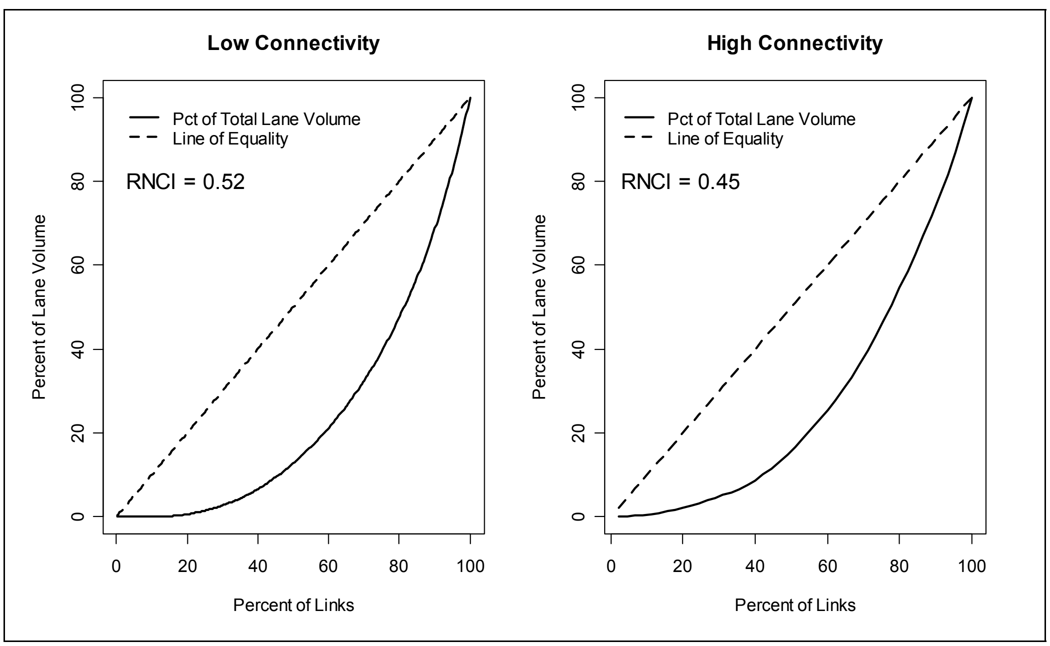

Figure 4.28: Neighborhood collector RNCI for different portions of the network

4.6.3 Aggregating RNCI values across roadway types

Two aggregation tests were done to address the problems identified in the previous section. The first combined all the arterial class links into one type and all collector class links into another type and computed RNCI values for these two aggregated types. The second approach combined all roadway types by computing a RNCI value based on the ratio of ADT to capacity rather than the ratio of ADT to lanes. Lane capacities vary by roadway type, so using capacity in the calculation normalizes the variation between road classes.

Figures 4.29 and 4.30 show the results of combining the arterials together and the collectors together. In this case the differences in the high and low connectivity results are as expected. There is less difference in the arterial numbers because the counter directional results for major arterials are counteracted by the effects of the other arterial types. Although this appears to have addressed the problem it is still a concern because the results depend on what types are aggregated together. A different grouping might have resulted in a different outcome.

Figure 4.31 shows the results of combining all types together using lane capacities to normalize differences between types. This produces results in the expected direction. It avoids any bias due to decisions on how to aggregate link types. This aggregation approach though reduces the difference in the RNCI values between network portions.

