North Corridor Transit Project

Technical Report

Transit Ridership Forecasting

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Acronyms and Abbreviations

AAZ	Alternatives Analysis Zones
APC	Automatic Passenger Count
AVL	Automatic Vehicle Locator
DRAM	Disaggregated Residential Model
EIS	environmental impact statement
EMPAL	Employment Allocation Model
ERP	Expert Review Panel
FAZ	Forecast Analysis Zone
FTA	Federal Transit Administration
GMA	Growth Management Act
HOV	high-occupancy vehicle
IIA	independence from irrelevant alternatives
JTW	journey-to-work
NTD	National Transit Database
PSCOG	Puget Sound Council of Governments
PSRC	Puget Sound Regional Council
RTA	Regional Transit Authority
RTP	Regional Transit Project
ST	Sound Transit
TPI	time point interval
TRB	Transportation Research Board

1. INTRODUCTION

This interim report describes the travel forecasting methods and assumptions used to produce system-wide and project-level transit ridership forecasts for Sound Transit (ST). Ridership forecasts for the North Corridor Transit Project will be included in the next version of this report in 2011. The approval of the ST2 expansion program in November 2008 requires ridership information to support development of additional fleet, maintenance bases, stations, and service extensions for all three modes, but especially for light rail.

The current version of the ST ridership model was developed using analytical ridership forecasting procedures developed over two decades of incremental methods applications. Over this time period, the methods have been subjected to substantial external review, including two independent Expert Review Panels, and two cycles of review by the Federal Transit Administration (FTA) over the course of New Starts grant applications for Link light rail projects.

The next ST model update will be 2012-based using new surveys and counts data with the general incremental modeling framework. The updated ST model is intended to be used to produce ridership forecasts in support of the New Starts application of the North Corridor Transit Project to FTA for entry into Preliminary Engineering. The following presents a brief history of ST transit ridership forecasting.

1.1 History of Transit Forecasting at Sound Transit

The history of transit forecasting analysis at ST began at Seattle Metro (now King County Metro) in 1986. Work by Brand and Benham, of Charles River Associates, led to Metro's consideration of "a quick-responsive incremental travel demand forecasting method" [1] based on the concept of staged forecasting analysis. Subsequently, in 1986, Metro installed "logit mode-choice equations for pivot-point analysis"[2] (as described by Ben-Akiva and Atherton;[3] Koppelman;[4] Nickesen, Meyburg and Turrnquist;[5] and many others) on EMME software. In 1988, Metro staff highlighted the relationship[6] between Metro's transit forecasting methods and the Puget Sound Council of Governments (PSCOG) regional model.

ST and the Regional Transit Project (RTP) further developed forecasting analysis procedures in the early 1990s, prior to the November 1996 voter approval of *Sound Move: The Ten-Year Regional Transit Plan*. An Expert Review Panel (ERP)—formed in 1990 under the auspices of the Legislative Transportation Committee, the Secretary of Transportation, and the Governor—oversaw development of the first generation of the ST incremental model. This model is described in the November 1993 *Travel Forecasting Methodology Report* published by the RTP.

The ST model was updated in the late 1990s in support of the Central Link Light Rail Transit Project Environmental Impact Statement (EIS) and the North Link Light Rail Transit Project Supplementary EISs. The underlying ST model procedures used to perform transit ridership forecasting analysis in

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[1] Brand, D., and J.L. Benham, "Elasticity-Based Method for Forecasting Travel on Current Urban Transportation Alternatives," Transportation Research Record No. 895, 1982.

[2] Harvey, R. "Pivot-Point Analysis of Transit Demand Using EMME/2," an Internal Paper, Municipality of Metropolitan Seattle, May 1986.

[3] Ben-Akiva, M. and T. Atherton, "Methodology for Short-Range Travel Demand Predictions," Transportation Economics and Policy, v.7, 1977.

[4] Koppelman, F., "Predicting Transit Ridership in Response to Transit Service Changes," ASCE 109, 1983.

[5] Nickesen A., A. Meyburg, and M. Turnquist, "Ridership Estimation for Short-Range Transit Planning," Transportation Research B, v.17B, 1983

[6] Harvey, R. "Comparison of Metro and PSCOG Modeling" a Memorandum to File, March 7, 1988.

support of the North Link Light Rail Projects were documented in the *Transit Ridership Forecasting Technical Report,* issued in November 2003 by ST.

1.2 Report Organization

This report contains four chapters. This introductory chapter summarizes the methods used to produce ridership forecasts for ST and discusses important methodological considerations. Chapter 2 describes the individual methods used for each step of the travel forecasting process. Chapter 3 describes validation of the ST model to 2004 conditions. This model validation exercise has two purposes: (1) to highlight problems with the forecasting process that might have otherwise been overlooked, and (2) to incorporate changes that could improve the forecasting results. Chapter 4 discusses the specific input data and assumptions used to perform staged ridership forecasting analysis. This chapter also includes build-up analysis results for Stages 1 and 2 ridership forecasts.

1.3 Sound Transit Incremental Planning Model

The ST incremental model has been updated to a new base year (2004). Development of the base-year transit-trip tables involved a rigorous analysis of actual ridership volumes along each transit route and a realistic simulation of observed transit service characteristics for peak and off-peak periods. External changes in demographics, highway travel time, and costs are distinctly incorporated into the process in phases, prior to estimating the impacts of incremental changes in transit service. The ST model relies on the Puget Sound Regional Council (PSRC) regional model for data on external changes.

In the first stage of ridership forecasting analysis, only changes in PSRC model trip distribution results or demographics are considered. In the second stage, other external non-transit changes, such as highway travel time (congestion), costs (including parking costs), and household income, are taken into consideration.

The first two stages of ridership forecasting analysis result in a forecast of zone-to-zone transit trips within the Regional Transit Authority (RTA) district boundaries, absent any changes in the transit system. In the third and final stage, incremental changes in the transit level of service (e.g., access, wait, and ride travel times) and user costs are considered. Finally, transit trips are assigned to the future-year transit network.

Like all travel forecasting models, the ST model has some limitations. Because it uses average daily ridership, it is not particularly strong at assessing the effects of special events, such as sports games or major festivals, or special generators, like major international airports. Furthermore, the ST model is ill-suited for analyzing structural changes in regional land use beyond those already included in PSRC demographic forecasts or for forecasting in outlying areas of the three-county region where there is minimal existing transit service. Finally, the model does not explicitly take into account any differences in safety, comfort, or user friendliness of bus versus rail transit service.

1.4 Important Considerations and Constraints

This section discusses five important considerations and constraints in travel forecasting methods. Most of these were taken from the FTA guidelines on transit project planning.[7] The following considerations reemphasize the use of best professional practice:

- Careful standards for validation
- Consistent application of policy assumptions across alternatives

[7] Current procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA).

- Use of identical land use plans and constant overall travel demand patterns across alternatives
- Generic attributes of modes
- Analysis of service levels and travel forecasts for reasonableness

1.4.1 Careful Standards for Validation

Validation is a vital component of any travel forecasting effort. It demonstrates that the forecasting procedures can replicate observed travel patterns in a region, to sufficiently support reasonably reliable forecasts of future travel patterns. In project planning, travel forecasting methods are expected to predict changes in travel patterns that are caused by general changes between now and the forecast year and by specific changes introduced by each alternative. The ST model has been validated against actual 2004 transit ridership.

1.4.2 Consistent Policy Assumptions across Alternatives

A large number of inputs to the travel forecasting process are at least partially subject to the policy decisions of local and state agencies. To isolate the differences generated by a specific proposed project (e.g., a fixed guideway rail transit system), all conditions that are not directly attributable to the proposed project must be held constant. It is therefore required that the forecasts hold the policy setting constant across all alternatives evaluated. These policies include:

- Fare level and structure
- Levels of service provided by the transit system
- Zoning policies
- Parking policies and prices
- Right-of-way availability

This constraint means that forecasts prepared for FTA evaluation and EIS presentation should contain as few differences as possible between alternatives. For example, service levels on feeder buses should reflect a general service policy that is applied consistently across alternatives. Assumptions on land use development, regional income, parking costs, and other variables not specific to the transit alternatives under consideration in the corridor must also be held constant.

1.4.3 Constant Travel Patterns across Alternatives

Forecasts of the overall travel demand for which transit and HOV facilities compete can also be confounding. The FTA requirement that land use policies be consistently applied removes some sources of variability in population and employment forecasts. This requirement goes beyond the constraint mandating that the population and employment forecasts themselves be held constant. In basic forecasts for modes that have differing levels of grade separation, it eliminates guessing about the extent to which a particular alternative might shift residential and commercial development.

1.4.4 Generic Attributes of Modes

There is currently much discussion of the differences in ridership potential associated with the less tangible qualities of various transit technologies. This discussion typically focuses on the perceived differences between technologies in terms of visibility, comfort, convenience, and other characteristics that are difficult to quantify. Because there is limited data to support inclusion of these less tangible qualities in the analysis, the ST model treats transit modes very generically. However, this is an area for which the FTA is investigating possible approaches to model improvement. Many urban areas now submit forecasts to the FTA that account for differences in reliability between bus and rail.

A few studies have directly addressed this question and indicated that some measurable differences can be isolated. One important result is that these differences appear to be associated with physical differences in facilities and services, not with unexplainable factors. For this reason, ST now includes a very small quantified reliability difference in the transit line boarding and waiting times.

1.4.5 Analysis of Service Levels and Travel Forecasts

Developing ridership forecasting requires estimating large amounts of supporting data that is of potential interest to a variety of audiences. Examples include population and employment changes in various subareas, increasing congestion levels, travel time savings created by new transit guideways, and transit's share of various travel markets. Reviewing this information can be crucial to isolating problems in initial forecasts and increasing the credibility of the final results.

2. PROCEDURES FOR TRAVEL FORECASTING

This chapter describes the methods and procedures used in the ST transit forecasting model, including the input data required by the ST model and its relationship to the PSRC model.

2.1 Introduction

Section 2.1 describes the methodology used to develop transit forecasts, the data requirements, and the data available. Section 2.2 describes the relationships between the ST and PSRC models. For instance, this section provides an overview of the methodology used by the PSRC to produce land use forecasts that are critical to the ST model and the ridership forecasting analysis. The transportation analysis zone system is described in Section 2.3. The mode choice model structure, specification, and coefficients are presented in Section 2.4. Summary descriptions of the process used to develop base-year transit-trip tables are described in Section 2.5. Possible changes in population/employment, highway congestion, and cost (i.e., the application of the staged build-up forecasting analysis) are discussed in Sections 2.6 and 2.7. A discussion on changes in transit service is included in Section 2.8.

2.1.1 Incremental vs. Synthetic Methods

There are two different approaches to developing transit forecasts: synthetic methods and incremental methods. Synthetic methods estimate existing transit travel patterns by using separate sequential models to

- Allocate regional population and employment projections to zones
- Estimate the total number of trips from these zones
- Estimate the origin/destination patterns of these estimated trips
- Estimate the travel mode share likely for each estimated origin/destination pattern
- Estimate specific links and lines in the highway and transit systems used by these synthesized trips

Incremental methods are simpler and more efficient for transit ridership forecasting and analysis because they

- Are directly based on observed (rather than estimated) baseline travel patterns of transit users
- Allow for concentrating efforts on transit network analysis, for studies whose primary goals are questions about alternative transit networks
- Are more conducive to the separate evaluation of population and employment changes, highway congestion and cost, and transit services through the three stages of the forecasting process
- Focus on direct comparisons rather than on complete simulations of travel behavior
- Are more usable for intermediate evaluation
- Eliminate the often laborious and time-consuming calibration of sub-choice models, since they do not require replication of base-year travel patterns for these markets

The FTA guidelines on transit project planning[8] summarize the major differences between the two approaches. Figure 2-1 contrasts the setting in which synthetic and incremental methods are applied. The upper part of the figure depicts the application of a conventional mode-choice model—termed "synthetic" because it estimates mode shares entirely from abstract descriptions of times, costs, income levels, etc. The lower part of the figure shows the use of an incremental

[8] Current Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA)

approach, so labeled because it starts with baseline transit travel patterns and shares and predicts the changes (or increments) in the shares.

Thus, the major difference between the two approaches is that the incremental method uses existing transit travel patterns and shares as the measure of the current attractiveness of each mode, whereas the synthetic method uses times and costs.[9]

The FTA guidelines on transit project planning have identified three strong characteristics of the incremental approach that make it attractive for many applications. According to the FTA, the incremental method "is well grounded in the reality of baseline travel patterns; it deals only with marginal changes; and it focuses attention on the changes in land-use and transportation that drive the evolution of travel patterns over time."[10]

The FTA guidelines have also identified a number of limitations that render incremental methods less desirable in some situations. Limitations include "large data requirements, an inability to deal with markets that do not exist today, possible unreliability where markets are poorly developed today, and difficulties in dealing with changes in socio-economic characteristics."[11] Using the following four criteria, the ST model has overcome many of these shortcomings.

1. **Data Requirements**—According to the FTA, "because incremental methods rely solely on data collection to describe base-year travel patterns, data requirements are relatively high."[12] The detailed route-level data by time-of-day from the ridership counts now available via Automatic Passenger Count technology (APC) and from 1992 and 2004 transit on-board surveys provide observed baseline travel patterns within the RTA boundaries for both model validation and applications. ST now has available directional and time-of-day counts for every segment of every transit route in 80 percent of the ST service area and 90 percent of the transit market.

2. **New Markets**—"Because all incremental methods build from base-year conditions, they cannot be used to forecast future travel patterns for a market that does not exist in the base year."[13] The existing transit market and coverage within the RTA boundaries are quite extensive. Therefore, the use of ST incremental methods would only have limitations in application to rural areas beyond the district boundary.

[9] Ibid

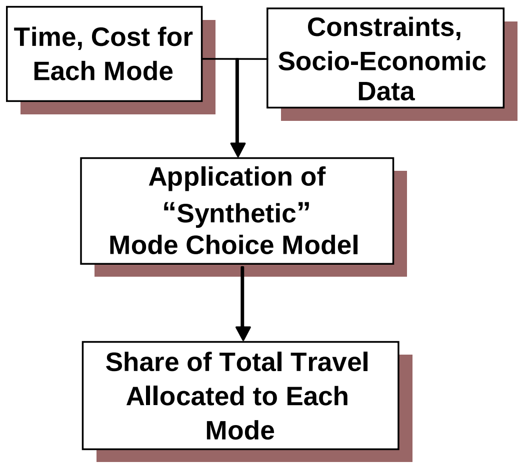
[10] Ibid

[11] Ibid

[12] Ibid

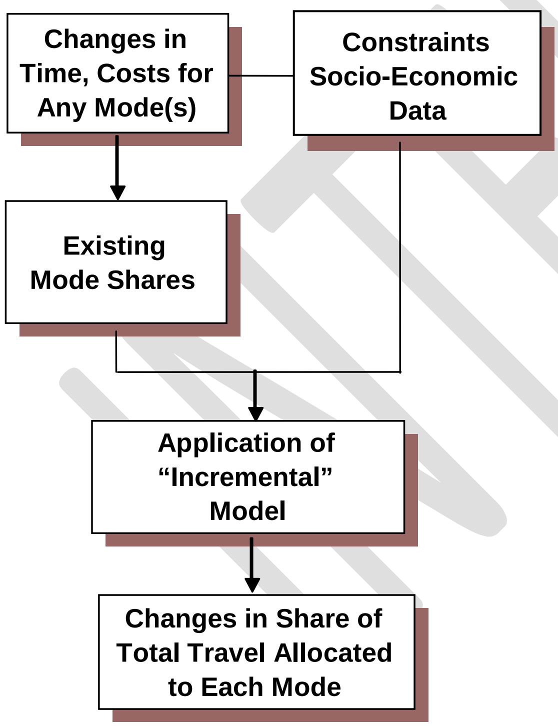
[13] Ibid

Figure 2-1. Synthetic and Incremental Approaches to Forecasting



SYNTHETIC APPROACH

- Attractiveness of modes described by their time and costs
- Socio-economic variables included automatically (if part of model)
- Each application independent of base conditions
- No guarantee that shares reflect baseline conditions



INCREMENTAL APPROACH

- Changes in service levels for one or more of the modes
- Differentiation by socio-economic groups difficult in some methods
- Initial attractiveness of modes measured by current shares of existing travel
- Each application starts with baseline conditions
- Results certain to be “reasonable” in that they are adjustments to current shares

3. **Limited Markets**—According to the FTA, "auto-access to transit is perhaps the primary example of a market that plays an important role with many transit guideways but is only marginally developed in the current bus system."[14] Presently, about 15 percent of bus and rail riders within the RTA boundaries use automobile to access transit via formal and informal park-and-ride sites. Therefore, this particular issue does not restrict the application of ST incremental methods.
4. **Socio-Economic Changes**—"In previous applications of incremental methods to transit project planning, the forecasts have largely ignored the influence of possible changes over time in real income or auto-ownership."[15] The ST model has overcome this particular shortcoming by using a normalizing cost variable with respect to income to capture some of the historical trends of decline in transit ridership shares over time resulting from the trend in increased income and car ownership.

It is important to recognize that the sensitivities to change in the incremental approach are not approximations of the sensitivities in the synthetic approach—they are virtually identical. The incremental methods are mathematically parallel to the synthetic methods and are applied in the same level of detail that would be used in a synthetic approach.

2.1.2 Data Available for ST Planning

The key sources of data available for ST planning include

- The Puget Sound Regional Council (PSRC)
- Transit operators in the three-county area—Sound Transit, King County Metro, Pierce Transit, Community Transit, and Everett Transit
- The U. S. Census Journey-to-Work data
- The National Transit Database (NTD)
- State and local agencies

The PSRC's land use forecasts and median income estimates are key inputs to the modeling effort. The ST model uses the most current land use forecasts available from the PSRC. The estimates of household income are used to normalize all costs in the ST forecasting process.

The PSRC regional forecasting model also generates highway travel times for past and future years. This information includes separate travel times for vehicles that qualify for high-occupancy vehicle (HOV) lanes. The PSRC model also provides traffic volumes on regional highway facilities for traffic impact analysis, and local jurisdictions provide traffic volumes on local arterials for station impact analysis.

The essential basis for incremental mode choice modeling analysis is the detailed route-level transit ridership information by time-of-day for the base year. The 2004 and 2009 on-board surveys conducted by Sound Transit provide additional detail on riders of all Sound Transit services. The 1992 transit surveys conducted by four transit agencies, the 2000 U.S. Census Journey-to-Work, and the 2009-2010 three-county Commute Trip Reduction Act (CTRA) surveys provide a more complete cross section of representative transit trips.

The transit operators provided detailed ridership counts by route and time-of-day. The King County Metro (KCM) and ST Automatic Passenger Count (APC) databases were the primary source of the actual (or observed) route-segment passenger loads for creating the 2004 PM peak and off-peak

[14] Current Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.

[15] Ibid

trip tables. The transit operators also provided the operating schedules in effect for the base condition (winter 2004). These schedules, along with the Automatic Vehicle Locator (AVL) data from Metro King County on actual speed and reliability for ST and Metro route segments, are the foundation of the transit service descriptions for the base years. Finally, the Census Journey-to-Work data establishes base-year transit and carpool shares for 2000.

The following sections discuss how these various databases were developed and include more detail on how they are being used on this project.

2.2 Relationship to PSRC Modeling

2.2.1 Summary Comparisons of the PSRC and ST Models

The ST and PSRC modeling procedures are closely inter-related and highly complementary. The ST model uses measures of regional change in travel demand and highway congestion derived from the PSRC model. Summary comparisons of the PSRC and ST modeling procedures are highlighted below:

- The PSRC model is a four-county synthetic modeling system comprising land use, trip generation, trip distribution, modal split, and assignment models. It also includes several feedback loops based on intra-regional accessibility.
- The ST model is a three-county, three-stage, fully incremental system purposely designed for detailed corridor-level transit planning and transit patronage forecasting.
- The PSRC's regional population and employment forecasts are used to predict travel demand growth.
- ST uses the PSRC's time and cost coefficients for its mode choice model.
- ST uses PSRC information for all non-transit input to the incremental transit ridership model.

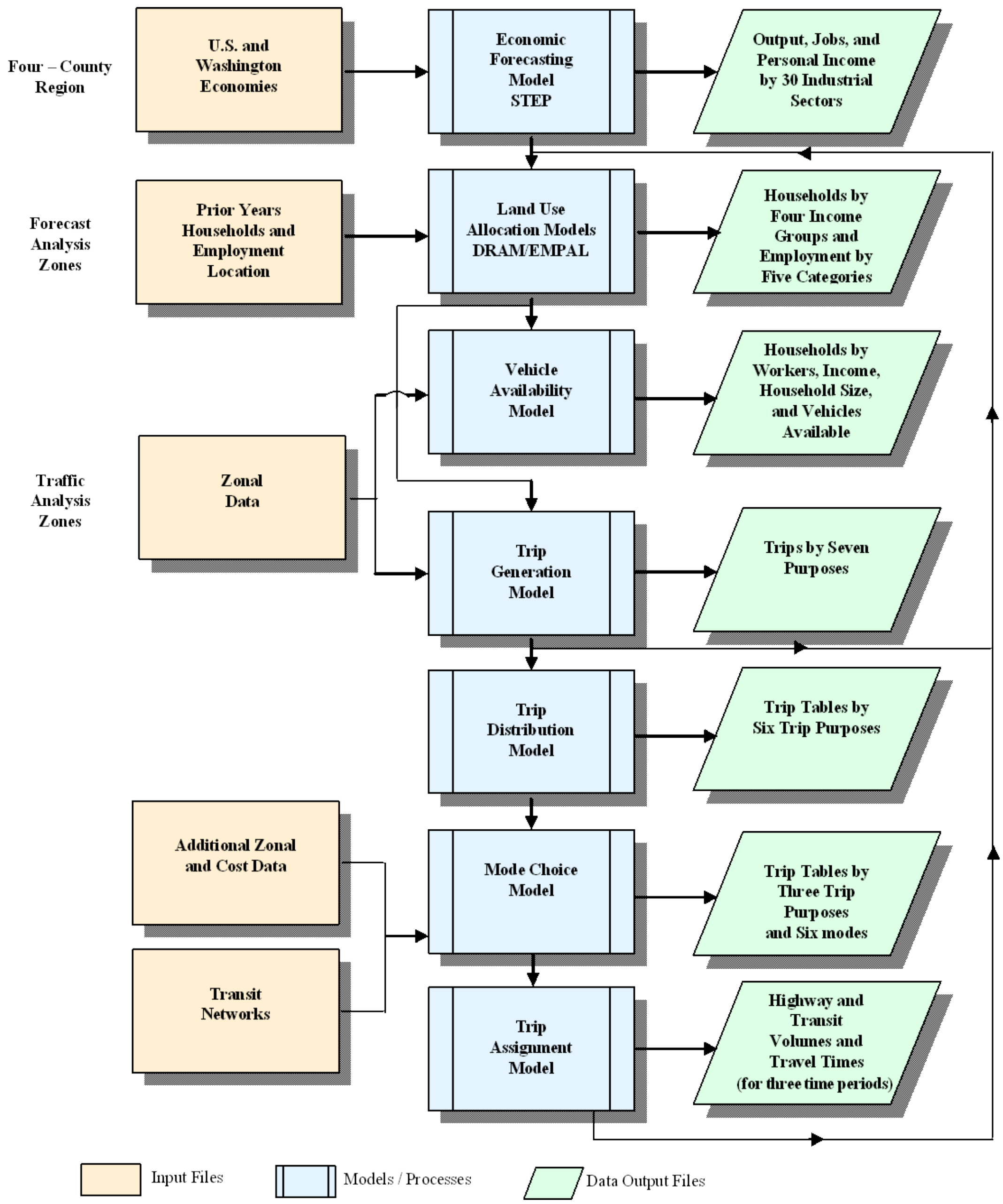
2.2.2 Preparation of Demographic Forecasts

This section summarizes the procedures used by the PSRC to forecast regional population and employment.[16] Figure 2.2 summarizes the PSRC land use and travel forecasting process. The demographic projections that are used for the ST forecasts are prepared by PSRC staff and circulated for review by a wide variety of public and private organizations. The PSRC demographic projections are used for the ST forecasts because they

- Are the adopted projections for the region
- Are the product of technically sound methods and reasonable assumptions
- Have undergone thorough review by the region's counties and local jurisdictions within the context of the State Growth Management Act (GMA)

[16] PSRC Travel Model Documentation, Final Report, September 2007.