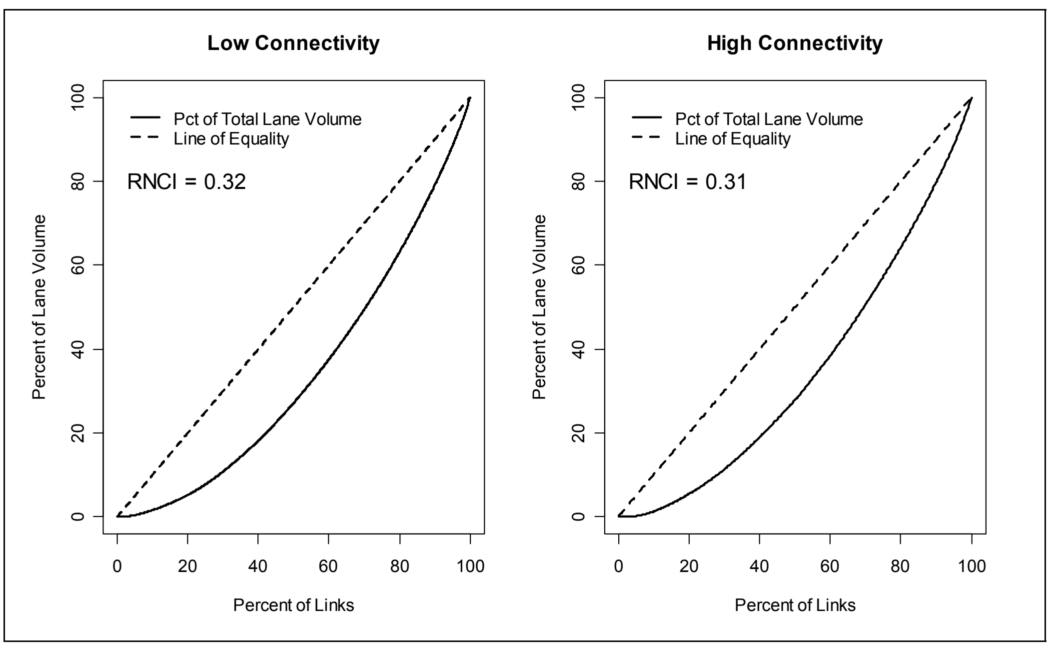

Figure 4.29: Average arterial Road Concentration Network Index

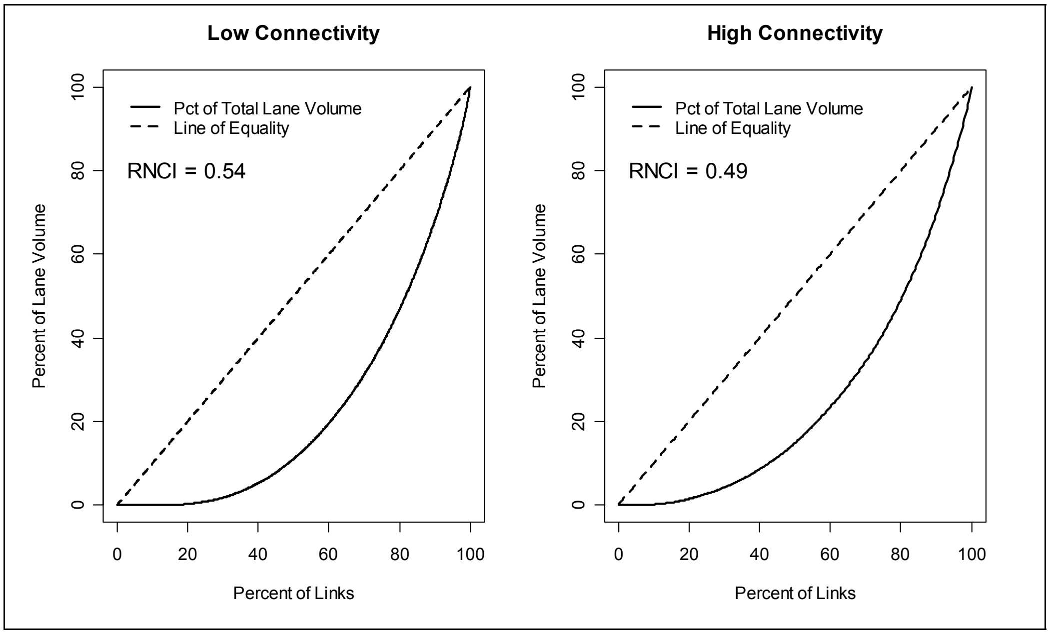

Figure 4.30: Average collector Road Concentration Network Index

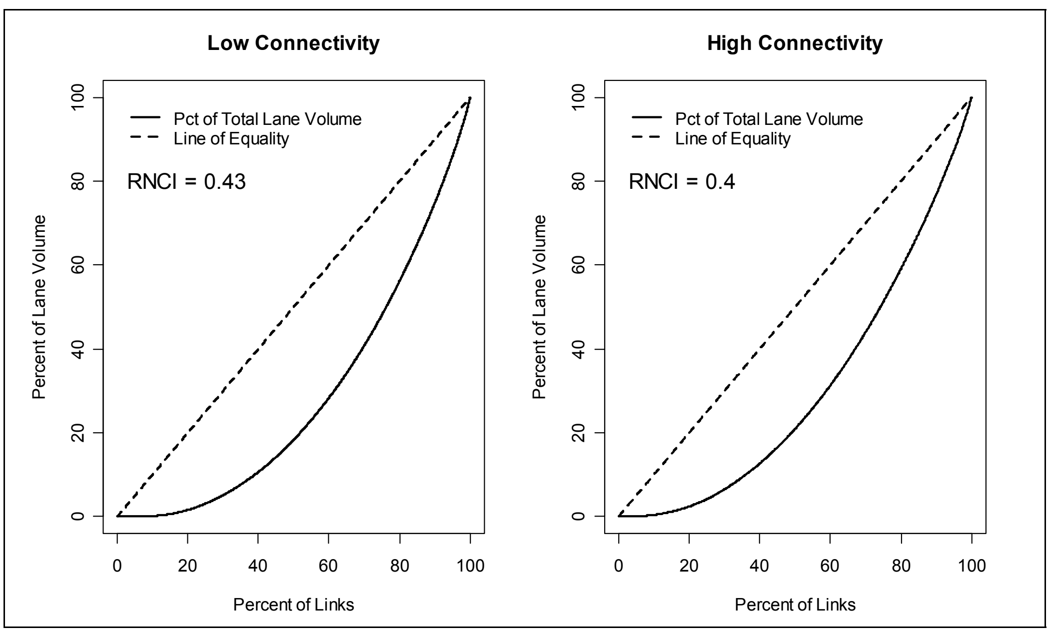

Figure 4.31: Capacity weighted average arterial and collector Road Concentration Network Index

5.0 EVALUATION, CONCLUSIONS, AND RECOMMENDATIONS

5.1 EVALUATION OF RESULTS

5.1.1 Urban Mobility

The annual Urban Mobility Report produced by the Texas Transportation Institute has proven to be an effective way to communicate the state of the local transportation system to the public. It contains both transportation system inventory data and estimates of mobility-related system performance for the current year, as well as for each of the previous 20 years. Nearly all of the measures are easily understandable to lay persons. They can readily discern mobility trends in their own community, and see how it compares to others. Given the popularity of the UMR, we feel that there is great value in extending some of the UMR mobility measures for evaluating future transportation alternatives.

The UMR must rely upon standardized observed data, primarily roadway inventory and average daily traffic count data from the Highway Performance Monitoring System. Travel delay relationships are then developed from more complete data sets, which include observed volumes and speeds under varying conditions of congestion, and incident delay over smaller increments of time, from selected traffic management centers across the U.S. There are many simplifying assumptions that are necessary in the application of the UMR methodology with HPMS data. However, there is tremendous value in applying a consistent methodology and using consistent observed data, over a 20-year period, to 85 U.S. metropolitan areas. Travel forecasting models, which produce very detailed estimates of traffic volumes, speeds, and delay on each element of the model network, offer the opportunity to extend the UMR mobility performance measures for evaluating alternative future scenarios.

One remaining challenge is the reconciliation of mobility performance measure (PM) values derived from local models with those derived from observed (HPMS) data. Of course, a well-calibrated base year model that is run for all time periods in a day would be expected to produce 24-hour link volumes comparable to those in the HPMS; so a simple substitution of daily model volumes for HPMS volumes in the UMR methodology might produce comparable results.

This approach, however, would rely on the UMR's simplifying assumptions, such as the assumed VMT distributions by time of day and the assumed relationships between daily traffic volumes and delay. Models, on the other hand, are run for specific time periods during the day, representing both congested and uncongested conditions, and they produce more precise delay estimates for each network link. Thus, the recommended approach, as demonstrated in this project, is to use the richer model data to derive base year PM estimates, and then scale these estimates to those published in the UMR. Those scaling factors would similarly be applied to future year model estimates. On the basis of the results obtained here, it is further recommended that delay be computed relative to free-flow conditions.

Two other ideas pertaining to the reconciliation, or scaling process, are set forth for future research. The first is that the number of peak hours represented by base year travel demand model runs would be approximately equal to the "Number of daily rush hours" estimate published in the UMR for that year. For future year runs, the analyst would first use the ADT model results to compute the Roadway Congestion Index (RCI) value, then find other urban areas in the current UMR with comparable values and check their "Number of daily rush hours." If necessary, the future year peak periods would be extended (e.g., from 2 hours to 3 hours) using either survey peak factors or departure time choice models. The second idea is that if the planning agency has historic model data, it would be useful to compute the mobility measures for several previous years and check to see if the scaling factors remain within a narrow range.

5.1.2 Transportation Cost Index (TCI)

The Transportation Cost Index (TCI) has been shown in this study to be a useful way to describe and map urban accessibility. It can be computed and aggregated by geographic level, income stratum, and trip purpose, and can be weighted to develop regional averages. The parallels between the popular Consumer Price Index "market basket" concept and the TCI could be further cultivated to result in a measure of overall land use / transport system performance that the public can relate to.

The method adopted for identifying the reference zone using log sums of JEMnR access utilities was found to do a good job of identifying a TAZ that has a high level of accessibility. The method includes filters to assure that only zones containing households having access to all transportation modes are included in the choice set. In practical applications it will be important that the reference zone be one that is meaningful to local stakeholders. The study method can be used in application to provide initial ratings that are used by stakeholders along with other information deemed important to arrive at a choice of reference zone.

It was found that the reference zone should not be used to determine reference market areas or market baskets. The results are too variable to be reliable. The variability comes from uneven land use patterns, the effects of aggregating data into TAZs and the use of thresholds. Market baskets can be more reliably estimated by averaging the market baskets for all zones calculated using the percentage of trips method. The trip percentage used to determine the size of the market basket should be considered carefully. The higher the value, the more the result will measure regional accessibility and mask accessibility to local attractions. Testing of alternative percentages will be an important early step in applying the methods. The scripts that have been developed facilitate the testing process.

Additional research and analysis needs to be applied to questions of how the methods affect equity analysis. It is recommended that the same cost coefficients be used to convert utilities to dollar cost equivalents for all income groups. Other researchers may wish to consider this recommendation further. More research needs to be done on the question of whether market baskets should be different for different income groups. To some extent, income constrains opportunities, so constraining the market basket for lower income households creates a bias against those households. On the other hand, incomes are associated with other household attributes that significantly affect travel needs. Higher incomes are associated with more workers in the household and greater needs to purchase goods and services that are not provided by the household. Elderly households often have low incomes and fewer needs for travel. Research should be done on testing the use of other variables such as household size, number of workers and age instead of income to establish market baskets.

The TCI tests show that the method used to aggregate market access costs by different travel modes has a significant effect on the results. All three methods (average cost, minimum cost, and composite cost) were found to provide useful perspectives and are recommended for application and further testing.

The model area "edge effects" should be taken into account. Where the model area encompasses the entire urbanized area, as in the Medford example, the increased transportation costs at the edges are realistic. But where the urbanized area represented by the model is near other urbanized areas (the southern edge of metropolitan Portland, for example), a portion of the "market basket" for edge TAZ's may be obtainable in the adjacent urban area. In those instances, the representation of trips that traverse the external cordon, by income group, purpose, and mode of travel, should be considered.

Finally, to maximize the potential usefulness of the TCI, there should be ways to translate the "market basket" of opportunities to real-world conditions as revealed by the proposed annual cross-sectional household activity surveys. The estimated (modeled) TCI should be compared to that calculated from annual revealed data from a representative sample of households.