Figure 2-2. Regional Land Use and Travel Demand Forecasting Process



Development of Regional Control Totals

The PSRC produces population and employment forecasts for the central Puget Sound Region (King, Kitsap, Pierce, and Snohomish Counties) using the STEP regional econometric model.

The STEP model is a simultaneous system of linear and nonlinear equations that predict a total of 116 economic and demographic variables. The database assembled for calibration of the STEP model includes information on annual values for a wide range of economic measures, such as regional population, regional jobs and earnings, regional output, national economic and demographic variables, and Washington State output and income variables. Output from the model includes forecasts of population, employment, and income for the four-county area. These forecasts establish control totals for the subsequent allocation of growth to individual subareas of the region.

Allocation of Growth to Subareas

Within the regional forecasts from the STEP model, the PSRC uses an urban activity model to allocate growth to local planning areas throughout the four-county region.

In application, the PSRC first estimates the future-year number of jobs in each Forecast Analysis Zone (FAZ) for each of the five industry sectors based on

- The base year number of jobs in the FAZ, by sector
- The proximity of the FAZ to all other job locations in the region
- The density of employment activity (or rental space) in the FAZ
- The travel time to the FAZ from household markets in the region
- Specific inputs from local jurisdictions on long-term commercial development plans.

The total number of jobs in each industry sector is constrained by regional totals for the future year forecasted with the STEP model. Given the projected number of jobs by FAZ, PSRC then predicts the residential location of the workers based on

- The composite travel impedance from job locations to each residence zone
- The base-year proportions of the household income groups in each zone
- Several land-use characteristics of the zone, including residential land use, residential density, degree of development, and relative accessibility
- Specific inputs from local jurisdictions on long-term residential development plans.

PSRC calculates the population by using ratios of average household size derived from the projected regional trend from the base year to future years. Using the number of households projected for each FAZ, PSRC estimates the number of single and multiple family households using a set of variables relative to their regional counterparts. Finally, they predict residential land per household and total land (used and unused) in the zone from a set of housing, land use, and growth variables. Household and population totals are constrained by regional totals for the future year forecasted with the STEP model.

Demographic Forecasting Review Process

The forecasts are for 10-year increments up to 2040 and include detailed allocations for 219 FAZs. These forecasts and allocations are widely used by the state as well as by local governments, public agencies, and private organizations.

The forecasts undergo extensive review by the staff and elected officials of state, county, and local governments. The PSRC makes adjustments to the allocations in response to concerns of local jurisdictions through a continuing process of review, comments, and negotiation. There are no cases in which the regional control totals are adjusted.

2.2.3 Summary Description of the PSRC Travel Demand Models

The PSRC maintains a four-step conventional synthetic travel-demand modeling system consisting of trip generation, distribution, mode choice, and trip assignment models[17]. Zonal trip ends are estimated using a set of trip rates classified by home-based work, home-based college, home-based shop, home-based other, home-based school, non-home-based work, non-home-based other, and three truck types. Trip distributions are estimated using a "gravity" model. The PSRC mode-choice model structure is a logit-based model comprised of two transit modes, three auto modes, and two non-vehicle modes.

2.3 Development of Zone and District Systems

The ST travel forecasts are produced for a 780-zone system of Alternatives Analysis Zones (AAZ) developed specifically for the ST model but based upon the PSRC's zonal system. The 780-zone system includes about 20 zones splits within the North Corridor around potential station locations as well as 23 external zones representing 6 ferry connections and 17 areas outside the RTA boundaries. Summaries of these forecasts are prepared using 27 summary districts or other levels of aggregation (e.g., by corridor or by county) as needed.

2.3.1 Forecast Analysis Zone and Traffic Analysis Zone Systems

The PSRC's FAZ structure is each agency's basic land-use zone structure and consists of 219 FAZs that cover all the land area within the four-county region. It is at this level of detail that local jurisdictions, through the PSRC, agree upon allocations of future population and employment throughout the region. FAZ boundaries encompassing Snohomish, King, and Pierce Counties are shown in Appendix B.

2.3.2 Alternatives Analysis Zone System

The AAZ system used to produce the ST travel forecasts is based on the zones maintained by the PSRC for regional forecasts of travel demand within the four-county central Puget Sound region. The ST zone system differs from the PSRC's system in two aspects.

Most importantly, the ST system does not have the same geographic boundary as the PSRC system. Whereas the PSRC includes a Four-County region (Snohomish, King, Kitsap and Pierce Counties), the 1993 state-established RTA excludes the largely rural areas of North and Northeast Snohomish, South and Southeast Pierce, and East King Counties, as well as all of Kitsap County, Vashon Island, and the Gig Harbor peninsula. Areas outside the RTA district are external to the ST model.

Furthermore, in areas along proposed ST fixed-guideway transit investments, the ST zone structure uses smaller zones, split within PSRC zones. Keeping the two zone structures as similar as possible reduces the level of data manipulation that would otherwise be necessary. The ST 780-zone AAZ system is also shown in Appendix B.

2.3.3 Summary Districts

Summary districts were created from the AAZ system in order to

[17] PSRC Travel Model Documentation, Final Report, September 2007.

- Provide a consistent basis for aggregation of certain model inputs, when such aggregation is appropriate
- Calculate the modal shares required in the model validation and application phases
- Prepare summary reports on trip tables and travel time skims

The 27 summary district breakdown and 11 summary district breakdown are shown in Appendix B. These districts were carefully constructed to provide distinctive summary travel patterns by geographical area and corridor.

2.4 Sound Transit Mode Choice Model Methodology

2.4.1 Model Structure

The ST mode-choice model structure, which is an incremental logit model, uses a pivot approach in the development of forecasts and uses the PSRC regional mode choice travel time and cost coefficients.

Incremental Logit Model

The incremental approach predicts changes in travel behavior based on existing travel behavior and changes in level of service. The incremental form of the logit model is derived from the standard logit formulation, which is[18]

(1) $$S_i = \frac{\exp(\mathrm{V_i})}{\mathrm{SUM_j}^{\mathrm{m}}\,[\exp(\mathrm{V_j})]}$$

where

$\mathrm{V_i}$ = utility of mode i in choice set m (j=1,2,3, .., i, ..m)
Contains measurable components of transportation systems such as travel time and cost as well as socio-economic attributes of trip makers.

$\mathrm{S_i}$ = share of using mode i

[18] Domenich, T., and D. McFadden, “Urban Travel Demand—A Behavioral Analysis,” North Holland, Amsterdam, 1975.

Ben-Akiva and Lerman indicate that "using elasticities is one way to predict changes due to modifications in the independent variables. For the linear-in-parameters multinomial logit model, there is a convenient form known as the incremental logit which can be used to predict changes in behavior on the basis of the existing choice probabilities of the alternatives and changes in variables." The incremental form of logit model is[19]

$$(2) \qquad S_i^f = \frac{S_i \text{ x } \exp(\text{DIFF } V_i)}{\text{SUM}_j{}^m \, [S_j \text{ x } \exp(\text{DIFF } V_j)]}$$

where

S_i	=	base-year observed probability of using mode i from choice set m
S_i^f	=	new share (i.e., forecast year) of using mode i (interzonal average)
DIFF V_i	=	change in utility of mode i (interzonal average)
	=	V_i^f - V_i = (DIFF CONST_i) + B_k x (DIFF $\text{VAR}_{i,k}$)

and

DIFF CONST_i	=	difference (future - base) in mode-specific constant for mode i,
B_k	=	coefficient for attribute k
DIFF $\text{VAR}_{i,k}$	=	difference in numeric variable VAR k of alternative i
f	=	variable with superscript "f" represents value in forecast year.

All transportation models, including the PSRC synthetic model, assume that the difference between the unmeasured attributes (e.g., comfort and image) between transportation systems in the base year and future years is negligible. As a result, the term representing the difference in mode-specific constants (i.e., DIFF CONST_i) falls out of the computations. The only terms remaining in Equation 2 pertain to those attributes (e.g., travel times and costs) for which a measured change might occur, as well as Equation 3:

$$(3) \qquad \text{DIFF } V_i = B_k \text{ x DIFF VAR}_{i,k}$$

The mode-specific constants in a synthetic model theoretically represent the effects of unmeasured attributes and often account for over half of the explanatory power in synthetic mode choice models. In practice, these constants are quite large and compensate for all types of errors in synthetic models, even network coding idiosyncrasies. They are used as overall adjustment factors to move the model results close to targeted regional totals. The constants typically range as high as 50 to 150 minutes of equivalent in-vehicle time. Without these constants, synthetic models cannot replicate the regional totals for a base year.

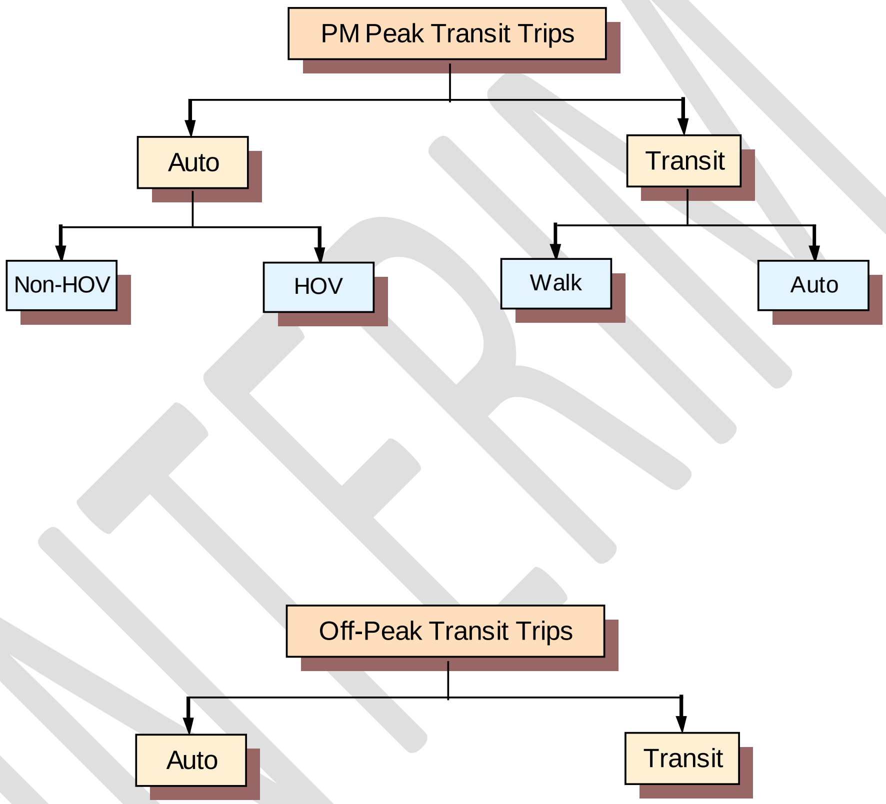
Nested Logit Model

According to the Independence from Irrelevant Alternatives (IIA) assumption, logit models require that all of the modes defined in the choice set m (for travelers) be independent of one another.

[19] Ben-Akiva, M. and S.R. Lerman, Discrete Choice Analysis Theory and Application to Travel Demand, The MIT Press, Cambridge, MA, 1985.

However, the IIA requirement is usually difficult to maintain in a simultaneous structure, such as the synthetic model used at the PSRC. In practice, a sequential (or nested) logit model that is less restrictive than the simultaneous form is often used. The nested logit model groups appropriate submodes under the primary modes (i.e., auto and transit), as shown in Figure 2-3. For the auto mode, the sub-choice is between single and multiple occupancy. For the transit mode, the sub-choice is between access to transit by walking or by automobile. Suggestions from the FTA on the appropriateness of nesting can be found in the FTA presentation by Jim Ryan at the January 2004 Transportation Research Board (TRB) Annual Meeting. [20]

Figure 2-3. Mode Choice and Modal Structure



The natural logarithm of the denominator of a logit model (Equation 1) is a single "inclusive" index I_m[21] indicating the desirability of the main mode m and taking into account the attributes of access modes. This index is often called "LogSum" and calculated from

(4) $$\mathrm{LogSum} = \mathrm{Ln}\,\{\mathrm{SUM}_j^m\,[\exp(V_j)]\}$$

where

V_j was defined before for Equation (1)

[20] Travel Forecasting for New Starts Projects, TRB 83rd Annual Meeting, Session 501, January 13, 2004.

[21] McFadden,E., A. Talvities and Associates, Demand Model Estimation and Validation, Urban Travel Demand Forecasting Project (UTDFP) Final Report Vol. V, University of California, Berkeley, CA, 1977.

McFadden[22] has identified the coefficients K for the LogSum variable as indices of similarity of the alternatives comprising the inclusive price.

For the transit lower level, the composite disutility of the sub-modes (walk- and auto-access) represents transit to the upper level choice. For transit mode t, the LogSum is

(5) $$\text{LogSum}^t = -\ln\left[\exp(V_{walk}) + \exp(V_{auto})\right]$$

where

V_{auto}	=	utility of the auto-access mode
V_{walk}	=	utility of the walk-access mode

The structure for PM peak period shown in Figure 2-3 is fully incremental[23] because it uses the incremental logit model at both the lower-level and upper level nests. The incremental form is highly desirable because it relies on observed data that describes current conditions, rather than using models to estimate these conditions.

Derivation of Changes in LogSum Variable

In a fully-incremental mode choice model, the changes in ridership between future and base-year conditions are calculated based on the incremental logit formulation (Equation 2) both at the primary level of hierarchy (i.e., auto vs. transit) and at the lower levels (i.e., auto occupancy and mode of access).

Because the incremental model requires the difference in the values of LogSum variable (i.e., DIFF LogSum^t for the mode of access), the underlying components of this difference need to be spelled out first within the context of standard logit formulation (Equation 1). The derivation process starts by using the definition of difference in the LogSum values and ends up with a simple formula consisting of the logarithmic summation of the exponential difference in the utility of each mode (i.e., future - base year) weighted by the respective base year observed share. The mathematical derivation is presented below.

Incremental change in LogSum^t of Equation 5 can be represented by

(6) $$\text{DIFF LogSum}^t = \ln\left[\exp(V^f_{walk}) + \exp(V^f_{auto})\right] - \ln\left[\exp(V^b_{walk}) + \exp(V^b_{auto})\right]$$

[22] Ibid

[23] Dehghani, Y. and R. Harvey, A Fully Incremental Model for Transit Forecasting: Seattle Experience, Transportation Research Board, Record # 1452, 1994.

Incremental change in LogSum for mode m (i.e., transit or auto), representing the upper-level of the nested logit structure, can be written as

$$\text{DIFF LogSum}^m = \ln\{\text{Sum}^{n}{}_{i}[\exp(V_i+\text{DIFF } V_i)]\}\text{-} \ln\{\text{Sum}^{n}{}_{i}\ [\exp(V_i)]\}$$

or

$$= 1\text{n}\left[\frac{\text{Sum}_i^n\ [\exp(V_i + \text{DIFF } V_i)]}{\text{Sum}_i^n\ [\exp(V_i)]}\right]$$

$$= 1\text{n}\left[\frac{\text{Sum}_i^n\ [\exp(V_i) \times \exp(\text{DIFF } V_i)]}{\text{Sum}_i^n\ [\exp(V_i)]}\right]$$

(7) $$= 1\text{n}\ [\text{Sum}_i^n\ (\text{Sum}_i\ \ \times \exp(\text{DIFF } V_i))]$$

where

DIFF LogSum^t	=	difference in LogSum term for transit mode t (future – base year)
V^f_{walk}, V^f_{auto}	=	the utility of walk and auto access modes in future
V^b_{walk}, V^b_{auto}	=	the utility of walk and auto access modes in the base year
DIFF LogSum^m	=	difference in LogSum term for mode m (e.g., auto or transit) in the upper level of the nested structure (future base year)
V_i	=	the utility of submode i (e.g., walk or drive access attributes) under nest n (e.g., transit)
S_i	=	base-year observed share of using submode (e.g., walk or drive access) under nest n
DIFF V_i	=	difference in the utility (e.g., travel time) of submode i under nest n (future - base year).

The coefficients of variables (e.g., travel time) included in the utility of a sub-mode i are equal to comparable mode-choice coefficients from the upper-level nest for the same variables (e.g., travel time), scaled by the corresponding LogSum coefficient (K^i).

Values for DIFF LogSum variables resulting from Equation 7 are used in the incremental logit formulation (Equation 2) to estimate new interzonal modal shares. Nesting coefficients vary between 0.0 and 1.0 and measure the degree of similarity and dissimilarity of a group of sub-modes from other modes in the upper-level nest. For example, a nesting coefficient of 1.0 on the transit nest of Figure 2-3 indicates that auto- and walk-access sub-modes are dissimilar (independent) from auto mode, implying that they should have been structured simultaneously instead of having a nested form. A conservative nesting coefficient of 0.50 is used in the ST model for the PM peak period.

2.4.2 Model Specification and Coefficients

As indicated in the previous section, since the mode-choice model structure is fully incremental, the mode-specific constants fall out of the computations. Therefore, it is not necessary to estimate values for modal constants. The model includes

- Travel time and cost variables in the utilities of the transit sub-modes, walk and drive access (e.g., in-vehicle, out-of-vehicle times, transit fares)
- Travel time and cost variables in the utilities of the auto occupancy sub-modes (e.g., parking and auto operating costs)

The auto travel cost is a composite variable and combines auto operating, parking, and auto ownership costs. This composite variable is divided by the ratio of zonal median income over the base-year regional median income and used in Stage 2 of the ST ridership forecasting analysis. Transit fares are also normalized similarly with respect to zonal median income and used in Stage 3 of the ST ridership forecasting analysis.

The reason for the normalization of the cost variable is to capture change in income and car ownership and their effect on transit ridership shares over time. The ST model uses travel time and cost coefficients similar to the PSRC mode choice models. The coefficients used in the ST model are

- -0.0253 for in-vehicle travel time (which falls within the FTA's acceptable range of -0.02 to -0.03)
- -0.0022 for travel cost (in 2000 dollars), implying a value of travel time of $6.90/hour (in 2000 dollars), which was about one-third of the average wage rate in 2000 in the Puget Sound Region
- A relative ratio of 2.0 for out-of-vehicle over in-vehicle transit travel times, which falls within the FTA's acceptable range of 2.0 to 3.0

2.4.3 Census Journey-to-Work Data

Base Mode Shares

Equation 2 highlights the importance of having a reasonable estimate of S_i (the existing shares for each alternative mode). The Census Journey-to-Work (JTW) information provides the base interzonal auto and transit shares required for the ST incremental mode choice model. In the 2012 update to the ST model, the 2010-2011 Washington Commute Trip Reduction Act (CTRA) surveys will provide the base interzonal auto and transit shares.

Summary tabulations of the daily auto and transit trips for 1980, 1990, and 2000 are presented in Table 2-1. As the summary model shares for 2000 indicate, changes between mode shares from 1990 to 2000 are relatively small.

Base mode shares are computed by aggregating shares to the 27 summary districts at the work ends only. Home end shares are calculated at the FAZ level. Calculating the shares at this level (i.e., 27-district-to-FAZ) preserves the variation in current mode-choice behavior and, therefore, the elasticities in the logit model.

**Table 2-1. Summary Share of Transportation Means Used by Workers—
1980, 1990 and 2000 Census Journey-to-Work Data Files**

Location (Home End)	Year	SOV	Carpool	Transit	Total
Snohomish County	1980	74.0%	22.9%	3.2%	100.0%
	1990	83.4%	13.2%	3.4%	100.0%
	2000	84.6%	11.7%	3.7%	100.0%
King County	1980	68.0%	19.5%	12.5%	100.0%
	1990	78.5%	12.3%	9.2%	100.0%
	2000	76.4%	12.9%	10.7%	100.0%
Pierce County	1980	77.6%	19.2%	3.2%	100.0%
	1990	83.5%	14.4%	2.1%	100.0%
	2000	83.2%	13.1%	3.7%	100.0%
Total	1980	70.6%	19.9%	9.5%	100.0%
	1990	80.4%	12.9%	6.7%	100.0%
	2000	79.5%	12.7%	7.8%	100.0%

The mode shares shown here take into account only the motorized modes. Non-motorized modes, such as walk and bicycle, have not been included. The "motorcycle" mode was included under the SOV mode, and the "ferry" mode was included under the transit mode.

2.4.4 Discussion of Staged Build-Up Analysis Application

The patronage forecasting procedures described in the previous sections are applied in three distinct stages. This application method explicitly recognizes a build-up approach to the ridership forecasts and encourages the analysis of intermediate results in the process as well as checking results for reasonableness. Specific contributions to changes in ridership at each stage are calculated and analyzed separately as they build on each other. The three stages are

- Overall growth in travel related to population and employment growth
- Changes in ridership related to changes in highway congestion and costs
- Changes in ridership related to transit service changes, including transit fares.

By applying forecasting analysis in stages, the method also ensures that only those changes that are important to the study question will be considered. For example, it is common in ridership forecasting (and preferred by the FTA) that only the change in transit service be carried into the future year analysis of transit alternatives. Therefore, all demographics, such as land use, trip distributions, as well as gas and parking prices, are effectively held constant when comparing transit alternatives.

Staging the forecasts in this way makes these consistencies transparent and reduces superfluous calculations. When only variations in the transit service are under consideration, Stage 3 is the only step needed to calculate each variation.

This method does not preclude varying inputs other than the transit service (i.e., for sensitivity testing) but allows such variation to be addressed simply and specifically rather than as a hidden piece of a very large model.

2.5 Base-Trip Table Development

The essential basis for incremental mode choice modeling analysis is the need to rely on actual transit travel patterns. Capturing existing travel patterns was achieved in the ST model by using available, pertinent data that provided a complementary balance between survey data and detailed route-level transit ridership information by direction and time-of-day for the base year. Chapter 3 includes a detailed discussion of the process used to develop base year (2004) peak and off-peak transit-trip tables.

2.6 Stage 1—Changes in Demographics

2.6.1 Formulation of Stage 1 Forecasting Analysis

The ST ridership forecasting analysis depends on PSRC model databases for the overall growth in travel demand. Growth estimates could either be derived from PSRC model trip distribution results or directly based on forecasts of demographics. The PSRC model is currently being refined and, until reasonable and stable trip distribution results become available and validated, travel growth will be derived from forecasts of households and employment. A summary tabulation of the demographic forecasts adopted by PSRC is presented in Table 2-2.

Growth in total households and employment between 2004 and a future year is calculated at FAZ-level and applied to the base year (2004) transit-trip tables. The results of the Stage 1 analysis are the estimated transit trips for a future year. The secondary impacts of growth on transit demand (i.e., increased highway congestion) are not yet accounted for at the end of Stage 1.

Table 2-2. Summary of PSRC Four-County Demographic Forecasts

Forecast Year	Total Employment	Households	Population
1970	740,000	630,000	1,939,000
1980	1,033,000	845,000	2,240,000
Percent Change from 1970	**40%**	**34%**	**16%**
1990	1,445,000	1,071,000	2,749,000
Percent Change from 1980	**40%**	**27%**	**23%**
2000	1,745,000	1,283,000	3,276,000
Percent Change from 1990	**21%**	**20%**	**19%**
2020	2,225,000	1,707,000	4,149,000
Percent Change from 2000	**28%**	**33%**	**27%**
2030	2,503,000	1,940,000	4,553,000
Percent Change from 2020	**12%**	**14%**	**10%**

2.7 Stage 2—Changes in Highway Congestion and Cost

2.7.1 Formulation of Stage 2 Forecasting Analysis

Stage 2 considers how changes in highway congestion, auto costs (including parking and auto ownership costs), and income will influence mode choice.

The ST patronage forecasts use the PSRC model to estimate highway travel times. These times are tabulated in the form of 219 x 219 FAZ-to-FAZ times for each highway network. A weighted averaging process is used to convert the more detailed PSRC TAZ-based travel times to FAZ-level travel times. When a transit alternative significantly affects the highway system (e.g., taking freeway lanes for transit facilities), additional analysis of future highway networks and congestion using the PSRC model is required.

In the Puget Sound region, transit fares and auto costs (except parking costs) are usually assumed to increase only at the rate of overall inflation; therefore, they are usually immaterial to the ST model. The ST model, however, includes these variables for use in sensitivity tests that are not directly part of project planning ridership forecasts.

Stage 2 transit trip forecasts are calculated using the following incremental logit equation:

(8) $$\mathrm{Stg2Trn} = \frac{\mathrm{Stg1Trn}}{\mathrm{S_t} + (1 - \mathrm{S_t} \times [\exp(\mathrm{K} \times \mathrm{DIFF\ LogSum_h})]}$$

where

Stg2Trn	=	Stage 2 transit trip forecasts
Stg1Trn	=	Stage 1 transit trip forecasts
S_t	=	the base year observed transit shares from census data
K	=	nesting coefficient on the auto nest
DIFF $LogSum_h$	=	Difference in the LogSum values due to changes in highway congestion and auto costs (future - base year). Data from the U.S. Census and CTRA surveys (for the baseline share), highway skims, and auto costs are used in Equation 8 to estimate the DIFF $LogSum_h$ on the auto side.

Stage 2 transit-share forecasts (Stg2Shr) are also calculated as follows:

(9) $$\mathrm{Stg2Shr} = \frac{\mathrm{Stg2Trn} \times \mathrm{S_t}}{\mathrm{Stg1Trn}}$$

Resulting from the Stage 2 analysis are the transit trips for a future year, having accounted for factors external to the transit service itself. These results then serve as a platform for analysis of ridership on alternative transit networks.

In most project planning ridership forecasting, Stages 1 and 2 need not be calculated as often as Stage 3. It is only when a transit alternative is presumed to have a strong effect on external factors, such as land use or the regional highway network, that the entire process would have to be cycled through. However, the FTA's published guidelines strongly discourage such cycling iterations in the models when evaluating transit investments, and favors evaluating those effects separately from the transit ridership calculations.

2.7.2 Representation of Conditions on the Highway/HOV Networks

The PSRC and the Washington DOT (WSDOT) maintain a number of coded highway networks that represent the highway system in the Puget Sound region at various points in time. Future highway networks represent the adopted highway and HOV improvement plans, including such changes as the likelihood of tolls on SR 520 Bridge, for future years. ST usually relies on a recent version of the PSRC model that has been used by the WSDOT for major capital projects, such as the SR 520 project or the I-5 tolling analysis project, after that version has been through a documented project level validation.

2.7.3 Estimation of Parking Costs

A conservative 1.5 percent annual (real) growth in parking costs is assumed in the ST model. This is a significant reduction from the 3-percent real growth that was previously assumed by ST and the PSRC. According to the limited historic information available, parking costs have averaged 1.6-percent growth since 1960.

2.7.4 Estimation of Other Costs and Median Income

Because auto operating costs in the Puget Sound region are usually assumed to increase only at the rate of overall inflation, they are less significant to ST models. Base-year (2004) and future auto operating costs are estimated at $.20 per mile (in 2004 dollars). Auto ownership cost is assumed to remain constant (in real terms) at about $2.00 per trip. When these costs are assumed to remain constant over time, the terms drop out of the incremental equation and they have no effect on the forecasts of future transit ridership, other than the effect related to any assumed real increase in regional income.

2.8 Stage 3—Changes in Transit Service

2.8.1 Formulation of Stage 3 Forecasting Analysis

In the third and final stage of the forecasting analysis, the incremental changes in the transit level of service, including transit fares, are considered. This change (as indicated in Section 2.4.1) is reflected in the resulting relative values of the LogSum^t variable using the base-year and future transit networks.

The Stage 3 transit shares and ridership forecasts are calculated as follows:

(10) $$\text{P}'\text{ac} = \frac{\text{P}_{\text{ac}} \times \text{LOS}_{\text{ac}}}{\text{P}_{\text{ac}} \times \text{LOS}_{\text{ac}} + (1 - \text{P}_{\text{ac}}) \times \text{LOS}_{\text{wlk}}}$$

and

(11) $$\text{Stg3Trn} = \frac{\text{Stg2Trn} \times [\exp(\text{K} \times \text{DIFF LogSum}_{\text{t}})]}{\text{Stg2Shr} \times [\exp(\text{K} \times \text{DIFF LogSum}_{\text{t}})] + [1 - \text{Stg2Shr}]}$$

where

LOS_{ac}	=	Difference in (future - base year) utility of the park-and-ride access submode
LOS_{wlk}	=	Difference in (future - base year) utility of the walk-access submode
$\text{P}'\text{ac}$	=	Forecasted Stage 3 shares for the auto-access mode
P_{ac}	=	Base-year observed shares for the auto-access mode, derived from the base-trip table development process reflecting actual counts on park-and-ride facilities.
$\text{DIFF LogSum}_{\text{t}}$	=	Difference in the LogSum values due to changes in transit level-of service (future - base year)

Actual transit service that is taken into consideration in the ST model Stage 3 forecasting analysis is represented by means of a "coded network." Specific details on transit network preparation are included in Appendix C. Treatment of bus speed in the ST model is based on the degradation of roadway congestion, estimated by the PSRC multi-modal model in a manner developed in consultation with the FTA.[24]

2.8.2 Transit Fares

Any changes in transit fares are considered in Stage 3 of the ST model, along with changes in transit service. Transit fare matrices were developed for the ST model, and were assumed to be (a) the zone-to-zone averages in effect in 2004 (for the base year) and in late 2010 (for all future years), and (b) independent of transit path choices.

Independence from path choice is a reasonable approach to fares with the RTA District. Upon the introduction of the Orca smart card as the primary fare medium for all transit operators in the District, zonal fares are more appropriate than path-based fares. For most trips within the District path choice and transfers have become less relevant due to the very high market penetration of the regional employer pass programs and to the logic used in assigning cash value to trips involving more than one vehicle.

[24] Don Billen, Sound Transit, "Updated Treatment of Bus Speeds in the Sound Transit Model," Memorandum to Eric Pihl of FTA, dated August 1, 2002.

3. VALIDATION

Before a model can be used for analysis, it must be validated. The purpose of validation is to compare the performance of the model to the most recent observed data sources available in order to confirm that the model is accurately replicating current transit travel patterns and transportation system performance.

In project planning, travel forecasting models are expected to predict changes in travel patterns caused by

- General changes, such as population, employment, and economic changes, between the base year and the forecast year
- Specific changes introduced by each alternative

Consequently, the best validation tests are those that test the ability of the forecasting methods to accurately capture response to changes in population and employment levels, parking and gasoline prices, transit fares and service levels, as well as other conditions.

The incremental approach, which is used in the ST model, generally reduces the need for validation because it uses the observed data that typically would be used in validation as its base. However, it is still useful to check the overall performance of the forecasting against current known conditions.

This chapter is organized into two sections. The first section describes the overall analysis process for creating the 2004 PM peak and off-peak transit-trip tables, while the second section presents validation analysis results.

3.1 Base Year (2004) Transit Trip Table Development

A centerpiece of the ST incremental model is its reliance on "observed" transit travel patterns, as determined through transit ridership data, to create base year (2004) PM peak and off-peak transit-trip tables. The ridership data used to develop transit-trip tables includes the following:

- **2004 Passenger Load Data**—During the winter of 2004 (October 2003 to February 2004), King County Metro and ST collected detailed passenger load data on their bus routes using APC technology and hand-collected counts. These data include average weekday passenger loads by route segment, direction, and time of day, which provided the necessary information to establish ridership profiles along each route by time of day.
- **2004 Sound Transit On-Board Survey**—Between September 2003 and May 2004, ST conducted an extensive on-board survey of all of its transit services over a 9-month period.
- **2004 Boarding Counts**—Route-level total boardings were obtained from all transit agencies.
- **1992 On-Board Transit Surveys**—In 1992, transit agencies in the Puget Sound region conducted six on-board transit surveys that provided the required data to develop the base-year (1992) transit-trip tables for the earlier versions of the ST model.[25]
- **Other Counts and Survey Data**—Supplementary counts data from transit operators and from the NTD provided control totals for development of the 2004 base transit trips. Other survey data included a special survey of SR 520 riders in 2005 and the 2000 U.S. Census JTW data.

[25] Transit Ridership Forecasting Technical Report, Central Link Light Rail Transit Project (North Link), Sound Transit, November 2003.

Although on-board transit surveys provide the most accurate origin-destination data, it is extremely difficult and costly, if not impossible, for transit agencies to establish "observed" transit travel patterns solely from survey data. A typical on-board transit survey collects origin and destination data for only 30 to 35 percent of riders. Furthermore, survey experience indicates that surveys include strong sample biases that cannot easily be corrected. These sample biases would compromise the accuracy of base-trip tables, should they be based solely on survey responses. Because of these shortcomings, an alternative approach to building base-year trip tables was developed using ridership count data, as well as survey data.

The survey data was primarily used to establish a "seed" transit-trip table embodying representative cells (i.e., zone interchanges) in the matrices, thus ensuring that important transit markets were represented in the base-trip tables. This process also included an analysis of the survey data in order to replicate the average trip length frequency distribution exhibited in a transit-trip table produced by the PSRC model. This particular analysis assisted in further expansion of the open cells in the final seed matrix.

Passenger load profiles from the APC database and other counts provided segment level counts by direction and time period on each route. The frequency of segment-load points required for a given route in the trip development process depended on the variability of load profile for that route. For example, a route that experiences fairly uniform passenger loads throughout its trip did not require more than two or three locations for seeding directional passenger count volumes. Other routes, with more variability in passenger loads, require seeding of counts at more than three locations. About 1,700 passenger volumes were hand-coded into the 2004 database for matrix estimation, representing over 25 percent of the route segments or time point intervals (TPI).

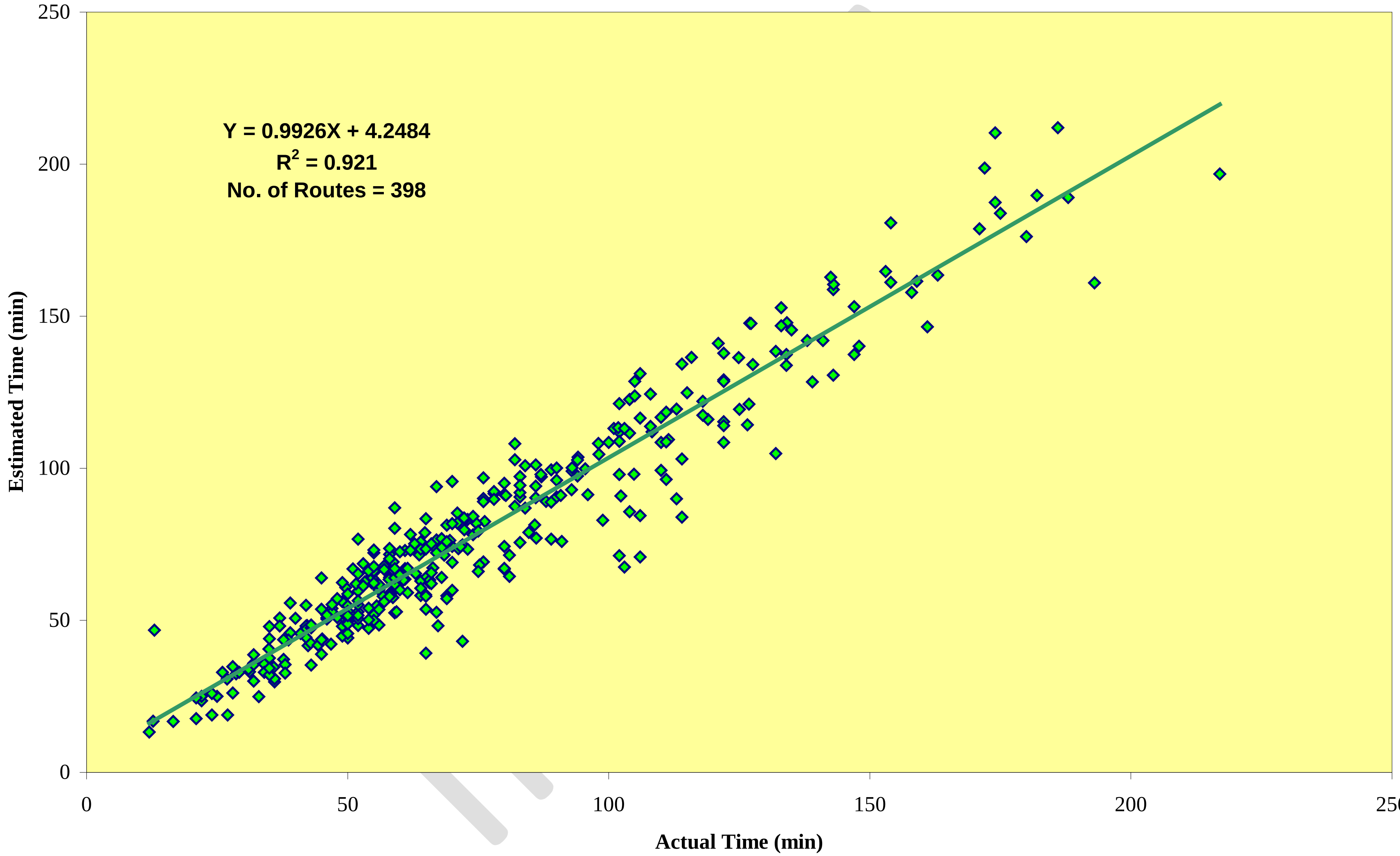
The base-trip-table development process relied on a validated base transit network as well as supplementary ridership count data, control totals, and actual average trip length measures. This process involved pursuit of a rigorous validation analysis, the results of which are discussed below.

Transit Network Preparation

The preparation of the base-year transit network was an important and significant part of the overall development of the base-year trip table. The accuracy of the resulting base-trip tables depended directly on the validity and quality of the base transit network, as well as ridership counts. Therefore, the base-year (2004) transit network was prepared and validated to accurately reflect transit service levels, as published in February 2004, as well as actual travel times by time-of-day. The travel times for each TPI were modified according to the AVL data for all routes operating within King County, on-time performance reports for routes in the other two counties, as well as on-time performance data for Tacoma Link and Sounder commuter trains.

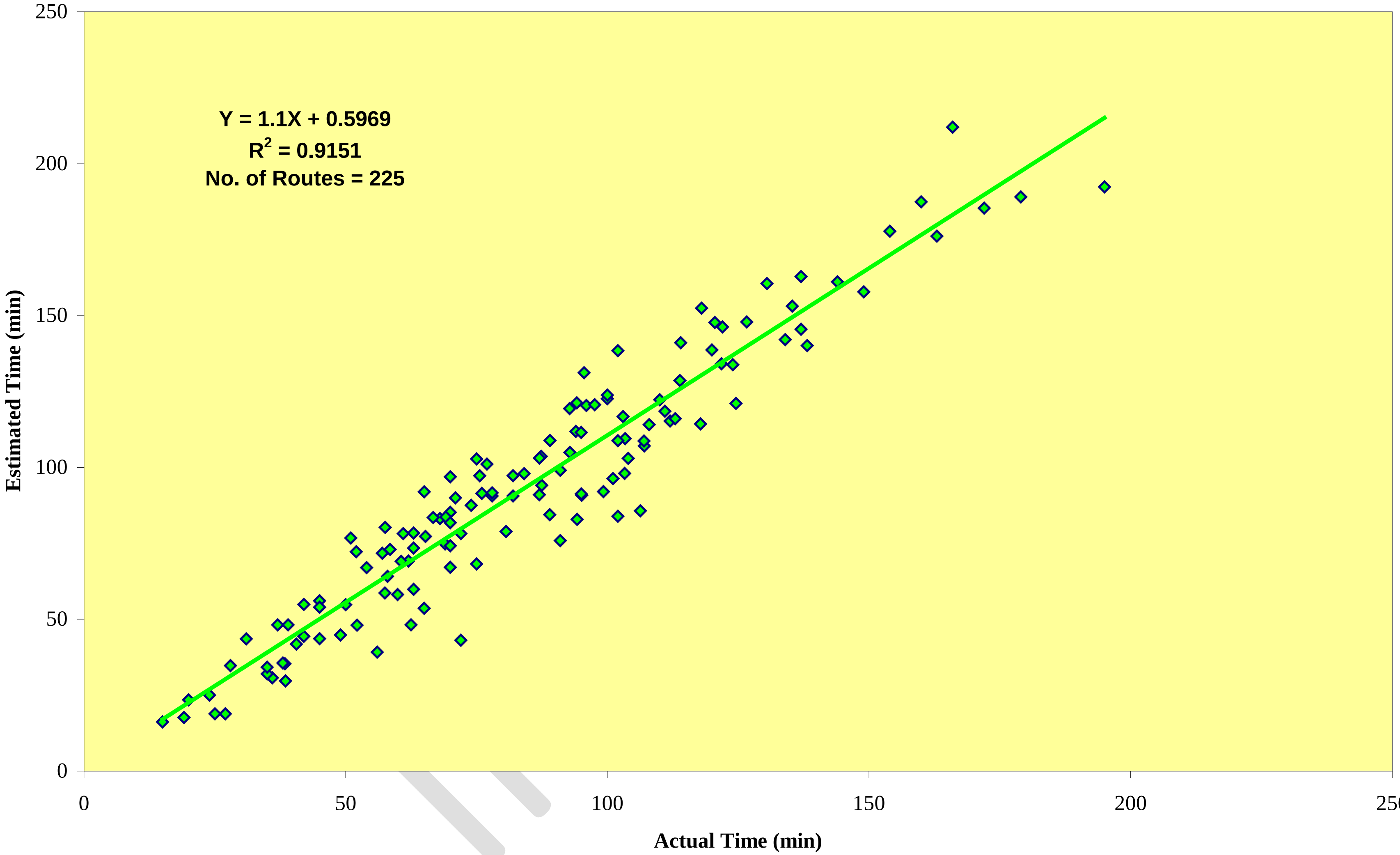
The resulting 2004 transit network operating parameters were compared against revenue hours, miles, and miles per hour in the NTD and were found to be within 5 percent on all measures. More significantly, as shown in Figure 3-1 and Figure 3-2, the estimated line times for the 2004 PM peak and off-peak transit networks at the individual route level were very similar to actual line times. Figure 3-1 and Figure 3-2 show the route-level dispersion between modeled and actual transit travel times around a simple regression line. The resulting statistics (R-square over 0.91 and the regression line parameter close to one) indicate a well-calibrated transit network that is capable of reflecting service levels accurately.

Figure 3-1. Comparison of 2004 PM Peak Actual vs. Estimated Line Times for All Agencies



[1] Actual times were available for most KCM Routes. Otherwise, scheduled times were used for comparitive analysis

Figure 3-2. Comparison of 2004 Off-Peak Actual vs. Estimated Line Times for All Agencies



[1] Actual times were available for most KCM Routes. Otherwise, scheduled times were used for comparitive analysis

Validation of Transit Service Reliability

The current ST model relies on actual transit vehicle speeds to more realistically represent transit service reliability. Although the long-term decline in bus operating speeds has been measured for the past 40 years, it has not been easy to measure the accompanying decline in service reliability until recently. However, Metro's AVL data now give complete information on actual bus times and bus schedule adherence. According to a recent analysis performed using AVL data, a rider must plan on a 9.2-minute delay for bus services. This corresponds to a 1.5-minute delay planning requirement for rail services.[26]

ST models have been using a boarding penalty to account for uncertainties related to using the transit system, including uncertainties about transferring between vehicles. Recent research on the perceptions of transit users has clarified that schedule adherence and transit stop attributes concerning personal safety are more important to the use of transit than are other station amenities.[27] Consequently, boarding penalties are reduced at stations with documented schedule adherence superiority and at transit centers and stations with positive security attributes (e.g., improved lighting and communication, 20-hour security patrols, fare-controlled platforms, and on-board fare inspectors).

Table 3-1 presents the model's boarding penalties, including wait time factors and time penalties that are assumed on escalator links. Note that in the ST model, walk and wait time resulting from a transfer is accounted for separately, including pedestrian and escalator links at rail stations, and all out-of-vehicle time is factored by 2.0.

Validation results using the boarding penalties indicated in Table 3-1 netted a much closer match to observed transfer behavior. These improvements occurred at the system level, the route level, and at transit center locations.

According to the prior model, 90 percent of commuter rail riders were estimated to arrive at King Street Station by bus. Consequently, the assignment of transfers between the downtown commuter rail station and the downtown bus tunnel were of particular concern. ST surveys have shown that only 43 percent of PM peak commuter rail riders arrive via downtown bus transfers, whereas approximately 50 percent access the King Street Station by walking. Although the current model's estimate of 60 percent arrival by bus is still somewhat high, it is much closer to the observed access pattern.

The current ST model also more accurately replicated the 2004 three-county transfer rate compared to the earlier ST model versions. For the 2012-base model update, new information on transfers will be available in 2012, both from the Fall 2011 surveys and from new data which can be derived from the Orca smart card fare payment database.

Ridership Counts Data Preparation

The King County Metro APC database was the primary source of actual (or "observed") ridership data. A comprehensive GIS database has been created at King County Metro to maintain and analyze the historical ridership data recorded by APC machines. The raw database included 24-hour count by TPI segments by direction, corresponding to an average weekday in spring 2004 for all King County Metro routes and ST buses operating in King County. Segment count data were

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[26] Billen, D., "Application of Transit to LOS Measures in the Seattle North Link Light Rail Corridor," 10th TRB—Transportation Planning Applications Conference, Portland, OR, 2005.

[27] Iseki, H. and Taylor, B., "Style vs. Service? An Analysis of User Perceptions of Transit Stops and Stations," *Journal of Public Transportation*, Center for Transportation Research, Vol. 13, No. 3, 2010.

extracted from the APC database for the 3-hour PM peak period (3:00 to 6:00 PM) and 18 hours representing off-peak hours outside the two AM and PM peak periods. In addition to TPI segment count, route-level boarding counts data were also obtained from each transit agency. From these data, the "optimal" TPI segment locations were identified so that an accurate load profile could be replicated on each route and by time of day.

Table 3-1. Boarding Penalty, Wait Time Factor, and Escalator Link Assumptions in the 2004 ST Model

	PM Peak	Off Peak
Regular Bus Stops		
Boarding Penalty	5.0 min	4.0 min
Wait Time Factor	0.60	0.60
Escalator Link	NA	NA
Transit Centers[1]		
Boarding Penalty	3.0 min	3.0 min
Wait Time Factor	0.50	0.50
Escalator Link	NA	NA
Downtown Bus Tunnel		
Boarding Penalty	3.0 min	3.0 min
Wait Time Factor	0.50	0.50
Escalator Link	1.0 min	1.0 min
Rail Stations (surface)		
Boarding Penalty	2.0 min	2.0 min
Wait Time Factor	0.50	0.50
Escalator Link	0.5 min	0.5 min
Rail Stations (tunnel or elevated)		
Boarding Penalty	2.0 min	2.0 min
Wait Time Factor	0.50	0.50
Escalator Link	1.0 min	1.0 min

[1] List of Transit Centers:
1) Bellevue Transit Center
2) Federal Way Transit Center
3) Northgate Transit Center
4) Burien Transit Center
5) Kent Transit Center
6) Auburn Transit Center
7) Kirkland Transit Center
8) Overlake Transit Center
9) Aurora Village Transit Center
10) Renton Transit Center
11) Lynnwood Transit Center
12) Tacoma Dome
13) Lakewood Transit Center
14) Everett Station
15) Tacoma Community College

Note: In both the path-building and the mode choice applications, all of these out-of-vehicle times are multiplied by 2.0.

Matrix Adjustment Process

A trip matrix adjustment methodology developed by Heinz Spiess[28] was used to assist in development of the base year (2004) PM peak and off-peak transit-trip tables. This methodology, which has been used extensively, minimizes the difference between estimated and "observed" volumes seeded at designated segment-load locations for each route. While this methodology achieves a close match of estimated to actual segment loads, additional refinements were necessary to improve accuracy in the resulting transit-trip tables. These refinements included

- New seed matrices were developed to capture sufficient non-zero cells, increasing these from 3 percent in previous model versions to 17 percent.
- An extensive set of segment-based counts data were used to accurately replicate the load profile on each transit route by time-of-day. This was achieved from an extensive iterative process and resulted in the identification of about 1,700 optimal segment load locations. This constituted about 25 percent of the total TPI segments in the APC database.

Conditions outlined above were complemented by an extensive and rigorous validation analysis effort. The validation analysis results for base-year (2004) transit trip development are discussed below.