5.1.3 Percent of Market Place Accessible by Non-Auto Modes

Percent of places containing the TCI "market basket" that are accessible by bus, auto, and bike is a promising indicator of multi-modal coverage and automobile dependence. This measure shows good responsiveness to conditions and it communicates effectively about the relative difficulty of meeting travel needs using non-auto transportation modes. This measure is dependent on how the "market basket" is defined, and upon reasonable assumptions regarding willingness to walk and bike. The maximum non-auto travel time assumption of 30 minutes or 30 minutes greater than the time for a comparable auto trip should be further examined and refined on the basis of household survey data.

5.1.4 Auto Dependence Index

The Auto Dependence Index (ADI) is a ratio of non-auto and average travel costs to access the TCI "market basket." Where the "Percent of Market Place Accessible" (above) is a measure of the <u>ability</u> to access the market basket without a car, the ADI is a measure of the <u>competitiveness</u> of the non-auto modes. The measure shows very clearly the disadvantage of travel by non-auto modes compared to auto modes. For areas with infrequent public transit service, such as Medford, it may be desirable to limit initial production-end wait times for certain trip types, such as home-based work and college, since transit users often adjust their daily activity schedules to comport with transit schedules, with little perceived inconvenience. (This project assumed an initial wait time of one-half the headway.)

5.1.5 Freight Delay Costs

Freight Delay Costs is one measure of transportation effects on Economic Vitality. This analysis employed the cost and annualization factors from the UMR, but there is no need to reconcile the Freight Delay Cost performance measure with the freight delay component of the UMR Congestion Cost performance measure. There is the potential for much more in-depth analysis of freight delay.

It is primarily applicable to areas where the travel model, at a minimum, tracks internal and external truck trips on network links separately from autos. It can be further enhanced by using the following:

- Models that segment commercial vehicles by type (for example, heavy duty freight, light duty freight, service vehicles); and
- Models that segment commodities by type so that, for example, a mobile concrete mixer or asphalt delivery truck (perishable commodities and critical JIT delivery demands) may have a much higher delay value than a truck transporting furniture or clothing to a warehouse.

5.1.6 Road Network Concentration Index (RNCI)

The RNCI is a measure of system vulnerability attributed to concentrations of traffic on relatively few roads. It compares the modeled or actual vehicle-miles of demand per lane-miles of network supply (the distance term drops out) with a hypothetical uniform distribution of traffic. The RNCI was calculated using ADT traffic, where directional volumes on most 2-way links are about equal. A perfect RNCI score of "0" means that there is no difference between the modeled or actual distribution of traffic and this hypothetical uniform distribution. The higher the score (toward an upper limit of "1"), the less uniform the distribution and the higher the concentration on a few facilities.

This study performed an RNCI analysis on the Eugene model network and included scenarios where traffic was deliberately redistributed in a less efficient manner by removing a key centrally located Willamette River bridge. Comparisons were done by functional class and by area type (grid system versus discontinuous). The results were, for the most part, ordered as expected: higher functional classes had more even distribution than lower functional classes; well-connected grid portions of the network had more even distribution than discontinuous areas; and a with-bridge network had more even distribution than a without-bridge network. Nevertheless, there is more that needs to be done with the RNCI to transform it into a measure that can be meaningful to policy makers and the public.

The RNCI can also be thought of as a measure of efficiency, since the higher RNCI score indicates uneven use of network capacity. The difference in the RNCI between functional classes indicates that freeway capacity is most efficiently used, while collector capacity is least efficiently used. The area type differences indicate that capacity is most efficiently used in well-connected networks.

Further research should aim at making the RNCI meaningful to the public. The RNCI could be calculated for different urban areas and under varying levels of congestion, per the UMR. The ratios of RNCI values for different regions and scenarios may be more meaningful than the values themselves. While the "Gini" type graphs are informative, they could be supplemented with network plots color coded according to variance from mean capacity utilization by functional class.

5.2 CONCLUSIONS AND RECOMMENDATIONS

This research set out to inventory Oregon transportation plans, to identify policies that appear to lack adequate performance measures, to review performance measures in use elsewhere, to propose performance measures to address Oregon policies not currently addressed, and to test those measures and evaluate the results. Another objective, which provided the initial impetus for this research, was to identify performance measures that directly address the Oregon Transportation Planning Rule's policy to reduce automobile dependence.