3.2 Base-Year (2004) Validation Analysis Results

The validation analysis focused on evaluating (1) the updated transit-trip tables from the matrix adjustment process and (2) the accuracy of the assignment results, which is reflected in

- System-wide boardings and transfer rate
- Boardings comparison for Commuter Rail and Regional Express Bus routes
- Trip length frequency distribution of trip tables
- Route-level boardings
- Route-segment volumes by direction and by peak and off-peak periods
- PM peak and daily volumes comparison at selected screenlines

Table 3-2 presents system-wide linked and unlinked transit trips, including a comparison of daily boarding estimates to respective actual boardings. As shown in Table 3-2, the number of estimated versus actual trips is close, reflecting the breadth and quality of the underlying network and ridership counts data used in the trip table development process. The total estimated PM peak transit trips was 90,000, which is about 28 percent of the total 324,600 daily transit trips. Daily transit boarding results closely match those reported in the National Transit Database (NTD). The system-wide daily boardings reflect an overall transfer rate of 1.25. The validation analysis also closely replicated actual boardings on Commuter Rail and Regional Express Bus routes, as shown in Table 3-3.

[28] Spiess, H., "A Gradient Approach for the O-D Matrix Adjustment Problem," Formerly with INRO (EMME/2 Support Center), Haldenstrassee 16, CH-2558 Aegerten, Switzerland.

Table 3-2. System-Wide 2004 Linked and Unlinked Transit Trip Summaries

	PM Peak[1] Estimated	Off-Peak[2] Estimated	Daily[3]		
			Actual[4]	Estimated[5]	Est/Act
Linked transit trips	90,000	144,600	N/A	324,600	N/A
Total Boardings by Operator					
King County Metro	81,700	144,500	308,000	307,900	1.00
Sound Transit	11,200	13,600	33,000	36,000	1.09
Pierce Transit	7,700	16,000	35,000	31,400	0.90
Community Transit	8,800	7,700	26,000	25,300	0.97
Everett Transit	1,400	2,800	6,000	5,600	0.93
Three-County Total Boardings	**110,800**	**184,600**	**408,000**	**406,200**	**1.00**
Systemwide Transfer Rate	**1.23**	**1.28**	**N/A**	**1.25**	**N/A**

[1]PM peak period represents 3 hours between 3 and 6 PM.
[2]Off-peak period represents 18 hours outside 6 to 9 AM and 3 to 6 PM peak periods.
[3]Daily linked and unlinked transit trips were calculated based on PM peak times two plus off-peak values.
[4]Actual boardings were obtained from the National Transit Database and supplemented by available data from transit agencies.
[5]Estimated transit trips in the ST model reflect transit markets only within the ST boundaries that are smaller than the three-county total boundaries.

Table 3-3. Rail and Regional Bus Line Boarding Comparisons

	Actual	Estimated	Est/Act
Commuter Rail—South	3,800	3,600	0.95
Commuter Rail—North	300	230	0.77
Tacoma Link Light Rail	2,700	1,980	0.73
ST Everett-Seattle Express	3,510	3,120	0.89
ST Bothell-Seattle Express	1,940	1,900	0.98
ST Bellevue-Seattle Express	5,170	5,150	1.00
ST Pierce-Seattle Express	4,770	4,900	1.03

Figure 3-3 shows a similarity in the trip length frequency distributions between the two matrices in spite of the overall average trip length being reduced by about 1.6 miles, or 15 percent. Average trip length estimates produced for routes operated by each transit agency compared closely to their actual counterpart values as shown in Table 3-4. Trip lengths in the ST model for community transit are always shorter in the ST model because the CT service area and routes extend far beyond the ST district boundary and model area.

Figure 3-3. Travel Frequency Distribution for 2004

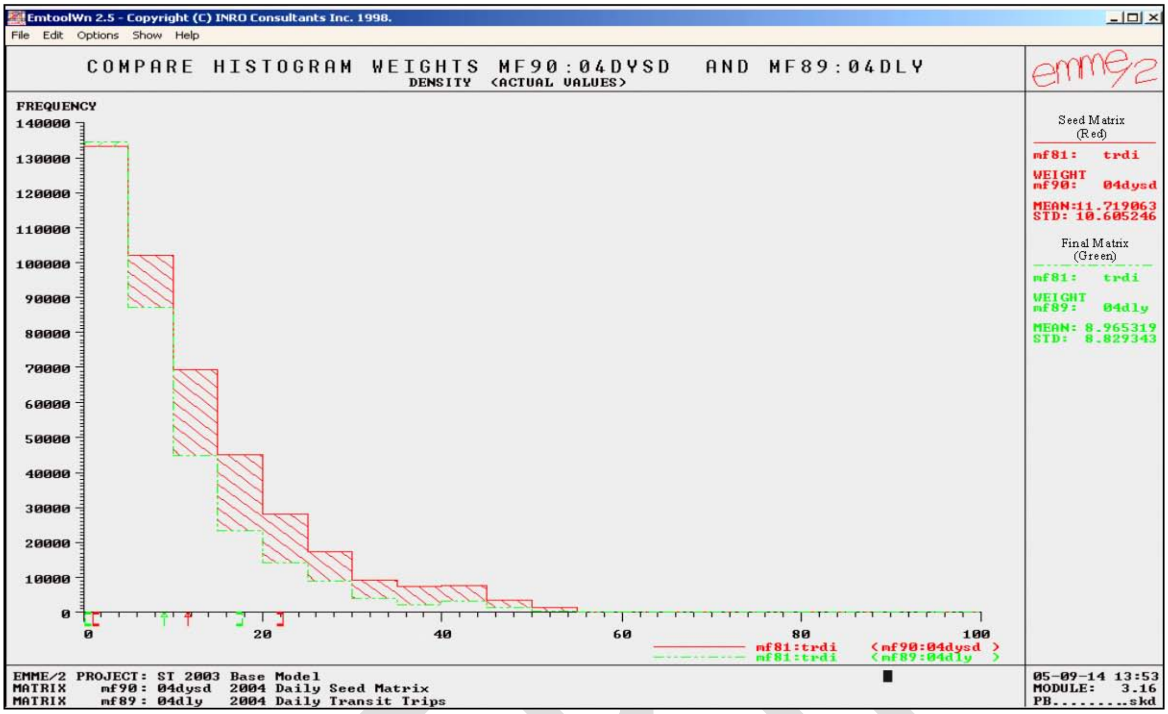


Table 3-4. Average Trip Length Comparison for 2004

Transit Operator	Actual	Estimated	Est/Obs
King County Metro	5.0	4.5	0.90
Pierce Transit	7.2	7.3	1.01
Community Transit[1]	12.0	10.0	0.83

[1]Note that Community Transit service area extends beyond the RTA area.

A route-level comparison of PM peak boardings for KCM and ST routes is shown in Figure 3-4, while Figure 3-5 shows a similar comparison for daily boardings including routes operated by all transit agencies. These results indicate a close match at the route level for both PM peak and daily boardings as exhibited in slope and R-squared statistics for goodness-of-fit. These measures came close to 1.0 for boardings on 281 PM peak routes and 398 off-peak routes, shown in Figure 3-4 and Figure 3-5, respectively.

To evaluate the matrix adjustment process, a comparative analysis of load volumes at "optimal" segment locations as well as an analysis of trip length frequency distributions between the seed matrix and final daily transit-trip tables were performed. Figure 3-6 and Figure 3-7 highlight the close match of estimated to actual loads at segment locations for 2004 PM peak direction and off-peak transit trips.

Transit volumes estimated from the transit assignment process are compared with actual transit passenger volumes in Table 3-5 at selected screenlines. Estimated PM peak and daily passenger volumes are within 10 percentage points of actual volumes at the screenlines shown in Figure 3-8.

Figure 3-4. Comparison of 2004 PM Peak Period Actual vs. Estimated Route-Level Boardings for KC Metro and ST

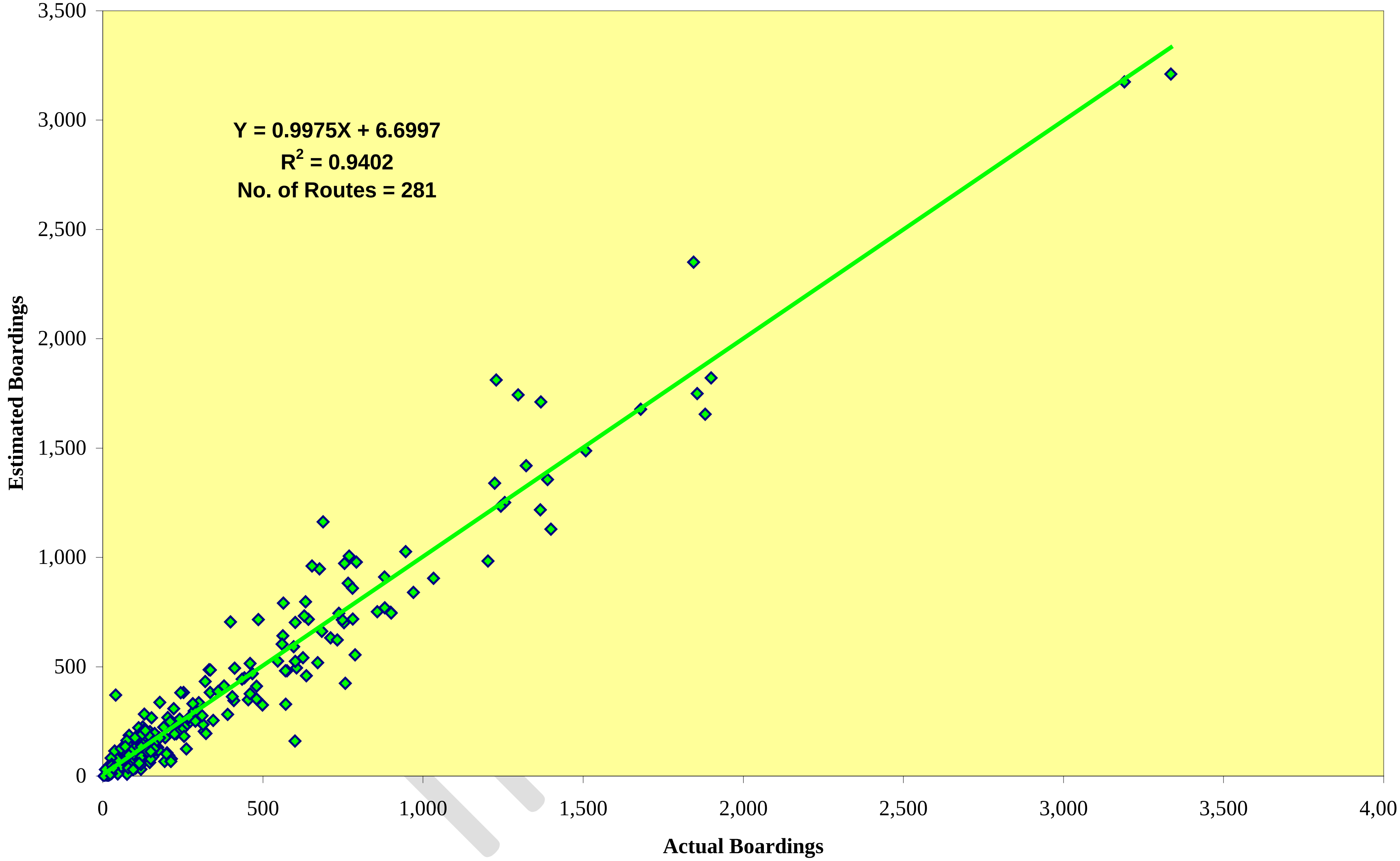


Figure 3-5. Comparison of 2004 Daily Actual vs. Estimated Route-Level Boardings for All Transit Agencies

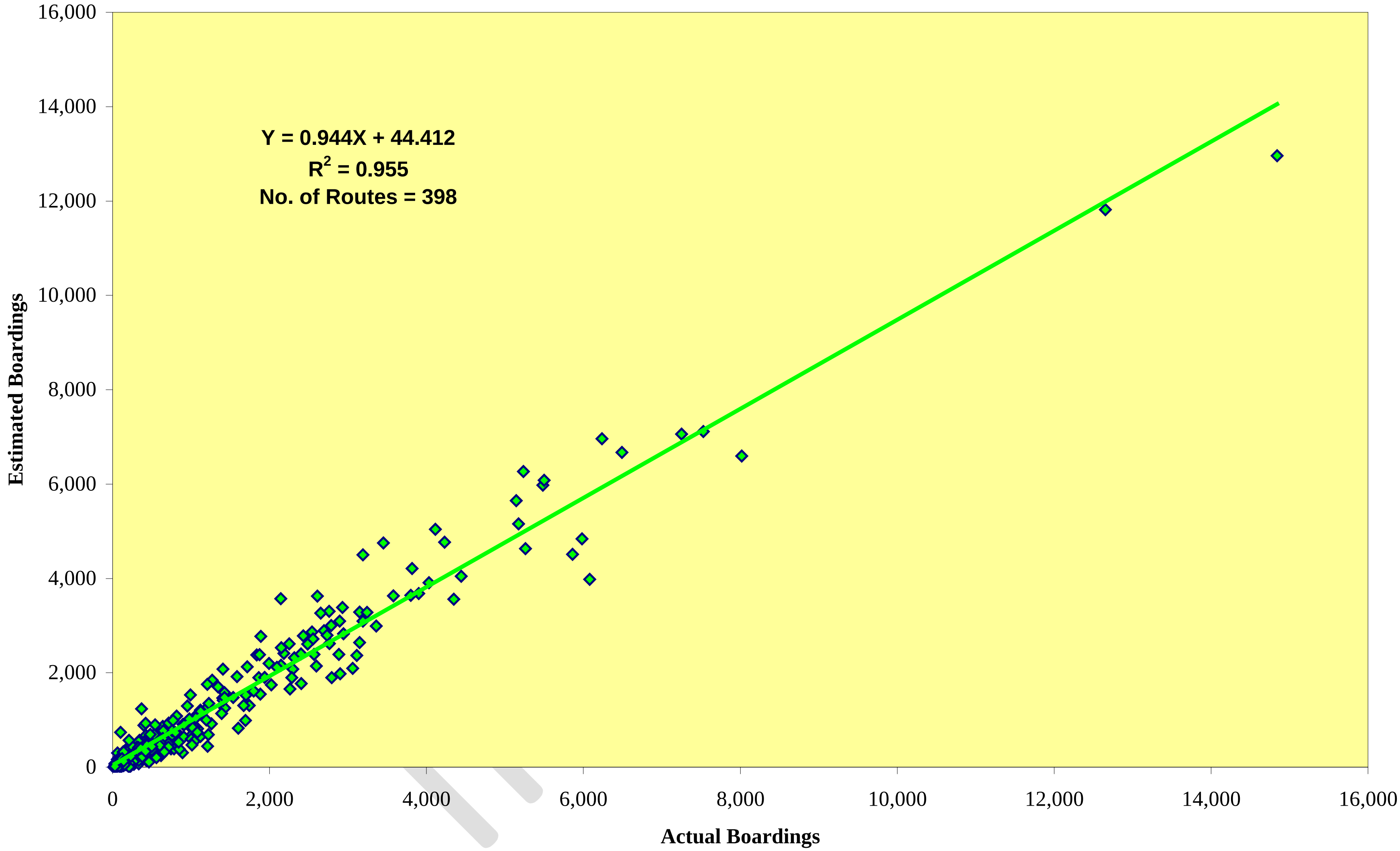


Figure 3-6. Comparison of 2004 PM Peak (Peak-Direction) Actual vs. Estimated Segment Loads for All Transit Agencies

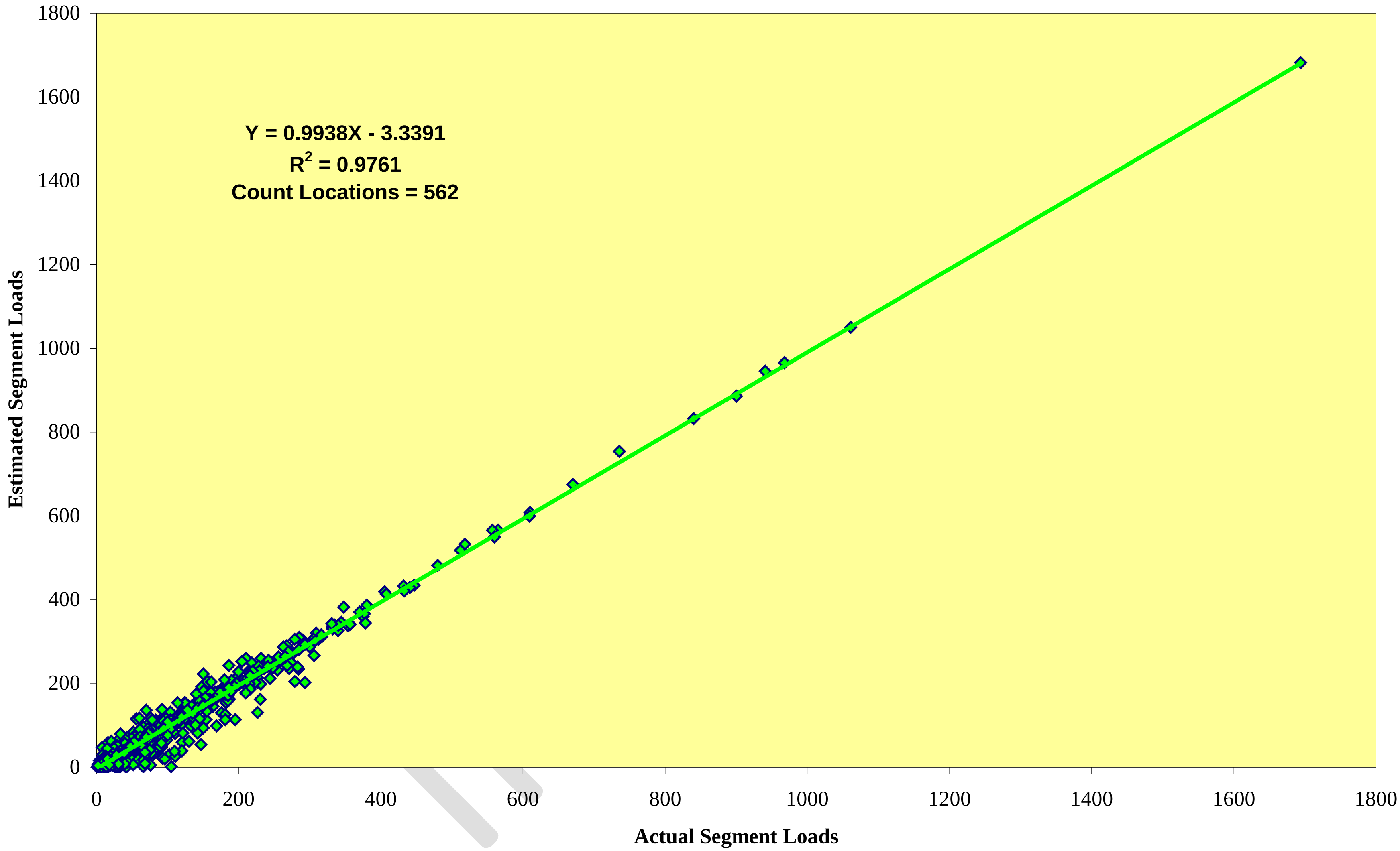


Figure 3-7. Comparison of 2004 Off-Peak (Both Directions) Actual vs. Estimated Segment Loads for All Transit Agencies

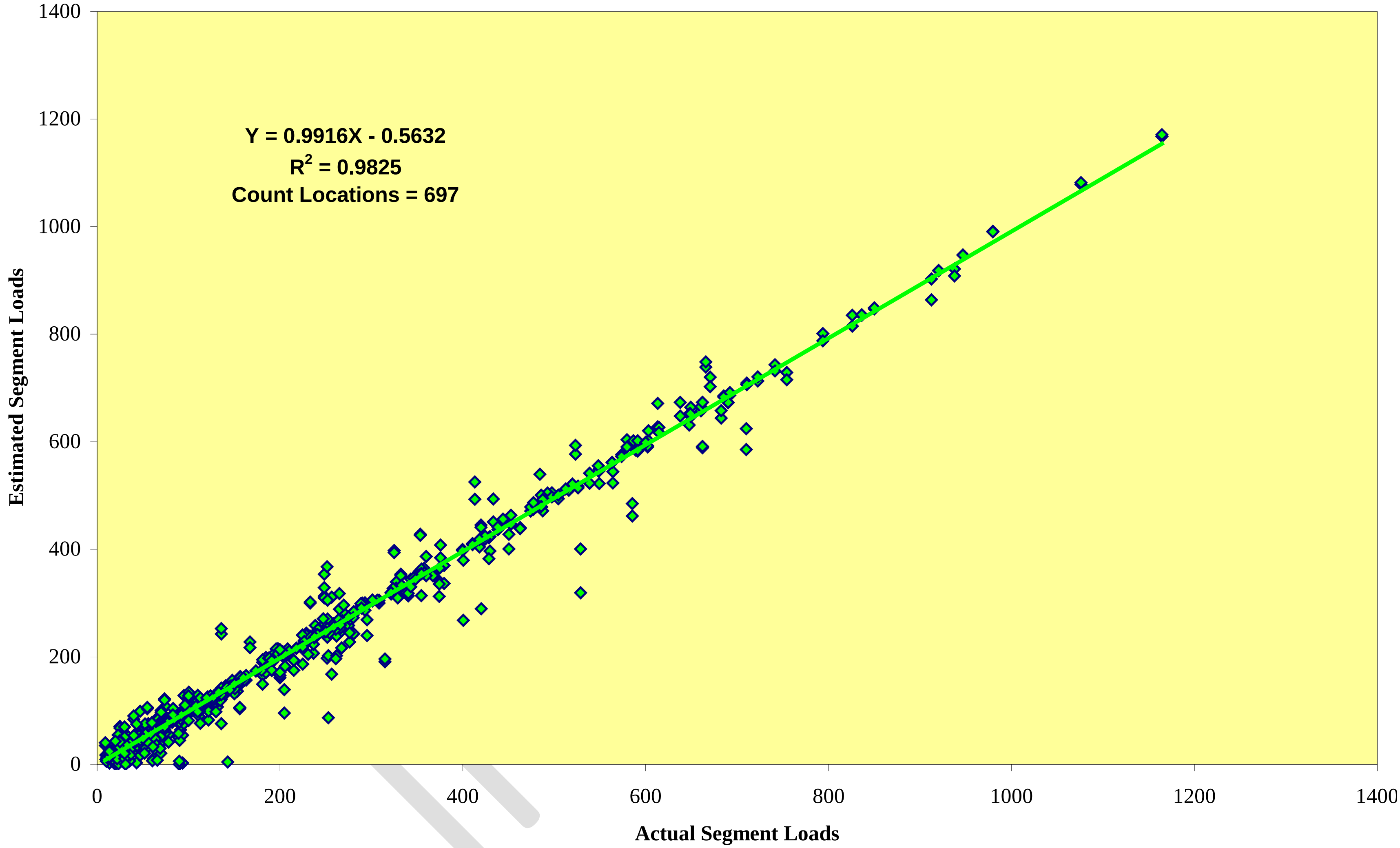
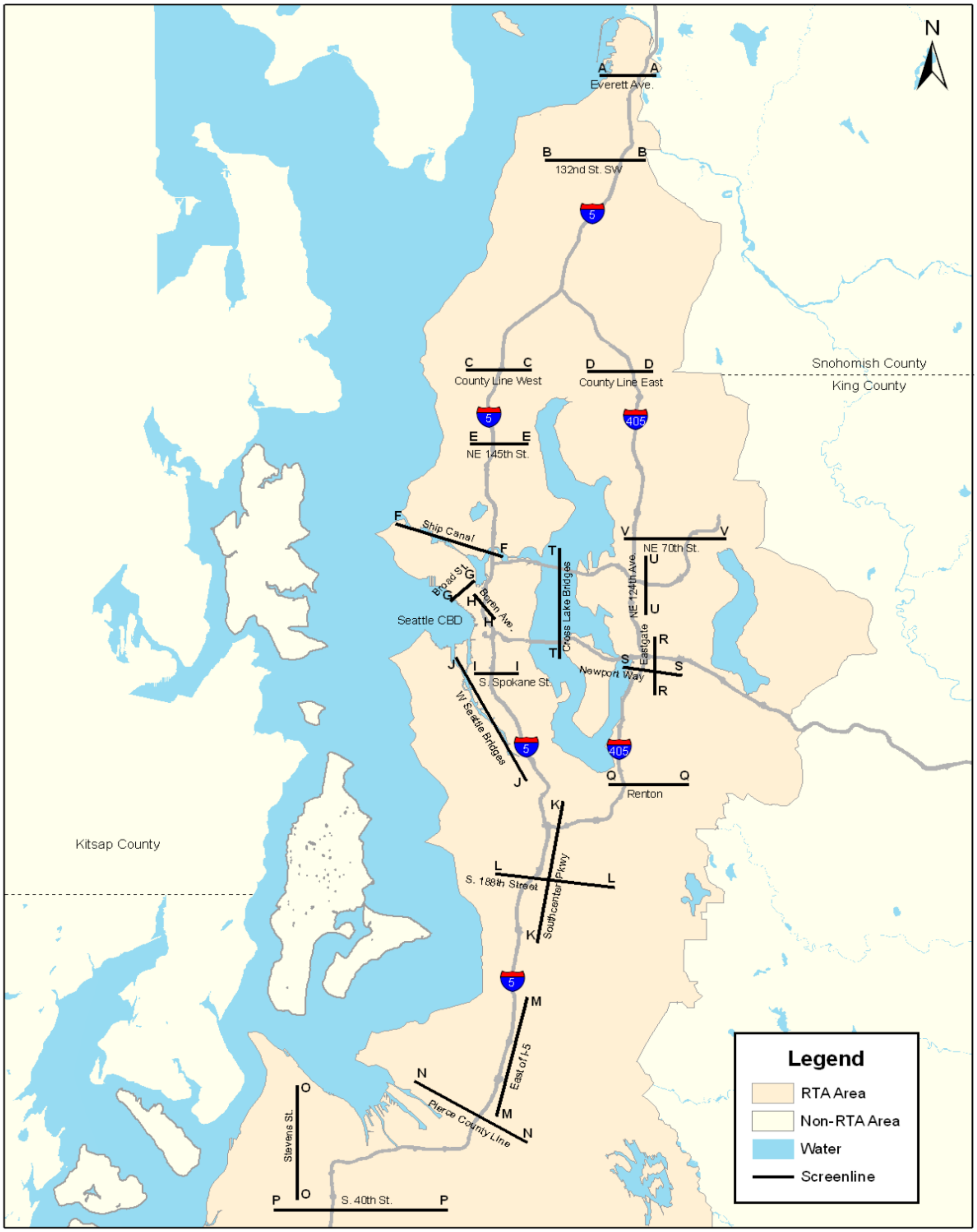


Table 3-5. Comparison of PM Peak and Daily Transit Volumes at Selected Screenlines—Base Year (2004) ST Model Validation Results

		PM Peak			Daily		
	Screenline	Actual	Estimated	Est/Act	Actual	Estimated	Est/Act
A	Downtown Everett, Everett Avenue	910	760	0.84	2,830	2,550	0.90
B	Snohomish County, 132nd Street SW	2,410	2,280	0.95	6,940	6,660	0.96
C	Snohomish County Line West	6,360	5,940	0.93	17,610	16,920	0.96
D	Snohomish County Line East	660	630	0.95	1,640	1,640	1.00
E	North Seattle, NE 145th Street	8,790	8,930	1.02	26,290	26,540	1.01
F	Ship Canal Bridges	19,630	21,090	1.07	65,240	66,840	1.02
G	Downtown Seattle, Broad Street	8,570	8,000	0.93	32,640	31,340	0.96
H	Downtown Seattle, Boren Avenue	20,070	22,010	1.10	75,570	76,950	1.02
I	South Seattle, S Spokane Street	14,610	14,640	1.00	47,890	48,610	1.02
J	West Seattle Bridges	5,190	5,370	1.03	20,520	21,840	1.06
K	Southcenter Parkway	880	890	1.01	2,970	3,060	1.03
L	South King County, S. 188th Street	7,300	7,490	1.03	20,460	20,220	0.99
M	Federal Way, East of I-5	390	480	1.23	1,640	1,900	1.16
N	Pierce County Line	3,370	3,230	0.96	9,000	8,690	0.97
O	Tacoma, Stevens Street	1,220	1,120	0.92	4,660	4,350	0.93
P	Tacoma, S. 40th Street	1,950	2,170	1.11	7,060	7,310	1.04
Q	Renton	2,400	2,270	0.95	7,410	6,900	0.93
R	Eastside, Eastgate	1,700	1,580	0.93	5,010	4,560	0.91
S	Eastside, Newport Way	1,040	890	0.86	3,070	2,610	0.85
T	Cross Lake Bridges	7,060	6,770	0.96	19,910	19,200	0.96
U	Eastside, NE 124th Avenue	2,270	2,430	1.07	7,790	7,900	1.01
V	Eastside, NE 70th Street	2,880	2,920	1.01	8,370	8,320	0.99

Figure 3-8. Transit Screenlines Location Map



4. PRIMARY ASSUMPTIONS AND BUILD-UP FORECASTING ANALYSIS RESULTS

This chapter discusses the specific input data and assumptions used to perform staged forecasting analysis to support the ST North Corridor Transit Project. It is divided into two parts. First, the underlying data and assumptions used in the modeling process are presented. Second, the interim (Stages 1 and 2) forecasting analysis results for 2030 are presented.

4.1 Key Input Data Assumptions

Year 2030 staged forecasting analysis was developed from the validated 2004 transit-trip tables. These forecasts include the effects of

- Population and employment growth and the transportation and transit projects included in the PSRC's Metropolitan Transportation Plan.
- Highway congestion forecasts based on available PSRC model databases.
- Transit service levels assumed for the North Corridor Transit Project—this effort is in progress and will be documented in the subsequent version of this report in 2011, including Stage 3 ridership forecasts.

Note that the staged forecasting analysis was also tested for 2010 taking into consideration the recent economic downturn. Results were reasonable in light of maturing patronage on the central light rail line. The specific assumptions and input data used to produce 2030-staged interim ridership forecasts are described in the following sections.

4.1.1 Demographic Forecasts

The Stage 1 2030 ridership forecasts[29] were produced using regional land use forecasts available from PSRC.[30] Table 4-1 shows district-level 2004 and 2030 land use forecasts. Figure 4-1 shows a map of district boundaries. FAZ-level 2004 and 2030 total households, population, and employment forecasts are shown in Table D-1 in Appendix D. The growth rates between 2004 and 2030 in regional total households, population, and employment forecasts (shown in Table 4-1) are 1.44, 1.33, and 1.41, respectively. These translate into annual compounded average growth rates of 1.41, 1.10, and 1.33 percent.

4.1.2 Special Generators

Major special events venues and major airports are considered special generators within travel models which do not adequately capture their trip ends by the normal model inputs.

There are three major sports stadiums in Seattle with capacities of 47,000 to 70,000 that could generate significant volumes of transit trips associated with events. For the 2004 base transit trip table development, a significant portion of these volumes would not have been captured. Because in 2004 the transit demand for events at Husky Stadium, Quest Field, and Safeco Field was served by specially operated bus routes with separate fares and no automatic passenger counting, the base year matrices exclude a large amount of the base year transit demand. The Link light rail system serves these venues directly and already experiences large surges in demand for events. However, since the largest surges have been associated with weekend events, and the ST transit

[29] See the *Build-Up Analysis Results* subsection of Section 4.2 for an explanation of Stages 1 and 2.

[30] This information is referred to as "2006 Small-Area" land use forecasts and is currently available at the PSRC website (*http://www.psrc.org/data/forecasts/saf*).

model is an average weekday model, it has not yet been considered necessary to add any special generator provisions to the model.

In the other case, the current 2004-based ST model has under-estimated daily boardings at the Sea-Tac Airport light rail station for both 2010 and for future years. This is based on comparison to average weekday boardings recently recorded in the first year of operation. Weekday boardings at Airport Station averaged 4,400 in July 2010, while the forecast weekday boardings for 2010 and 2030 were 2,900 and 3,300, respectively.

This shortcoming in the ST model will be somewhat rectified in the new 2012-base model using new Fall 2011 survey and count data. In the meantime, ST has installed a simple procedure to update the airport transit trips in the ST model for the off-peak period. It is the off-peak trips that are most severely under-represented in the current 2004-based model. This process involved the following steps:

- Identification of zones to which airport-bound off-peak trips could be allocated. For this purpose, year 2030 Stage 1 PM peak trips were used in its balanced format and corresponding proportion for each trip interchange calculated.
- Number of airport-bound off-peak seeded trips were distributed in the proportion of total peak airport bound trips to/from each TAZ.
- Finally, the resulting seed matrix was added to the 2030 Stage 1 off-peak trip table and then Stage 2 was rerun. This established an updated 2030 Stage 2 forecast upon which to run all Stage 3 forecasts.

Note that the number of additional airport-bound off-peak transit trips to be seeded was determined based on several iterations of the ST model Stage 2 and Stage 3 runs. With this correction, the 2030 forecast of daily boardings at the Sea-Tac Airport station is slightly higher (about 10 percent) when the 2030 trips are assigned to the 2010 transit network. When the 2030 trips are run through the transit model with the 2030 light rail network in place, the number increases to almost 6,000 daily, an increase of about 35 percent over the 2010 counts.

4.1.3 Highway Congestion and Bus Speed Degradation

The current version of the PSRC model adopted by WSDOT for the SR 520 Bridge Replacement and HOV Project (Final EIS Phase) was used to produce peak and off-peak highway times. The background (baseline) network assumed in the SR 520 model included only financially committed projects. Base year and 2030 highway networks within the North Corridor area were examined and further refined to better reflect current highway network and its performance. Subsequently, model runs were performed to produce peak and off-peak highway travel times required for 2030 Stage 2 ridership forecasting analysis.

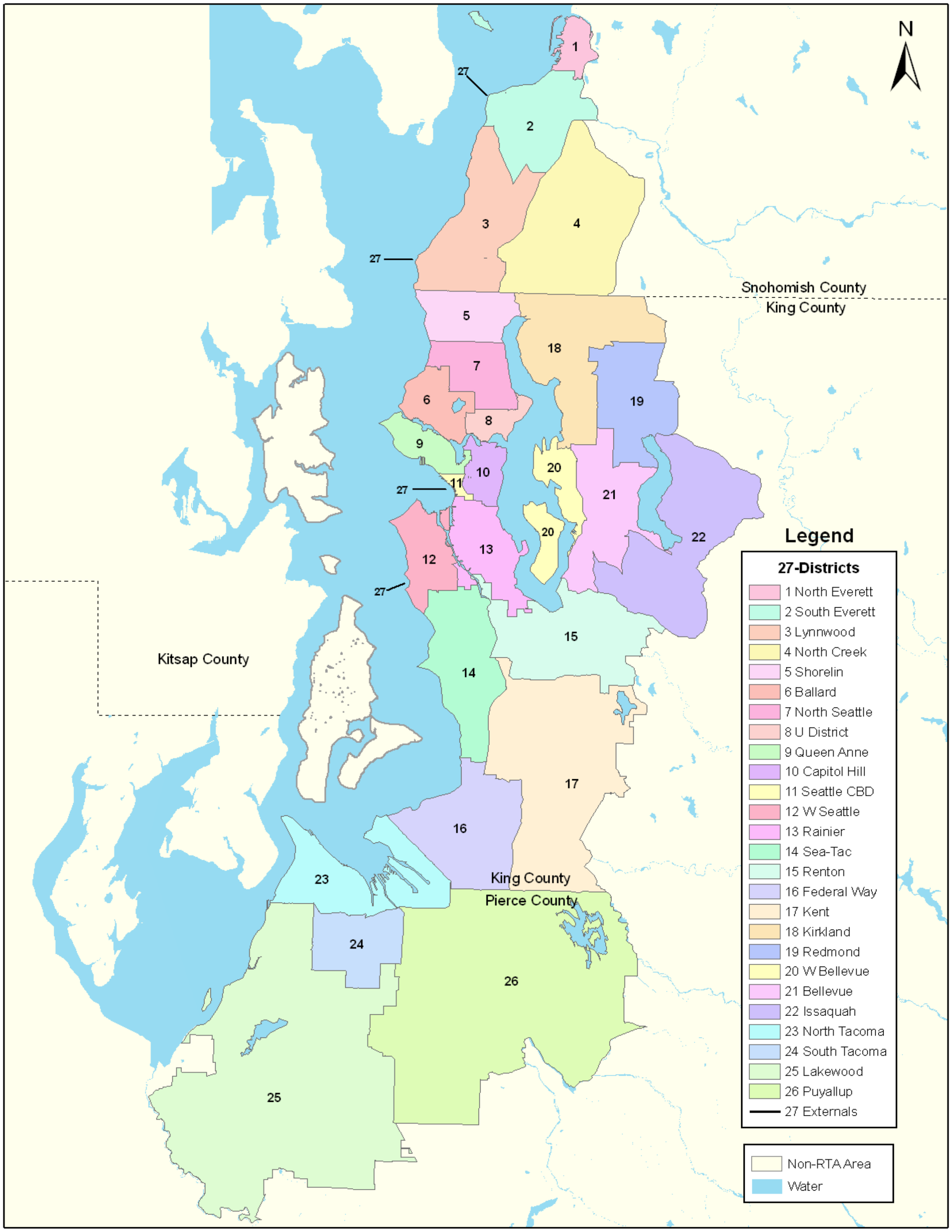
Table 4-1. Total Households, Population, and Employment for 2004 and 2030

No.	District Name	Base Year 2004			Year 2030[1]			Growth Rate—2030 over 2004		
		Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
1	North Everett	55,800	154,100	59,900	91,200	230,600	97,200	1.63	1.50	1.62
2	South Everett	34,200	86,400	59,500	51,200	117,800	83,500	1.50	1.36	1.40
3	Lynnwood	58,600	147,400	51,800	87,900	200,800	85,500	1.50	1.36	1.65
4	North Creek	94,800	268,900	51,400	161,300	417,800	83,800	1.70	1.55	1.63
5	Shoreline	26,600	68,100	17,500	29,500	70,300	20,100	1.11	1.03	1.15
6	Ballard	48,000	97,400	35,200	57,600	109,500	49,100	1.20	1.12	1.39
7	North Seattle	44,400	96,700	34,000	54,000	109,100	48,500	1.22	1.13	1.43
8	University District	17,400	45,700	44,800	21,600	50,700	54,400	1.24	1.11	1.21
9	Queen Anne	31,800	60,300	68,200	46,200	78,800	98,000	1.45	1.31	1.44
10	Capitol Hill	43,700	81,700	62,900	53,100	93,800	71,900	1.22	1.15	1.14
11	Seattle CBD	14,200	25,000	178,300	31,600	50,500	243,600	2.23	2.02	1.37
12	W Seattle	35,500	79,900	19,500	38,500	80,100	26,900	1.08	1.00	1.38
13	Rainier	31,900	90,800	83,700	38,100	99,800	116,000	1.19	1.10	1.39
14	Sea-Tac	50,200	128,800	59,800	62,100	146,500	73,900	1.24	1.14	1.24
15	Renton	49,600	120,700	104,500	66,500	149,300	155,100	1.34	1.24	1.48
16	Federal Way	44,400	119,500	36,900	55,500	136,500	45,700	1.25	1.14	1.24
17	Kent	98,100	266,200	118,000	150,700	379,300	165,200	1.54	1.42	1.40
18	Kirkland	62,700	159,600	69,500	86,800	203,600	104,900	1.38	1.28	1.51
19	Redmond	30,200	76,800	85,900	47,800	109,200	131,700	1.58	1.42	1.53
20	West Bellevue	21,700	49,400	55,400	35,400	69,100	102,900	1.63	1.40	1.86
21	Bellevue	41,200	101,600	78,600	55,900	125,800	106,900	1.36	1.24	1.36
22	Issaquah	41,700	111,700	33,400	66,600	169,600	52,200	1.60	1.52	1.56
23	North Tacoma	70,800	177,300	97,500	99,400	228,000	131,600	1.40	1.29	1.35
24	South Tacoma	32,900	93,400	35,200	40,900	103,300	46,000	1.24	1.11	1.31
25	Lakewood	70,900	190,300	81,400	87,500	212,900	99,000	1.23	1.12	1.22
26	Puyallup	103,900	281,900	55,800	181,400	464,100	90,700	1.75	1.65	1.63
27	Rest of Region	95,500	254,400	93,300	141,800	346,200	118,400	1.48	1.36	1.27
ST Area		**1,255,200**	**3,179,600**	**1,678,500**	**1,798,300**	**4,206,800**	**2,384,300**	**1.43**	**1.32**	**1.42**
4-County Region		**1,350,700**	**3,434,000**	**1,771,800**	**1,940,100**	**4,553,000**	**2,502,700**	**1.44**	**1.33**	**1.41**

Source: PSRC's "2006 Small Area" land-use forecasts. These forecasts are currently available on their website (http://www.psrc.org/data/forecasts/saf/)

[1]The forecasts for the year 2030 reflect the recommended land use forecasts by PRC for the Bel-Red sub-area (PSRC letter to Sound Transit dated May 21, 2009).

Figure 4-1. 27-District Boundary



In addition, model databases were used to develop arterial and freeway speed degradation rates required for Stage 3 forecasting analysis (see Tables C3a and C3b in Appendix C). Speed degradation estimates are based on a method (see Appendix C) that ST and FTA have agreed to. Changes in roadway performance will be examined as part of a benefit analysis for the transit investment packages.

4.1.4 Parking Costs

Zonal parking costs used in the ST model reflected a conservative 1.5-percent annual (real) growth in parking costs. This is a significant reduction from the 3-percent real growth assumed by ST and the PSRC prior to 2005. However, according to the limited historic information available, parking costs have averaged 1.6-percent growth since 1960.

For the purpose of representing hourly parking costs more accurately (used in Stage 2 for off-peak trips), a survey of downtown parking costs, scattered around the larger downtown (including Fist Hill and Belltown) was recently conducted. Based on the finding from this survey, 60 percent of daily parking costs were used to represent off-peak parking costs in the ST model. Zonal parking costs are shown in Table D-2 in Appendix D.

4.1.5 Other Costs and Income

Automobile operating costs for travel demand models are expressed in cents-per-mile. Typically, the costs include some or most of the out-of-pocket costs of driving a car, but none of the ownership costs. Automobile operating costs for these forecasts are assumed to remain constant, in real terms, from 2004 to 2030, at 20 cents-per-mile in real 2004 dollars. Because this basic assumption is that the costs of driving will increase only at the rate of inflation, this input has very little effect on these ridership forecasts.

Because PSRC no longer forecasts household income at the zonal level, the current set of ST ridership forecasts apply PSRC forecasts of the change in regional average household income to base-year zonal income data to estimate future-year zonal income. The ST model database represents (real) growth in income within 1 percent per year. This is consistent with the historical rate of (real) growth in income in the Puget Sound Region.

4.1.6 Transit Fares

In all model applications to date, fares have been assumed to increase at the same rate as the overall rate of inflation in the region. This is a policy assumption consistent with the local transit agencies' practice of periodically adjusting fares to keep up with increased operating costs. Transit fares for future years have been recently updated to reflect prevailing transit fares in 2010. Base year 2004 and future years (e.g., 2030) transit fares used in the ST model are, respectively, presented in Tables C2a and C2b in Appendix C.

4.2 Transit Service Levels

This section summarizes the underlying service levels assumed for the North Corridor Transit Project. This effort is not yet accomplished for this project because the alternatives are not yet fully defined; therefore this section will be completed in the next version of this report.

4.3 Ridership Forecasting Analysis Results

This section presents staged interim ridership forecasting analysis results. Stage 3 ridership forecasts will be included in the next version of this report.

4.3.1 Build-Up Analysis Results

As discussed in detail in Chapter 2.0, the ST patronage forecasting analyses were performed in three separate stages. This process distinguishes and facilitates the evaluation of incremental changes in demographics, costs, and highway and transit travel times.

In Stage 1, implied growth in land use forecasts (at the FAZ level) adopted by PSRC is used to expand base-year transit demand from a base year to a forecast year. Stage 2 of the ST modeling process considers the influence of changes in highway congestion, auto operating costs, parking costs, transit fares, and income. Changes in transit service levels are considered in Stage 3. The staged forecasting analysis results for 2030 PM peak and daily are summarized in Table 4-2 and Table 4-3.

The results of Stage 1 of the forecasting analysis indicate that changes in regional demographics between 2004 and 2030 result in an approximately 36-percent increase in daily transit trips within the three-county region (Table 4-3). Total households and employment for the three-county region are projected to increase, respectively, by 43 and 42 percent between 2004 and 2030. Employment for the Seattle downtown area is projected to increase by 37 percent between 2004 and 2030. Overall growth in transit demand related to growth is lower than regional employment growth, because a slightly higher percentage of the future employment growth occurs away from traditional transit markets.

In Stage 2 of the forecasting, analysis took into consideration the combined effect of changes in auto operating costs, parking costs, highway congestion, and income. These changes increased daily transit trips by about 11 percent relative to the Stage 1 2030 forecasts. These transit-trip increases resulted from increased parking costs and congestion, as discussed in Section 4.1. The direction of change in most variables would be expected to produce an increase in ridership in Stage 2.

District-level transit-trip table summaries for the base year are shown in Table 4-4 and Table 4-5 for PM peak and daily, respectively. Similar summaries will be presented for Stage 3 forecasts in the next version of this report.