The six performance measures identified and tested here address some important aspects of the under-evaluated policy areas identified in Task 1; but in most cases, the breadth of the policies themselves preclude comprehensive evaluation by a single measure. Moreover, some selected measures are new ideas (i.e., the TCI and the RNCI), which pose communication challenges because of lack of familiarity. Further work is needed to communicate the link between these measures and the plan policies they are intended to evaluate.

5.2.1 Use of these performance measures

The Mobility measures address policies that already have some associated plan performance measures such as volume-capacity ratios, vehicle hours of delay, and roadway level of service standards. This research takes a different class of observed measures of transportation system performance, a class introduced to the public in the annual Urban Mobility Report, and extends them into the transportation planning realm. It enables policy makers and the public to envision how established local mobility trends, already familiar to the public, are likely to be extended or altered under alternative land use and transportation system futures. These performance measures are ready for implementation in Oregon transportation plans.

The Transportation Cost Index (TCI) introduces a new way of measuring accessibility, as well as some aspects of balance, environmental justice, land use compatibility, and quality of life. Where traditional accessibility measures evaluate the number of opportunities within a particular time/cost contour, the TCI (conceptually similar to the Consumer Price Index) evaluates the cost of accessing a "market basket" of opportunities. As developed here, it can provide a useful means of comparing local geographic, socio-economic, and purpose-specific travel markets. Like most accessibility measures, it is affected by land use and transportation system changes, by changes in both auto and non-auto elements of the transportation system, and by changes in both travel time and monetary costs. It is more encompassing than many accessibility measures currently used in Oregon. However, further research is recommended to extend the TCI concept by identifying more uniform "market baskets" of opportunities, allowing TCI comparisons between urban areas, and perhaps leading to a single, consistent TCI metric, similar to the mobility measures in the UMR. Further research should also explore how to calculate the TCI for a representative sample of households using household activity survey data, to both validate the modeled values and to lead to trackable benchmarks.

The Percent of Market Basket Accessible by Non-Auto Modes and the Auto-Dependence Index (ADI), taken together, provide useful insights into how well a set of plan alternatives under consideration address the TPR policy to reduce auto reliance. These are far more direct measures of auto reliance than the current VMT/Capita, which can be heavily influenced by non-plan variables such as the local job market and fuel prices. The "Non-Auto Accessible Market Basket" measures the ability to get by without a car, and the ADI measures the relative convenience and attractiveness of the non-auto options. These measures are closely tied to the TCI, and their application in Oregon would be improved by refinements to the TCI. The idea of alternative mode availability that underlies the "Non-Auto Accessible Market Basket" has been proposed as an Oregon Transportation Plan performance measure, and could certainly be applied to MPO plans as well.

Freight Delay Cost is the only measure of transportation effects on economic vitality that has been developed in this project, and it is a limited one. It can be calculated in any number of ways, depending upon the quality and level of detail of the model data. The simplest approach assumes a blanket 5% undifferentiated commercial vehicles on all arterials, while more complex approaches track commercial vehicles of various types and commodities on specific routes, each with different time values of delay. For policies relating specifically to reducing freight delay, the more complex approaches to the performance measurement are recommended. At the present time, these approaches are most applicable to the Oregon II statewide model and the Portland Metro model. The smaller Oregon MPOs are currently exploring a common, transferable freight model based upon the TMIP "Quick Response Freight Manual."

The Road Network Concentration Index (RNCI) is a potentially useful measure of security, balance, and efficiency. Further research is needed to make this measure more meaningful to policy makers, possibly by different means of graphic communication.

5.2.2 Policies recommended for future research

5.2.2.1 Balance

The measures set forth in this research address some aspects of *Balance*. The Transportation Cost Index (TCI) can be used to assess balance of accessibility by geographic area and by income group. The Auto Dependence Index (ADI) can be used to assess balanced transportation mode availability. The Road Network Concentration Index (RNCI) can assess balanced capacity utilization.