Table 4-2. Build-Up Analysis: 2004 to 2030 Build-Up PM Peak Transit Trips by PM Origins and PM Destinations

		PM Origins				PM Destinations			
			2030				2030		
No.	District Name	2004	Stage 1	Stage 2	Stage 3	2004	Stage 1	Stage 2	Stage 3
1	North Everett	1,070	1,690	2,300		1,710	2,460	3,770	
2	South Everett	1,560	2,220	2,980		1,990	2,900	4,310	
3	Lynnwood	1,700	2,790	3,710		3,670	5,320	7,350	
4	North Creek	680	1,110	1,090		2,180	3,530	6,570	
5	Shoreline	800	920	960		2,440	2,610	3,100	
6	Ballard	3,410	4,790	4,830		6,790	7,830	9,080	
7	North Seattle	3,330	4,900	5,460		6,100	7,120	7,920	
8	University District	7,790	9,680	13,330		3,310	4,520	4,250	
9	Queen Anne	3,550	5,160	6,030		4,070	6,300	6,600	
10	Capitol Hill	8,660	9,960	11,270		8,190	9,620	10,040	
11	Seattle CBD	29,990	40,460	51,540		7,970	16,490	16,330	
12	W Seattle	1,260	1,800	1,690		3,590	3,760	4,100	
13	Rainier	6,010	8,440	9,480		5,830	6,910	6,670	
14	Sea-Tac	1,600	2,020	2,760		3,160	3,760	3,950	
15	Renton	2,000	3,010	3,780		3,280	4,140	4,760	
16	Federal Way	520	650	730		1,770	2,090	3,550	
17	Kent	1,860	2,530	3,010		3,050	4,170	6,380	
18	Kirkland	1,020	1,610	1,860		2,310	3,000	4,610	
19	Redmond	890	1,390	1,620		1,510	2,400	2,990	
20	West Bellevue	1,650	3,040	4,020		1,520	2,290	2,780	
21	Bellevue	1,790	2,400	2,640		2,510	3,360	3,780	
22	Issaquah	130	230	190		820	1,160	1,830	
23	North Tacoma	2,910	3,610	3,520		3,300	4,560	6,700	
24	South Tacoma	1,820	2,320	2,090		2,130	2,570	2,770	
25	Lakewood	1,200	1,630	1,490		2,260	2,680	2,940	
26	Puyallup	500	810	850		1,690	2,740	4,470	
27	External	330	450	480		880	1,340	2,100	
Total PM Peak Transit Trips		***88,030***	***119,620***	***143,710***		***88,030***	***119,630***	***143,700***	
%Change Relative to 2004			36%	63%			36%	63%	
%Change Relative to Previous Step in Build-Up Analysis			36%	20%			36%	20%	

Table 4-3. Build-Up Analysis: 2004 to 2030 Build-Up Daily Transit Trips in Origin/Destination Format

No.	District Name	2004	2030 Stage 1	2030 Stage 2	2030 Stage 3
1	North Everett	4,350	6,580	8,460	
2	South Everett	5,310	7,660	9,840	
3	Lynnwood	7,580	11,560	14,630	
4	North Creek	3,770	6,160	9,290	
5	Shoreline	5,360	5,920	6,350	
6	Ballard	18,890	23,820	25,030	
7	North Seattle	16,380	21,160	22,280	
8	University District	19,300	24,430	27,490	
9	Queen Anne	14,770	21,550	22,750	
10	Capitol Hill	33,050	38,790	40,100	
11	Seattle CBD	75,020	110,430	121,430	
12	W Seattle	10,110	11,710	11,590	
13	Rainier	22,390	29,590	29,560	
14	Sea-Tac	8,820	12,750	13,260	
15	Renton	8,970	12,710	13,880	
16	Federal Way	3,230	4,120	5,700	
17	Kent	7,620	10,620	13,690	
18	Kirkland	5,040	7,090	9,070	
19	Redmond	3,710	5,820	6,660	
20	West Bellevue	4,960	8,420	10,010	
21	Bellevue	6,790	9,050	9,630	
22	Issaquah	1,360	2,050	2,660	
23	North Tacoma	12,490	16,260	18,240	
24	South Tacoma	7,190	9,050	8,630	
25	Lakewood	5,720	7,160	7,040	
26	Puyallup	2,910	4,770	6,950	
27	External	1,940	2,840	3,750	
Total Daily Transit Trips		**317,030**	**432,070**	**477,970**	
%Change Relative to 2004			36%	51%	
%Change Relative to Previous Step in Build-Up Analysis			36%	11%	

Table 4-4. PM Peak Transit Trips—Base Year 2004

ORIGIN	DESTINATION	North Everett 1	South Everett 2	Lynnwood 3	North Creek 4	Shoreline 5	Ballard 6	North Seattle 7	University District 8	Queen Anne 9	Capitol Hill 10	Seattle CBD 11	W Seattle 12	Rainier 13	Sea-Tac 14	Renton 15	Federal Way 16	Kent 17	Kirkland 18	Redmond 19	West Bellevue 20	Bellevue 21	Issaquah 22	North Tacoma 23	South Tacoma 24	Lakewood 25	Puyallup 26	External 27	Origin Totals	Origin Shares
North Everett	1	520	280	60	130	10	10	–	–	–	–	20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	30	1,070	1.5%
South Everett	2	410	410	260	160	20	10	30	10	–	10	20	–	–	–	60	–	40	20	–	–	10	10	–	–	–	–	90	1,560	1.7%
Lynnwood	3	140	370	610	150	90	30	120	20	10	10	20	–	–	–	–	–	–	50	10	–	10	–	–	–	–	–	60	1,700	2.4%
North Creek	4	140	200	110	40	10	10	60	10	–	20	20	–	–	–	–	–	–	20	–	–	–	–	–	–	–	–	–	680	1.2%
Shoreline	5	20	60	100	–	130	120	170	50	20	30	40	–	10	–	–	–	–	30	–	–	–	–	–	–	–	–	10	800	1.7%
Ballard	6	10	30	40	10	120	880	410	280	430	360	410	80	120	40	50	10	10	10	10	30	30	–	10	–	–	10	20	3,410	5.8%
North Seattle	7	10	90	160	130	300	490	620	380	180	220	300	30	120	30	20	–	10	140	10	30	40	10	–	–	–	–	20	3,330	5.2%
University District	8	40	140	310	160	310	860	1,830	610	380	700	450	100	220	150	90	30	70	490	70	120	250	30	150	60	50	80	60	7,790	6.1%
Queen Anne	9	20	20	80	20	80	500	260	200	460	430	380	130	190	120	100	30	50	50	50	50	40	20	60	10	120	40	30	3,550	4.7%
Capitol Hill	10	40	30	200	90	140	750	500	500	410	1,360	1,380	440	1,380	300	190	90	120	70	150	100	110	70	30	20	40	30	130	8,660	10.2%
Seattle CBD	11	290	280	1,480	1,150	1,020	2,510	1,680	770	1,730	3,630	3,140	1,700	1,960	1,040	1,060	750	950	620	520	540	740	480	410	180	440	650	290	29,990	23.5%
W Seattle	12	–	–	–	–	10	30	20	10	40	120	150	480	130	130	90	10	10	–	–	–	–	–	–	–	–	–	20	1,260	3.2%
Rainier	13	20	20	100	40	100	300	150	230	220	800	700	360	980	380	480	260	360	30	60	40	80	30	60	20	30	110	80	6,010	7.0%
Sea-Tac	14	–	–	–	–	–	10	10	10	20	60	80	130	130	420	200	100	100	–	–	–	–	–	140	70	40	60	10	1,600	2.8%
Renton	15	–	–	10	–	–	30	10	10	30	80	110	70	270	280	460	100	330	10	10	30	70	10	10	–	–	40	10	2,000	2.9%
Federal Way	16	–	–	–	–	–	–	–	–	–	10	90	10	10	50	10	130	130	–	–	–	–	–	30	10	10	20	–	520	1.0%
Kent	17	–	–	–	–	–	10	10	10	20	30	130	10	70	140	200	170	760	–	–	10	10	–	70	10	10	190	–	1,860	2.4%
Kirkland	18	–	20	30	20	60	50	70	40	10	20	30	–	10	–	10	–	–	330	80	100	110	20	–	–	–	–	–	1,020	1.6%
Redmond	19	–	–	30	20	–	70	50	50	20	50	50	10	20	–	–	–	10	80	140	60	210	20	–	–	–	–	10	890	1.2%
West Bellevue	20	40	20	50	30	10	60	30	60	30	80	120	10	60	10	80	20	20	200	150	190	320	80	–	–	–	–	–	1,650	1.6%
Bellevue	21	–	–	10	–	10	60	40	50	30	110	140	10	60	20	140	10	30	150	250	190	460	40	–	–	–	–	–	1,790	2.2%
Issaquah	22	–	–	–	–	–	–	–	10	–	10	30	–	10	–	10	–	–	–	10	10	10	20	–	–	–	–	–	130	0.4%
North Tacoma	23	–	–	–	–	–	–	–	–	10	10	60	–	20	30	–	40	30	–	–	–	–	–	1,450	680	370	170	–	2,910	3.9%
South Tacoma	24	–	–	–	–	–	–	–	–	–	–	30	–	10	10	–	–	10	–	–	–	–	–	420	700	560	60	–	1,820	2.3%
Lakewood	25	–	–	–	–	–	–	–	–	–	–	10	–	–	10	–	–	–	–	–	–	–	–	280	330	510	60	–	1,200	1.8%
Puyallup	26	–	–	–	–	–	–	–	–	–	–	20	–	10	10	–	10	10	–	–	–	–	–	170	50	60	160	–	500	1.0%
External	27	10	10	20	10	10	20	20	10	20	40	50	10	40	10	10	–	10	10	–	–	–	–	–	–	–	–	–	330	0.6%
Destination Totals		1,710	1,990	3,670	2,180	2,440	6,790	6,100	3,310	4,070	8,190	7,970	3,590	5,830	3,160	3,280	1,770	3,050	2,310	1,510	1,520	2,510	820	3,300	2,130	2,260	1,690	880	88,040	100%
Destination Shares		1.5%	1.7%	2.4%	1.3%	1.7%	6.0%	5.1%	6.0%	4.5%	10.7%	23.0%	3.3%	7.1%	2.8%	2.9%	1.0%	2.4%	1.7%	1.1%	1.6%	2.2%	0.4%	4.0%	2.3%	1.8%	0.9%	0.6%	100.0%	

Table 4-5. Daily Transit Trips—Base Year 2004

ORIGIN	DESTINATION	North Everett 1	South Everett 2	Lynnwood 3	North Creek 4	Shoreline 5	Ballard 6	North Seattle 7	University District 8	Queen Anne 9	Capitol Hill 10	Seattle CBD 11	W Seattle 12	Rainier 13	Sea-Tac 14	Renton 15	Federal Way 16	Kent 17	Kirkland 18	Redmond 19	West Bellevue 20	Bellevue 21	Issaquah 22	North Tacoma 23	South Tacoma 24	Lakewood 25	Puyallup 26	External 27	Origin Totals	Origin Shares
North Everett	1	1,660	1,270	290	410	40	20	20	60	30	50	320	–	30	10	–	–	–	10	–	40	–	–	–	–	–	–	70	4,350	1.5%
South Everett	2	1,270	1,230	810	510	120	70	170	260	40	70	370	–	40	–	60	–	40	40	–	30	20	10	–	–	–	–	120	5,310	1.7%
Lynnwood	3	290	810	1,870	390	350	150	580	630	110	280	1,610	10	150	–	10	–	–	110	50	60	20	–	–	–	–	–	90	7,580	2.4%
North Creek	4	410	510	390	140	60	50	210	350	40	130	1,260	–	50	–	–	–	–	50	30	40	10	–	–	–	–	–	20	3,770	1.2%
Shoreline	5	40	120	350	60	530	450	870	610	200	290	1,290	50	160	10	10	–	–	220	10	20	20	–	–	–	–	–	30	5,360	1.7%
Ballard	6	20	70	150	50	450	3,310	1,690	2,380	1,660	2,070	4,550	380	920	140	190	30	40	130	130	180	150	60	20	–	–	10	80	18,890	5.8%
North Seattle	7	20	170	580	210	870	1,690	2,130	3,650	910	1,260	3,020	250	620	130	100	10	20	300	110	130	130	20	–	–	10	–	60	16,380	5.2%
University District	8	60	260	630	350	610	2,380	3,650	2,470	1,100	2,000	1,990	260	790	190	170	50	100	790	180	260	430	50	170	60	50	80	170	19,300	6.1%
Queen Anne	9	30	40	110	40	200	1,660	910	1,100	2,390	1,870	3,550	470	880	250	240	40	100	90	110	130	130	30	100	20	130	50	80	14,770	4.7%
Capitol Hill	10	50	70	280	130	290	2,070	1,260	2,000	1,870	5,940	10,740	1,330	3,810	600	520	140	220	160	270	290	310	120	90	30	60	30	350	33,050	10.2%
Seattle CBD	11	320	370	1,610	1,260	1,290	4,550	3,020	1,990	3,550	10,740	24,110	3,420	5,930	1,730	1,720	1,000	1,340	860	730	1,020	1,180	630	640	280	520	730	470	75,020	23.5%
W Seattle	12	–	–	10	–	50	380	250	260	470	1,330	3,420	1,970	940	570	240	30	40	10	20	10	20	10	–	–	–	–	50	10,110	3.2%
Rainier	13	30	40	150	50	160	920	620	790	880	3,810	5,930	940	3,680	830	1,360	360	740	70	120	130	170	60	150	40	60	130	180	22,390	7.0%
Sea-Tac	14	10	–	–	–	10	140	130	190	250	600	1,730	570	830	2,090	800	370	400	10	–	20	30	10	290	130	90	90	30	8,820	2.8%
Renton	15	–	60	10	–	10	190	100	170	240	520	1,720	240	1,360	800	1,760	180	850	30	30	180	300	30	50	10	20	50	30	8,970	2.9%
Federal Way	16	–	–	–	–	–	30	10	50	40	140	1,000	30	360	370	180	370	420	–	–	30	10	–	110	20	20	50	–	3,230	1.0%
Kent	17	–	40	–	–	–	40	20	100	100	220	1,340	40	740	400	850	420	2,750	–	10	40	40	–	140	40	40	230	10	7,620	2.4%
Kirkland	18	10	40	110	50	220	130	300	790	90	160	860	10	70	10	30	–	–	940	270	480	420	30	–	–	–	–	10	5,040	1.6%
Redmond	19	–	–	50	30	10	130	110	180	110	270	730	20	120	–	30	–	10	270	440	310	810	40	10	–	–	–	10	3,710	1.2%
West Bellevue	20	40	30	60	40	20	180	130	260	130	290	1,020	10	130	20	180	30	40	480	310	590	830	110	–	–	–	–	10	4,960	1.6%
Bellevue	21	–	20	20	10	20	150	130	430	130	310	1,180	20	170	30	300	10	40	420	810	830	1,670	90	–	–	–	–	10	6,790	2.2%
Issaquah	22	–	10	–	–	–	60	20	50	30	120	630	10	60	10	30	–	–	30	40	110	90	50	–	–	–	–	–	1,360	0.4%
North Tacoma	23	–	–	–	–	–	20	–	170	100	90	640	–	150	290	50	110	140	–	10	–	–	–	6,970	2,130	1,090	510	10	12,490	3.9%
South Tacoma	24	–	–	–	–	–	–	–	60	20	30	280	–	40	130	10	20	40	–	–	–	–	–	2,130	2,560	1,640	220	–	7,190	2.3%
Lakewood	25	–	–	–	–	–	–	10	50	130	60	520	–	60	90	20	20	40	–	–	–	–	–	1,090	1,640	1,800	190	–	5,720	1.8%
Puyallup	26	–	–	–	–	–	10	–	80	50	30	730	–	130	90	50	50	230	–	–	–	–	–	510	220	190	530	–	2,910	1.0%
External	27	70	120	90	20	30	80	60	170	80	350	470	50	180	30	30	–	10	10	10	10	10	–	10	–	–	–	10	1,940	0.6%
Destination Totals		4,350	5,310	7,580	3,770	5,360	18,890	16,380	19,300	14,770	33,050	75,020	10,110	22,390	8,820	8,970	3,230	7,620	5,040	3,710	4,960	6,790	1,360	12,490	7,190	5,720	2,910	1,940	317,010	100.0%
Destination Shares		1.5%	1.7%	2.4%	1.3%	1.7%	6.0%	5.1%	6.0%	4.5%	10.7%	23.0%	3.3%	7.1%	2.8%	2.9%	1.0%	2.4%	1.7%	1.1%	1.6%	2.2%	0.4%	4.0%	2.3%	1.8%	0.9%	0.6%	100.0%	

Appendix A: Surveys

Appendix A: Surveys

This appendix includes a summary of the recent surveys which are available to supplement past surveys. The new surveys were geo-coded to the ST model 759 zonal system and pertinent information was used to support the base year (2004) transit trip table development effort.

A.1 Sound Transit Survey

Sound Transit conducted an extensive survey of riders using Sound Transit trains and buses between September 2003 and May 2004. This survey yielded a variety of data including route number, time period, origin and destination location, as well as an expansion factor to expand from daily to annual ridership. The data was subsequently sorted into usable and unusable records, each of which was assigned an origin and destination AAZ. Finally, expansion factors were revised to reflect the lower number of usable records.

Records were deemed "unusable" if they were missing x,y coordinates either for the origin or the destination. Table A1 summarizes the percentage of "usable" records.

Table A1: Usable Records

	Bus	Sounder
Total Records	10,386	2,618
Total Usable	6,867	1,966
% Usable	66%	75%

Some of the usable records had either an origin or destination that did not lie within the Sound Transit district, but did lie within the PSRC region. These records were overlayed with the PSRC TAZ map and were assigned the corresponding PSRC TAZ. An equivalency table was then used to assign an appropriate external AAZ from the Sound Transit 759-AAZ system to these records. Table A2 summarizes the number of records that had an origin, destination, or both in either internal or external zones.

Table A2: Internal and External Origins and Destinations

	Bus	Sounder
Internal-internal	6,455	1,618
Internal-external	403	343
External-external	9	5

A.2 Revising Expansion Factors

After sorting the usable records by bus route and time period (Sounder records were just sorted by time period), expansion factors were revised to reflect the lower number of usable records. Since the expansion factors will be used to expand estimates from daily to annual ridership, each expansion factor needed to be increased to add up to the same ridership number. For each group of records (i.e., route 550 in the AM peak period), the expansion factors were revised using the following equation:

Old Exp Factor X (Sum of Total Exp Factors / Sum of Usable Exp Factors)

The resulting new expansion factors were then provided to the modelers along with origin and destination AAZs for each route / time period. Table A3 summarizes the number of usable records by mode and time period.

Table A3: Usable Records by Mode and Time Period

	Bus	Sounder
AM total records	2,470	1,243
AM usable	1,784	985
AM % usable	72%	79%
PM total records	3,193	1,375
PM usable	2,130	981
PM % usable	67%	71%
Offpeak total records	4,723	n/a
Offpeak usable	2,953	n/a
Offpeak % usable	63%	n/a

A.3 Survey of SR-520 Riders

A special survey of SR-520 riders was conducted by Northwest Research Group, Inc., in May 2005. This survey provided 944 usable origin-destination records of which 217 zone-pairs were not represented before in other surveys.

SOUNDTRANSIT

Appendix B: Maps

- **Forecasting Analysis Zones (FAZs)**
- **Alternative Analysis Zones (AAZs)**
- **27 and 11 Summary Districts**