Oregon transportation policies also call for balanced transportation investment, something that is not currently well-measured. The transportation plans deal in trade-offs among alternatives, each typically competing at some level for public investment. The Expert Research Panel recommended the following performance measure:

- ***Change in Consumer Surplus*** (preferably, by population segment)

The application of consumer surplus, welfare, and benefit-cost analyses may potentially deal with other aspects of *Balance.* Financial constraints and NEPA requirements have led us to carefully evaluate the economic, environmental, and social costs associated with any transportation project. By considering the "cost" side alone, transportation projects in general, and highway projects in particular, are considered to be, at best, a necessary evil. An analysis of consumer surplus could provide new insight into the social and economic benefits and may help to balance the discussion. The Federal Transit Administration's "New Starts" program requires an analysis that uses consumer surplus theory in the evaluation of new transit projects, using changes in time expenditures to access a fixed set of destinations.

Others have considered consumer surplus as a function of reduced travel costs and accessibility to a wider choice of activities, similar to our TCI. Other benefits may include access to better employment opportunities, higher property values, reduced costs of goods and services, and so forth. We recommend further research into the use of consumer surplus theory for evaluating road and bike projects, transportation system management (TSM) and transportation demand management (TDM) investments, development incentives, and other types of public investment related to transportation planning.

5.2.2.2 Reliability

Reliability is an important aspect of system performance, but current models have not adequately forecasted its key determinant; travel time variability. Some of the newer generation regional travel forecast modeling software promises more detailed network representation, dynamic traffic assignments, and a more seamless transition to microsimulation of corridors and subareas. Forecasting tools such as these may have the potential to forecast the effects of various plan alternatives on travel time variability by mode.

Meanwhile, the newer generation of GIS-based household travel surveys should gather much more precise route choice and travel time data. These data may ultimately increase our understanding of the effects of perceived travel time variability on travel choices. Further research is recommended into both the representation of reliability in the supply networks and the effects of perceived reliability on destination, mode, route, and departure time choices.

5.2.2.3 Safety

Recommended performance measures:

- ***Number of Traffic-Related Incidences by type (PDO, Injury, Fatality)***
- ***Cost of Crashes***

A great deal of research in the area of crash prediction models has been done in recent years. Engineers have gained a great deal of insight into the effects of road and intersection design elements on safety. Social researchers have conducted studies on the effects of age and gender, and enforcement measures such as random drunk-driver checks or camera recording of red-light runners. There have been few efforts at predicting the safety consequences of long-range transportation plan alternatives. Long range plans seldom deal with the more detailed design elements or enforcement issues, and much of the research has shown that infrastructure itself plays a relatively minor causal role.

There have been some efforts that use exposure-related techniques, where planners have associated crash rates with traffic volume and congestion levels, but there is considerable doubt about the reliability of such forecasts. Nonetheless, long range plan decisions <u>do</u> have safety consequences, even if some of the variables are unknown. The relative permanence of infrastructure and its influence on driver behavior is important, even if it seldom plays a primary role in causing crashes.

We recommend more definitive research into the effects of known planning variables on safety, such as the distribution of traffic by functional class and level of service, the effects of speed, the effects of land use types, the comparative effects of various intersection types, control types, roundabouts, the effects of demographic variables, the effects of trucks and designated routes, on-street versus off-street bicycle lanes, transit operations, and the effects of major ITS elements. New research should focus specifically on these and other variables that are typically forecasted for long-range land use and transportation plans, and such research should carefully control for all of the other variables

5.2.2.4 Economic Vitality

We recommend research into the effects of the transportation system on cumulative land value, and the effects of transportation improvements on private investment and job creation.

It is a challenge, however, to separate the transportation system influences from other factors. The Oregon II statewide model and perhaps the Portland MetroScope model might point the way to eventual performance measures. This research would examine the lagged effects of such factors as transportation system improvements, service to undeveloped areas, and improving LOS in congested areas, on private development. A fully integrated land use / transport model would be desirable. Potential performance measures would be related to new investment, and might include:

- ***Private / Public Investment Ratio***
- ***Number of Jobs Created or Enabled***

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