Figure B1: PSRC FAZ Map - Snohomish County

Figure B2: PSRC FAZ Map - King County

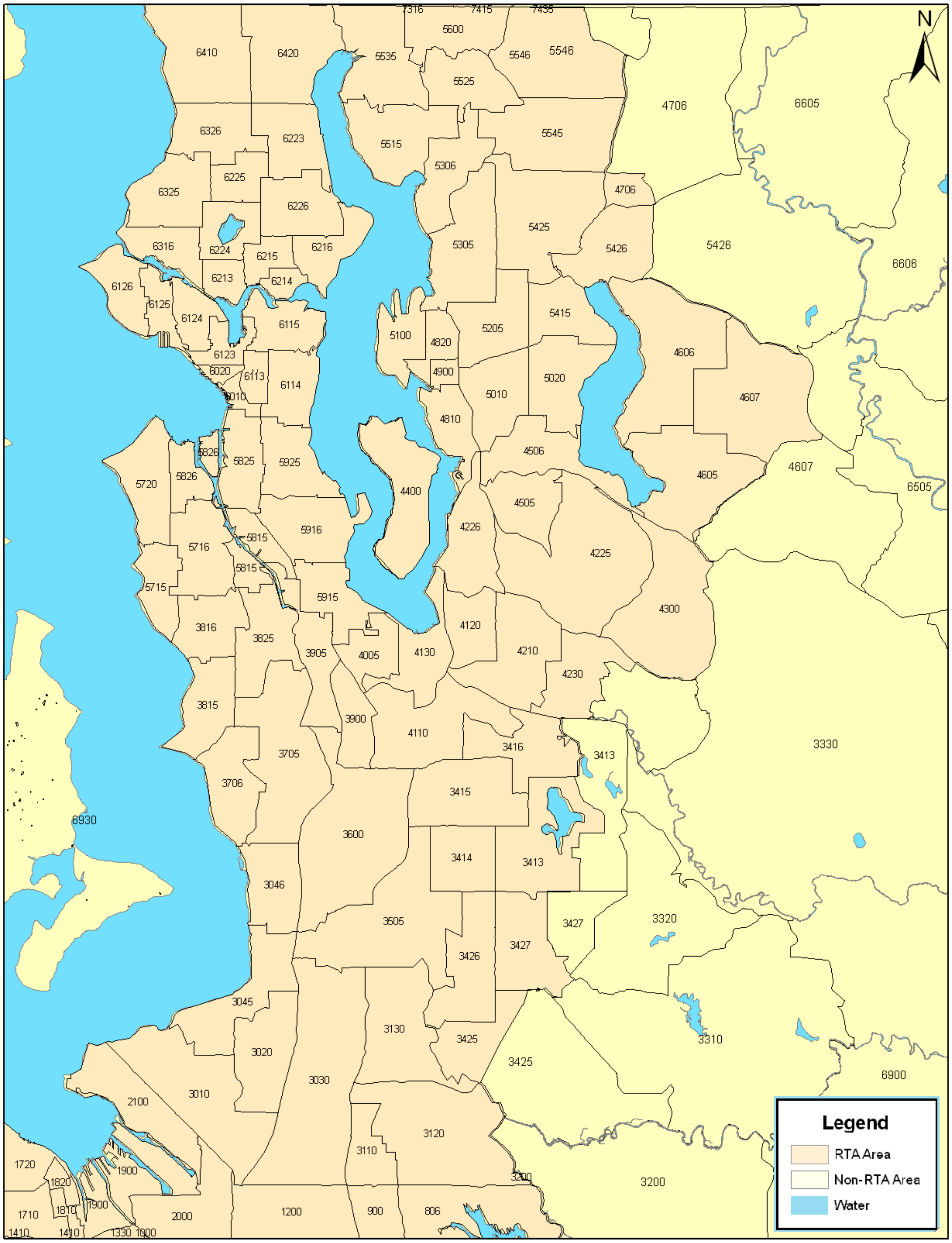


Figure B3: PSRC FAZ Map - Pierce County

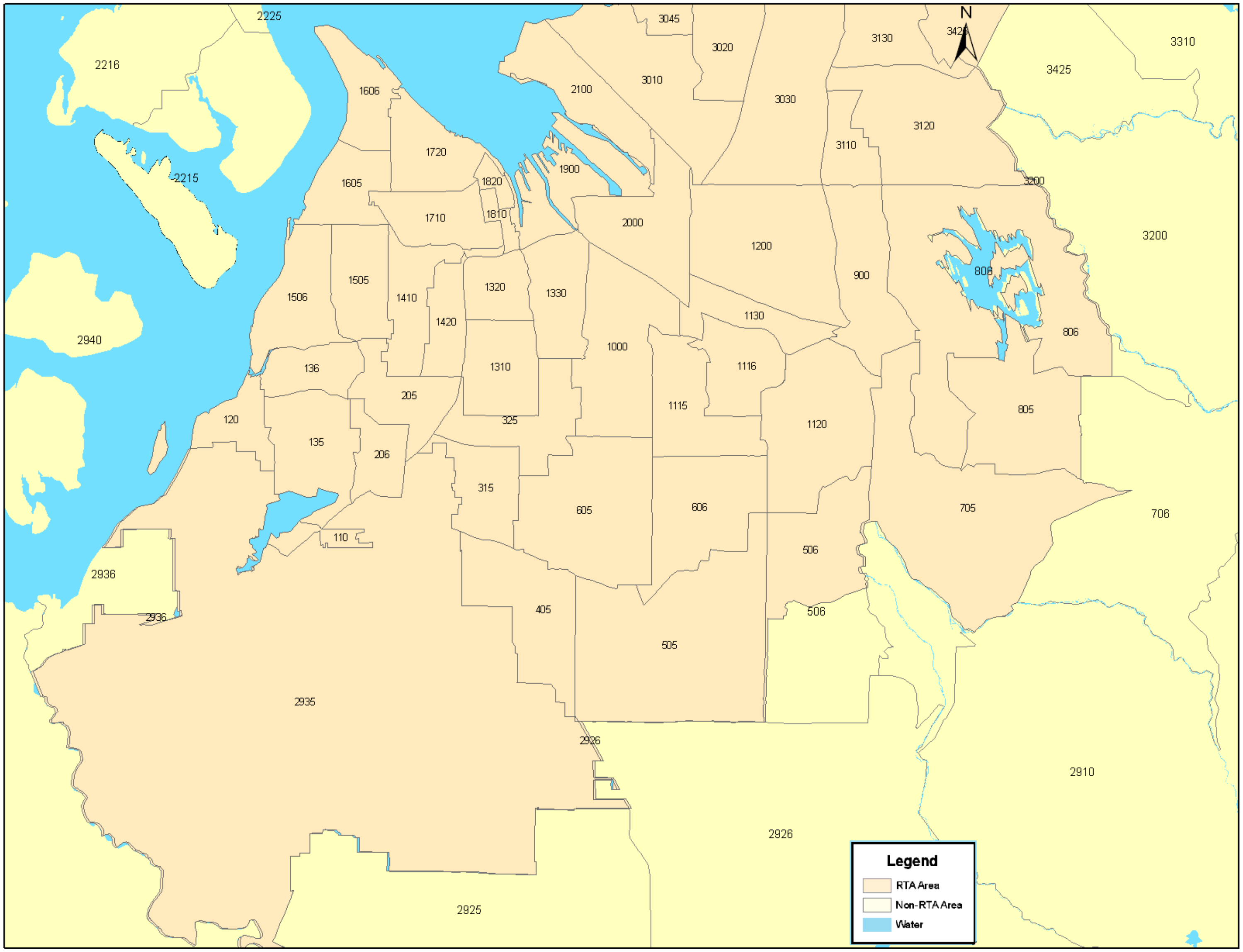


Figure B4: 780 Zonal System – King County

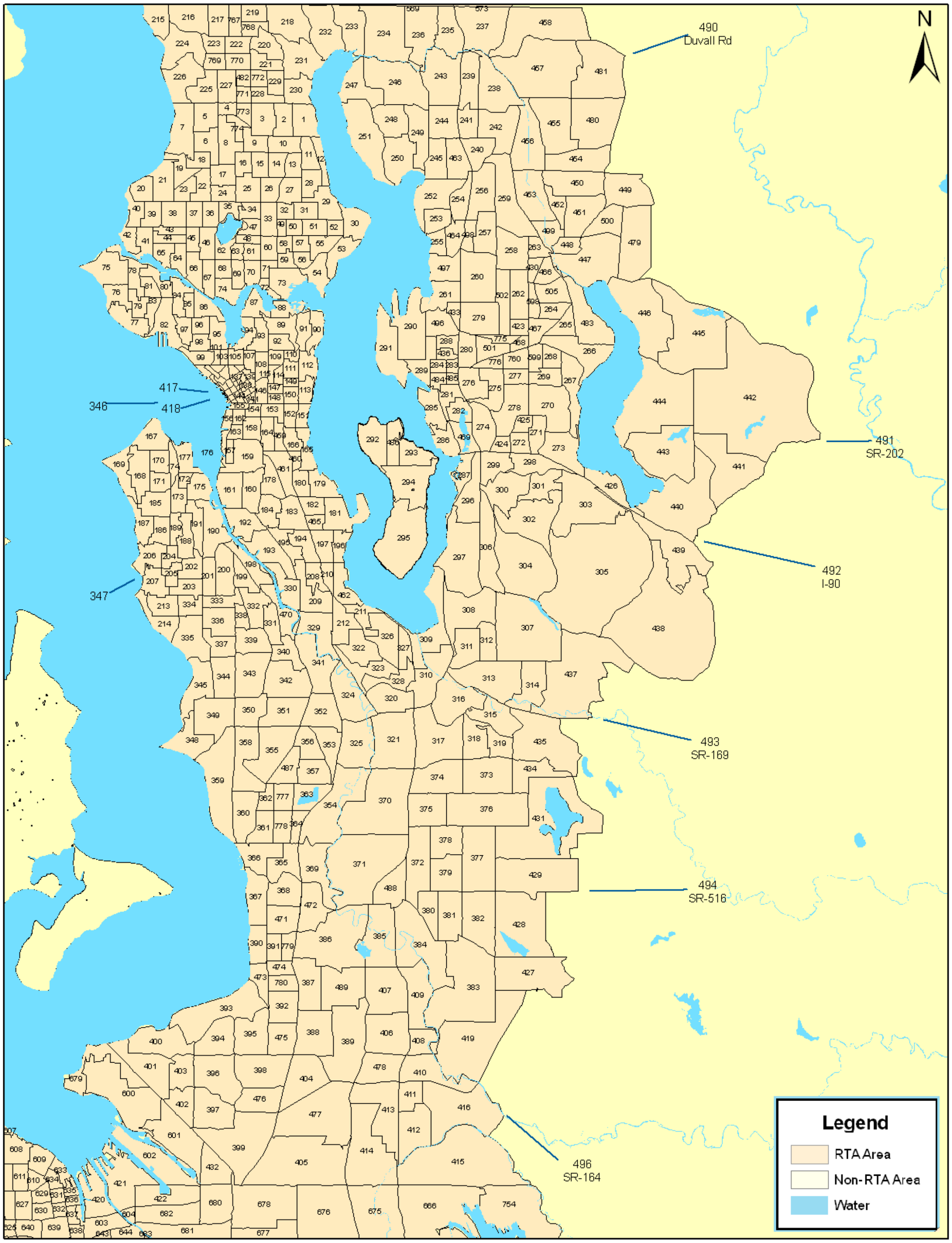


Figure B4a: 780 Zonal System – Seattle CBD

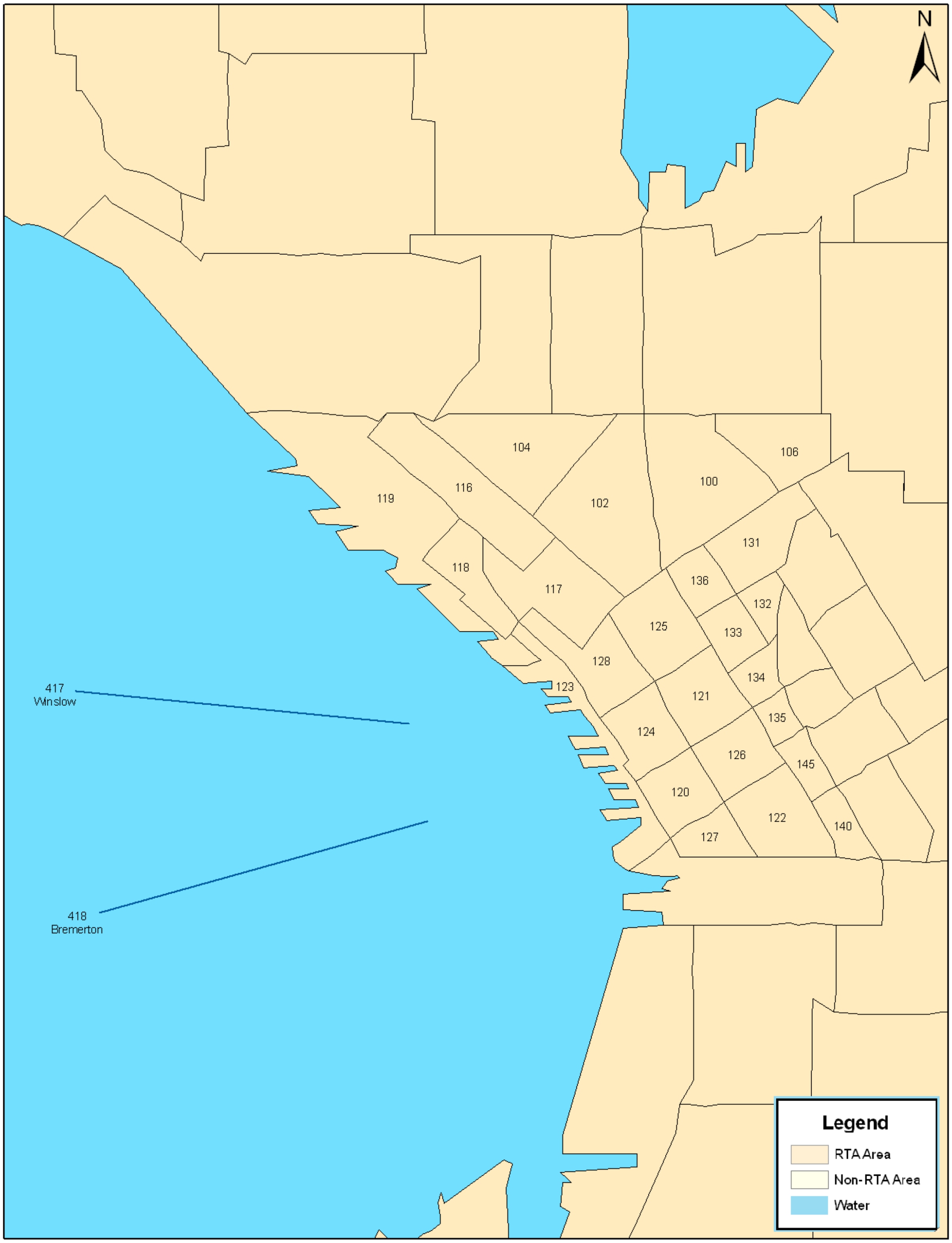


Figure B4b: 780 Zonal System – Capitol Hill, First Hill, Ballard & Queen Anne

Figure B4c: 780 Zonal System – North Seattle

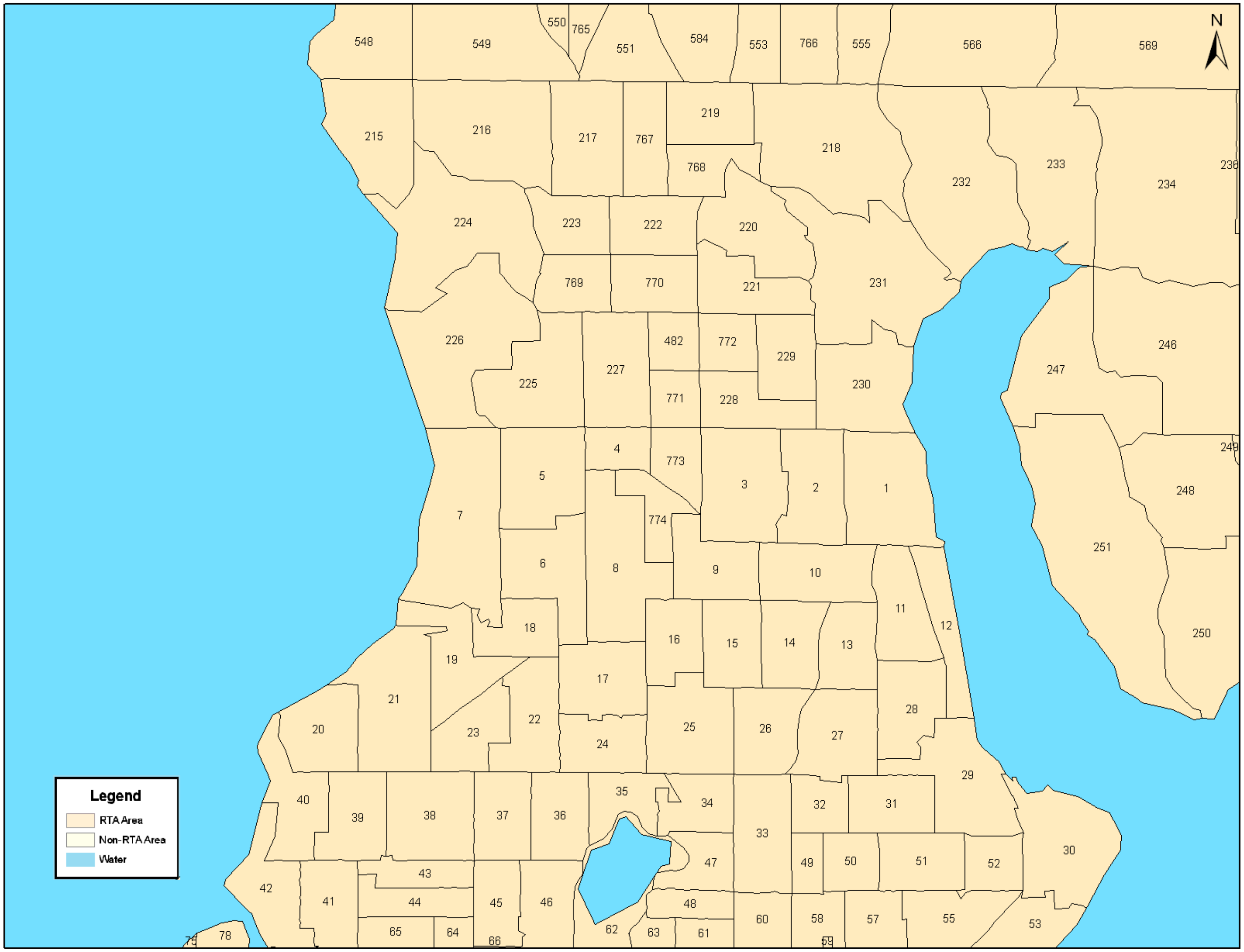


Figure B4d: 780 Zonal System – East King County

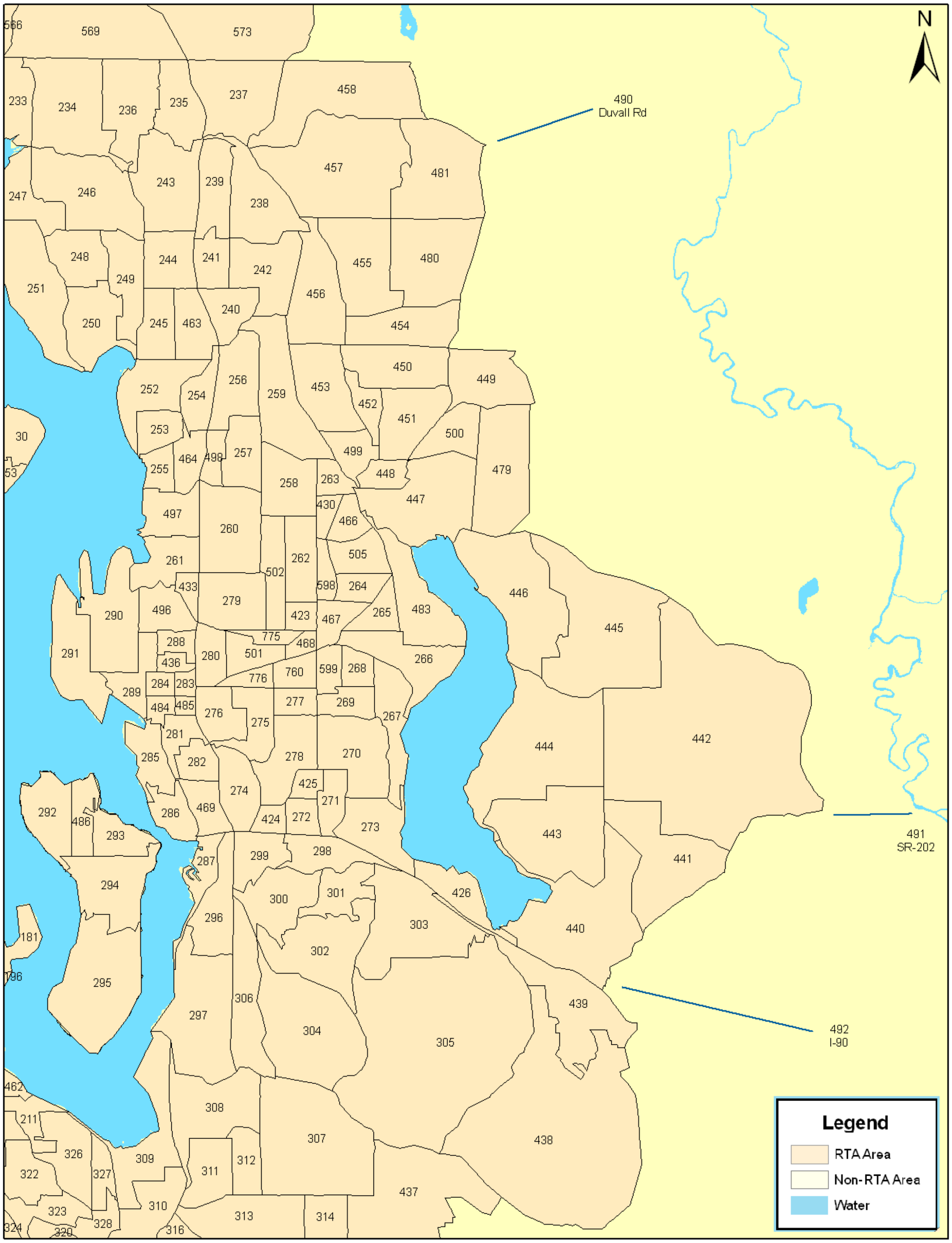


Figure B4e: 780 Zonal System – Southeast/West Seattle

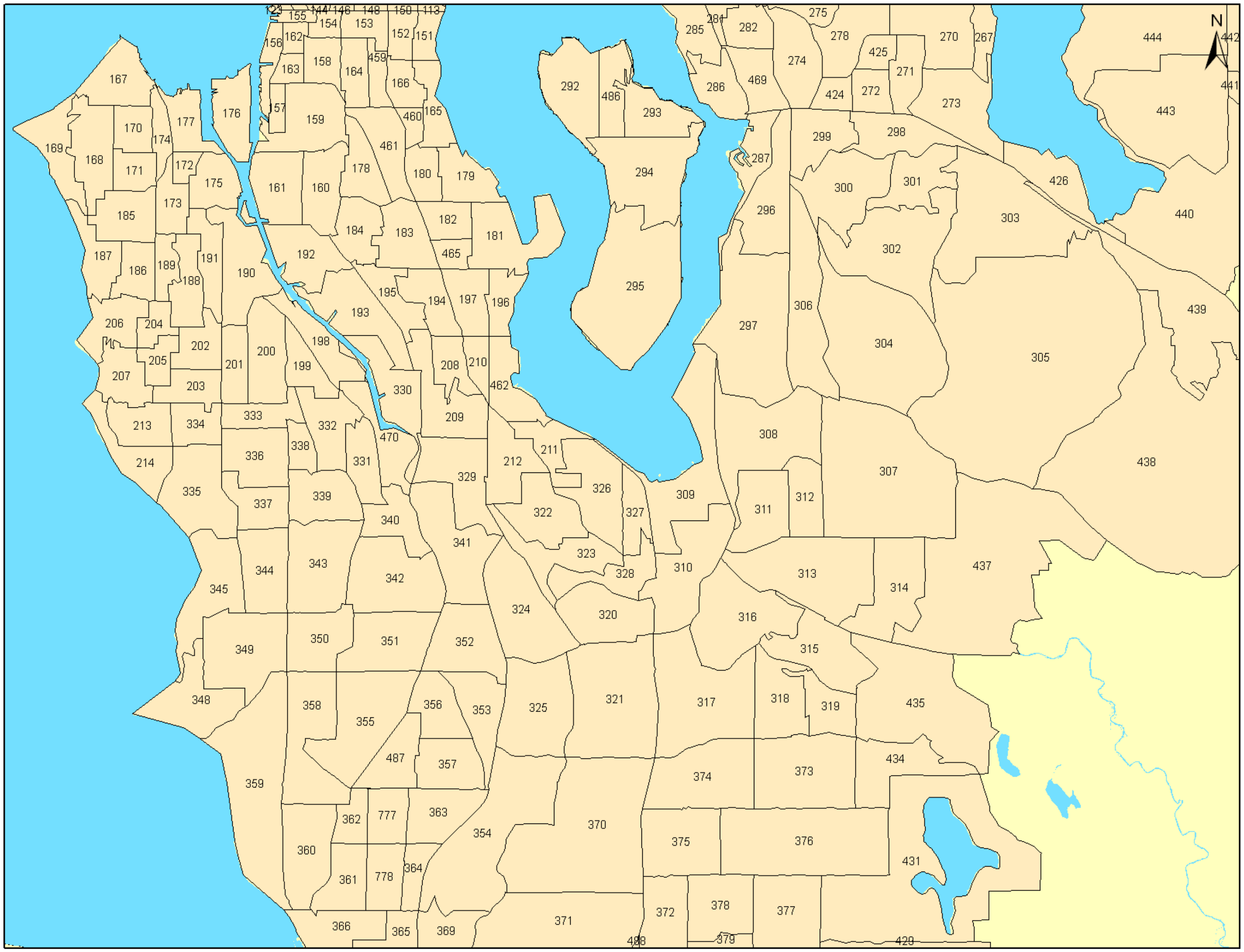


Figure B4f: 780 Zonal System – South King County

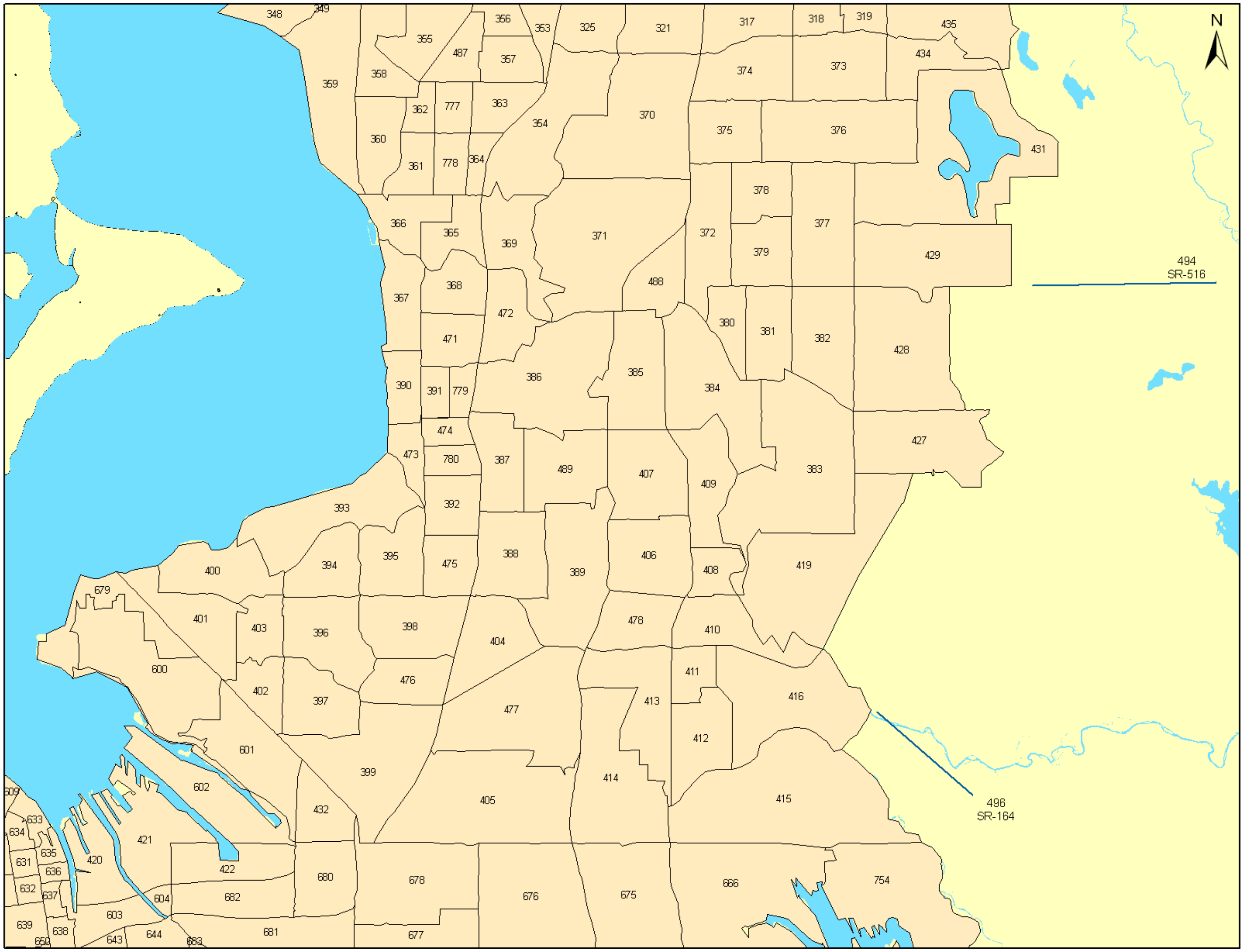


Figure B5: 780 Zonal System – Snohomish County

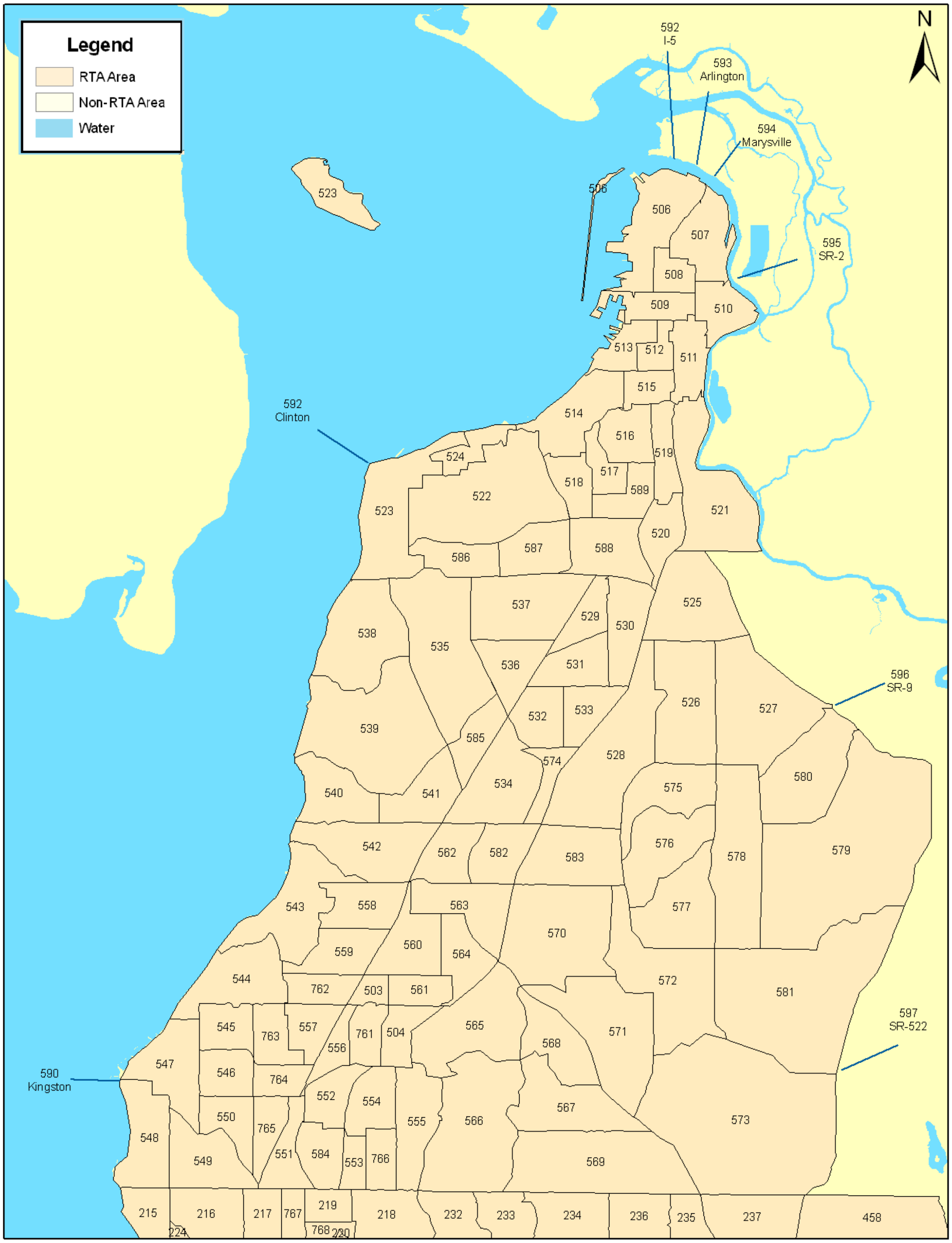


Figure B6: 780 Zonal System – Pierce County

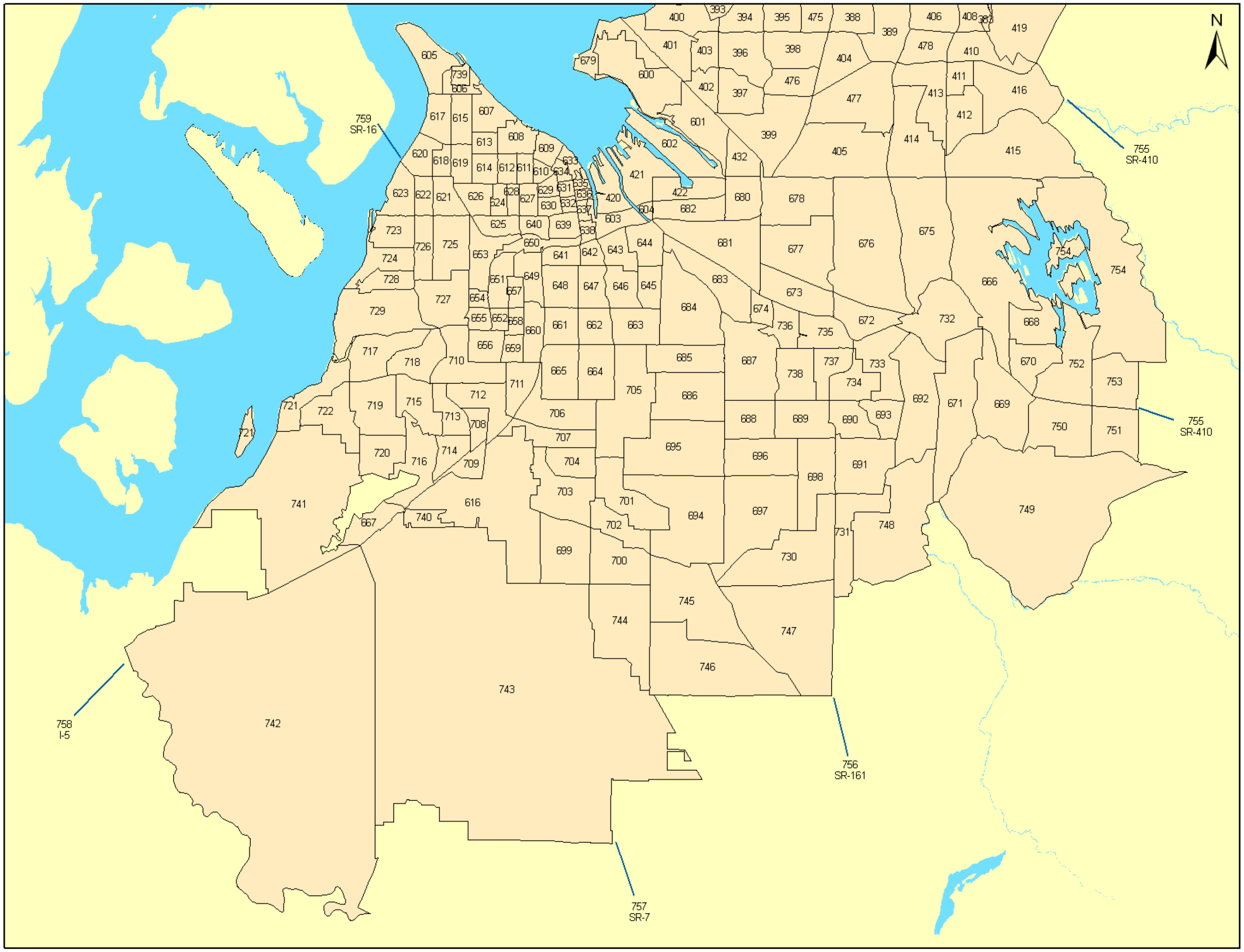


Figure B6a: 780 Zonal System – Tacoma

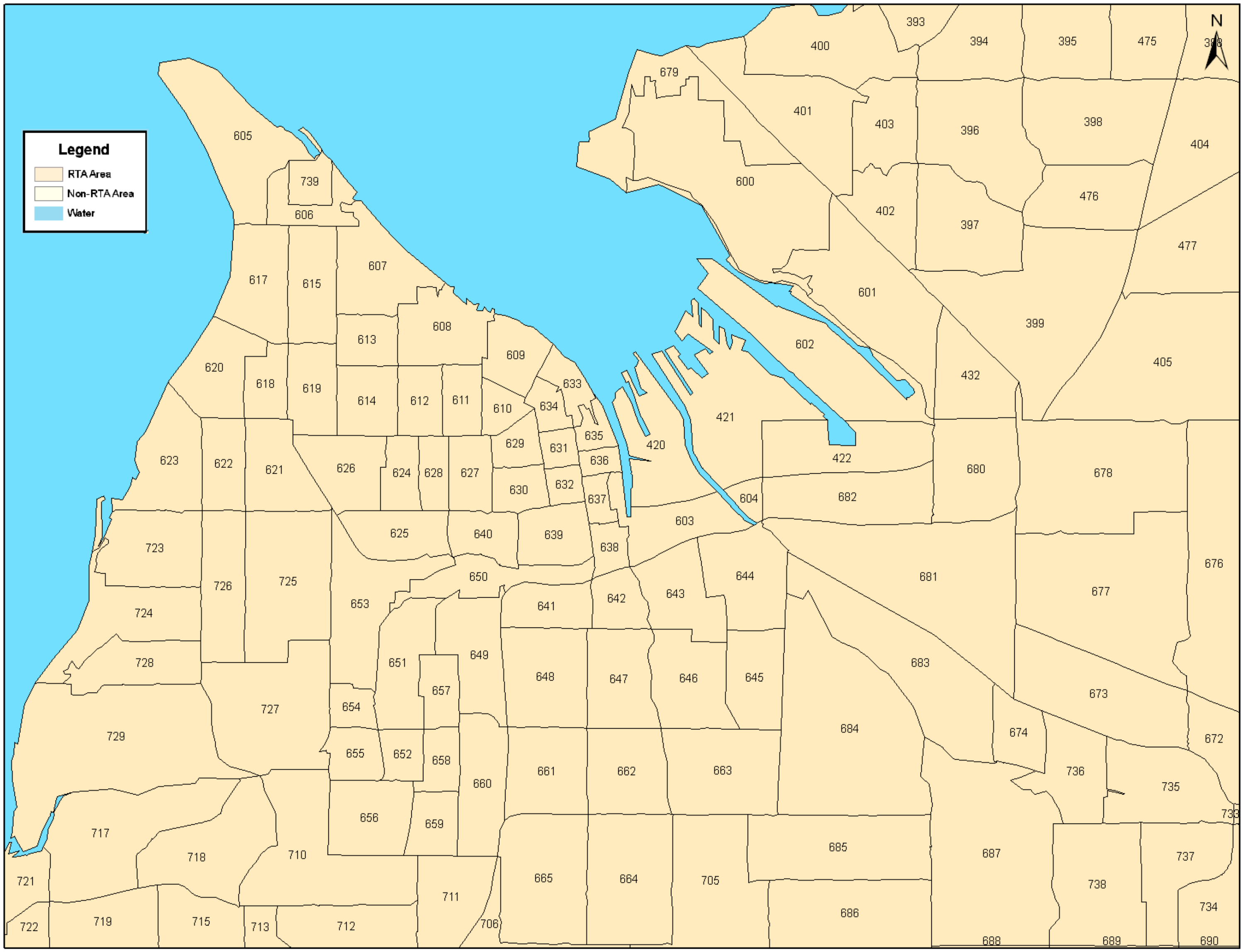


Figure B7: 27-District Boundary

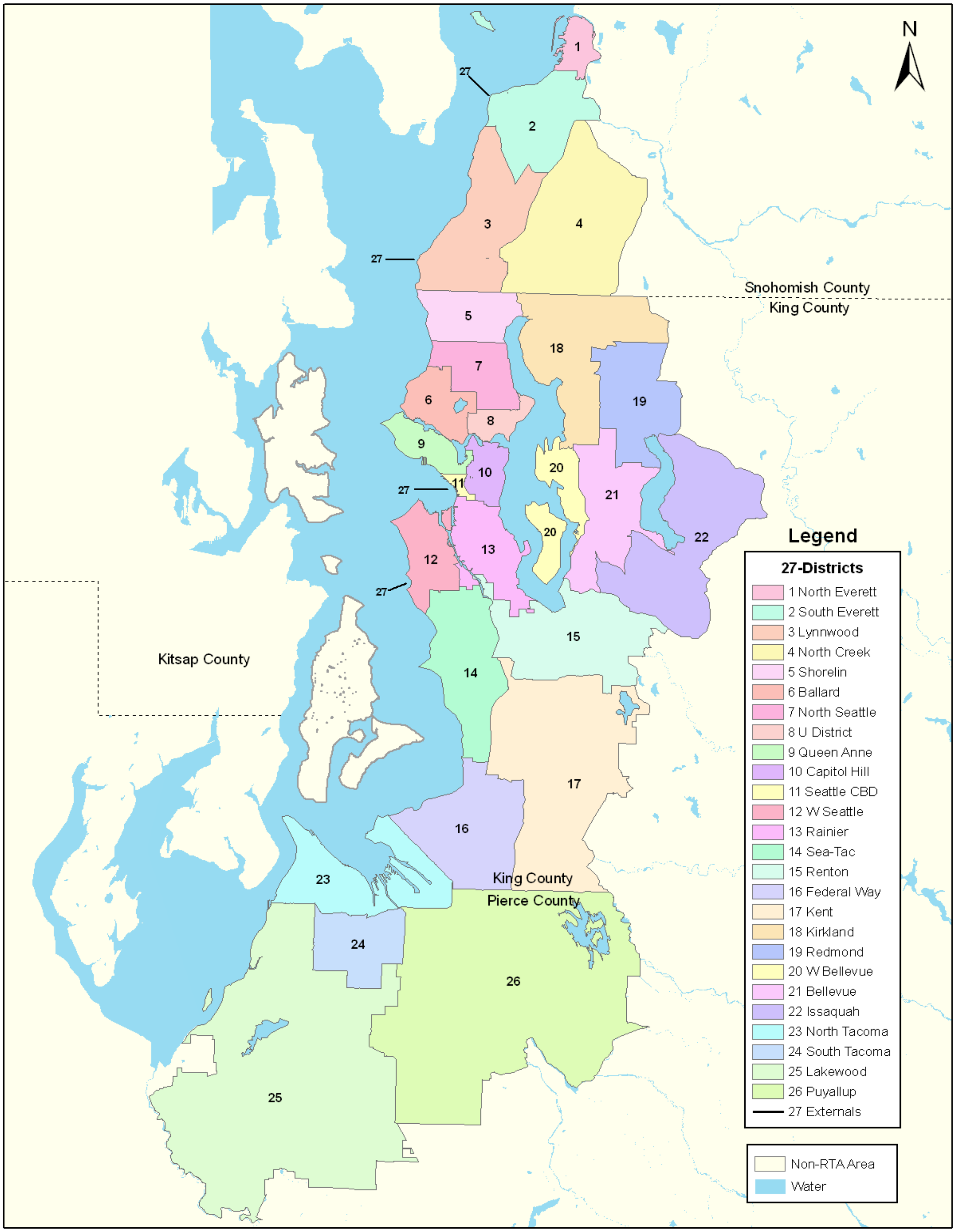
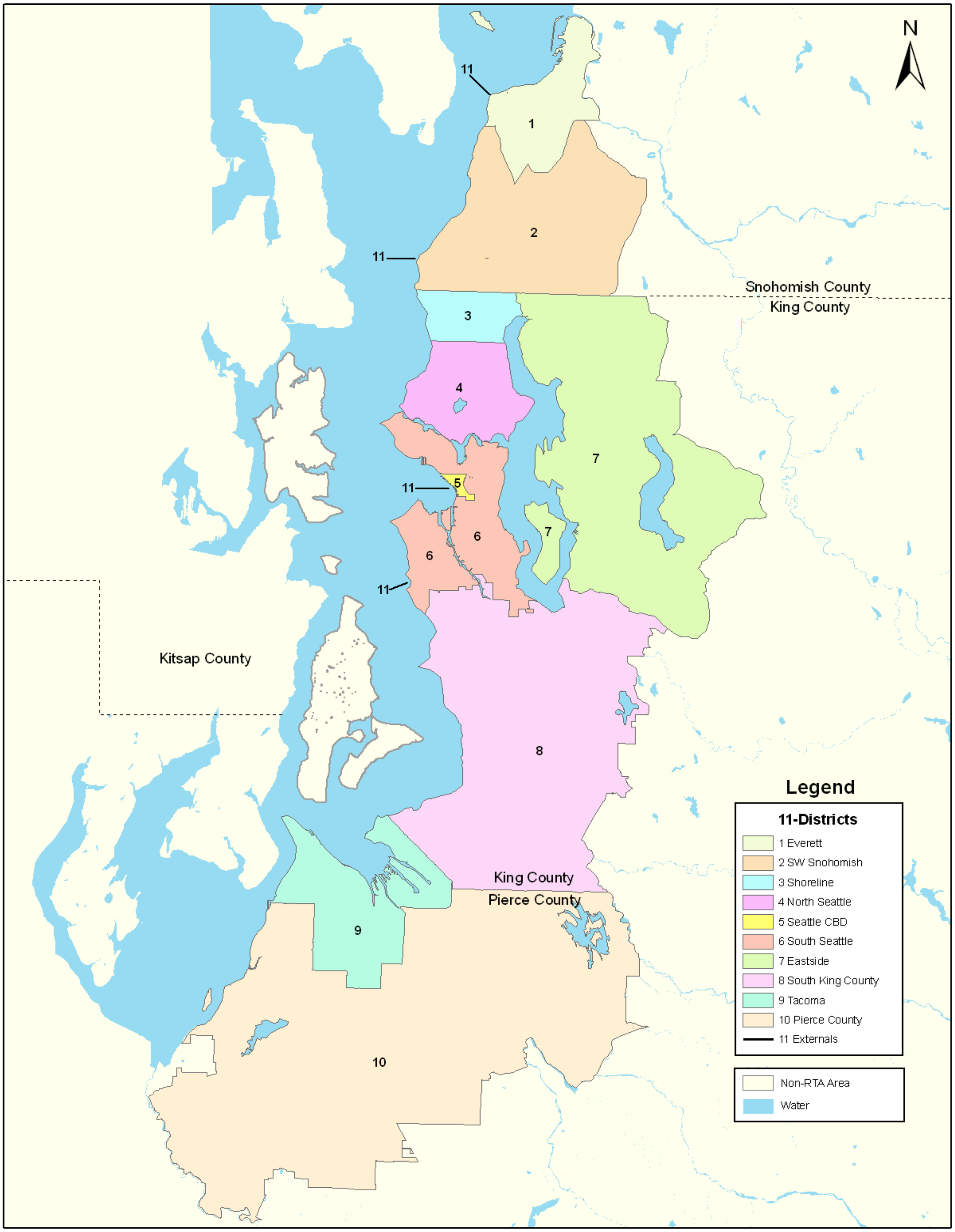


Figure B8: 11-District Boundary



SOUNDTRANSIT

Appendix C

- **Procedures for Transit Network Preparation**
- **Transit Fares**
- **ST Memorandum to FTA (Speed Degradation Procedures)**
- **Bus Speed Degradation Rates**

Appendix C:
Procedures for Transit Network Preparation

Actual transit service is represented in a transit ridership forecasting model by means of a "coded network." This service representation actually consists of two elements:

- A highway network, or "base network," is coded to create a computerized representation of existing and planned roads and exclusive transit right-of-ways in the study region; and
- Transit service assumptions are overlaid on this base highway network.

Significantly, for Sound Transit studies, the base network does not vary among alternatives. A single base network is used for all alternatives - meaning that for each alternative, elements of the base network may exist on which no transit service is coded. For example, rail rights-of-way are coded in every network although no rail service is coded for an all-bus alternative.

ST decided to construct a single base network for several reasons. One advantage of keeping the base network constant is that it eliminates spurious errors caused by roads or walkways which would be coded differently in different alternatives. A second reason for maintaining a single base network is that it minimizes differences in results due to accidental *differences* in access coding. Because a major aim of any forecasting effort is to capture differences among various alternatives, it is important that these differences are attributable to actual differences among the alternatives, rather than coding inconsistencies.

In contrast to the base network, the transit service that operates on this network does vary, both by forecast year and by alternative. The transit service network created for each alternative is represented by a set of bus and rail transit routes operated by local transit agencies.

C.1 Development of the Base Network

The base network is coded within this boundary and consists of links and nodes that represent the road system on which transit and automobiles travel. As mentioned previously, exclusive rights-of-way for transit and HOVs (e.g., transitways and rail tracks) are also coded, although they may not be used in every alternative. Park-and-ride lots are also coded, although they too may not be served by transit in every alternative.

Each of the links coded in the base network has a set of attributes consisting of the length of the link, the link type, the modes allowed on the link, the number of lanes on the link, a link speed, and the volume delay function. The link type codes, the modes, the volume delay functions, and link speeds are described in more detail below.

Network outside the study area is not coded, although the major roads leaving the study area are coded by means of external links. These links serve as method of accounting for travel into the study area from areas beyond the study area boundaries.

Link Type Codes

A two-digit number is used to code the link type. The first digit represents a facility type. The second digit can be used in a variety of ways, such as summing by cordons or by geographic area. The chart below shows the convention used for the first digit of the link type code:

Code	Link Type
0	Freeway HOV
1	Freeway HOV
2	Expressway or Highway
3	Arterial HOV
4	Arterial HOV
5	External Roads
6	Rail
7	Pedestrian Only Links
8	Walk Access to Zone Centroids
9	Auto Access to Zone Centroids

The link type coding does not directly affect the mode-choice model or the representation of transit service.

Mode Types

The following eight modes are specified on links within the base network:

Symbol	Mode Represented
c	Car
b	Bus
t	Trolley
r	Rail
a	Auto Access
w	Walk Access
p	General Pedestrian Links
x	Park and Ride Lot Connection (directional link)

The access modes (i.e., modes “a,” “w,” “p,” and “x”) are an important aspect of the base network. There is a minor variation in the way these access modes are represented in the PM peak and off- peak networks. In the peak networks, both auto access and walk access modes are allowed, while in the off-peak only walk access is allowed.

Walk-access links are coded with a speed of three miles per hour. The "w" mode allows walking from the base network to the zone centroid. The "p" mode permits all other walking, including walking from the zone centroid to the base network and streets. The separation of these two walk access modes makes it possible to differentiate between walk access transit trips and auto access transit trips.

The other two access modes, modes "a" and "x," are associated with the use of park-and-ride lots to access transit. Mode "a" allows auto trips between zone centroids and park-and-ride lots, and mode "x" represents walking within park-and-ride lots. A sample representation of the PM peak network using the access modes is shown in Figure C1a.

There are several reasons for using x-links to represent park-and-ride access to transit. First of all, using such links allows for counting the number of trips that use park-and-ride lots to access transit. Secondly, the use of such links will allow for modeling the effect of charging fees at park-and-ride lots, should this be desired. Thirdly, there is a certain disutility associated with having to park one's car and walk through a park-and-ride lot in order to get on a bus or train. Using x-links allows for the inclusion of this disutility in the model.

Finally, the use of x-links allows for a more even-handed comparison of park-and-ride access to transit between rail and non-rail alternatives. The use of x-links allows one to connect a single park-and-ride lot to both the street network and rail tracks. This means that under both an all-bus alternative (where transit would access the park-and-ride lot via the street network), and a rail alternative (where transit such as rail transit would access the same park-and-ride lot via the rail system), the park-and-ride lot in question would be connected to the exact same zones.

In the off-peak network each of the 759 zones in the network are connected with walk access links only. As in the PM peak, the walk access links are coded with a speed of three miles per hour. Both modes "w" and “p” allow walking from the base network to the zone centroid and vice versa. Mode “p” also allows walking on all surface streets in the network. The other two access modes, modes "a" and "x," are not used in the off-peak network. A sample representation of the off-peak network using the access modes is shown in Figure C1b.

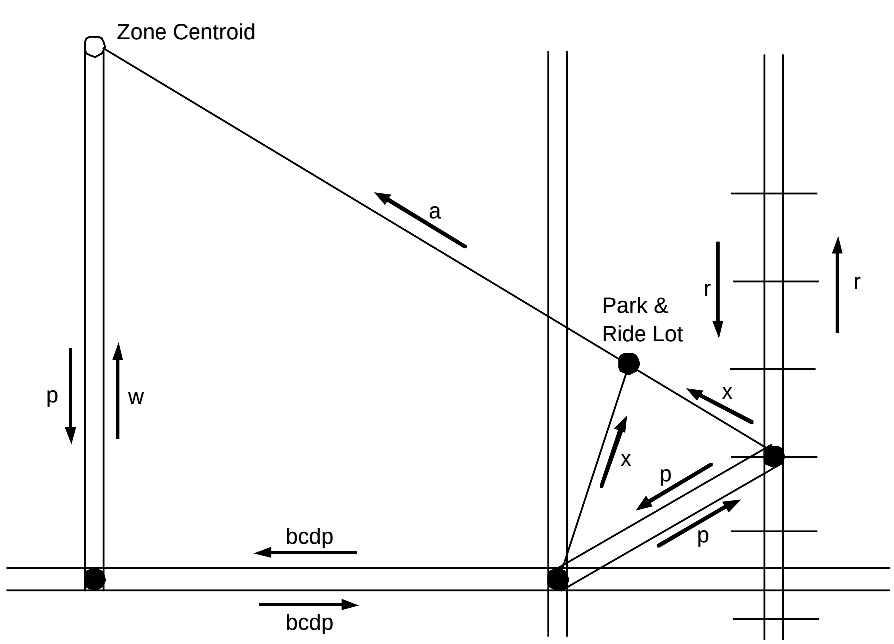
Development of the Future Transit Service Networks

Transit service networks are created to represent the transit service planned for each alternative and forecast year, as well as the service operated in the base years used to validate the model. Each service network is characterized by a unique set of routes, which may include rail lines, service on exclusive transitways, or HOV lanes. Each route is described by the nodes and links over which it travels, the travel time on each link, the locations where it stops, and its peak and off-peak headways. Each of these characteristics is described in detail below.

Route Patterns

Each route can be described by its route alignment, or the set of nodes and links over which it travels. The places where passengers are picked up and dropped off are coded by placing a dwell time on the nodes that represent bus stops for each particular route. All Sound Transit, King County Metro, Community Transit, Everett Transit, and Pierce Transit routes within the forecasting study area are coded for each alternative and forecast year, with the exception of any dial-a-ride service and routes that have less than three trips per direction per day.

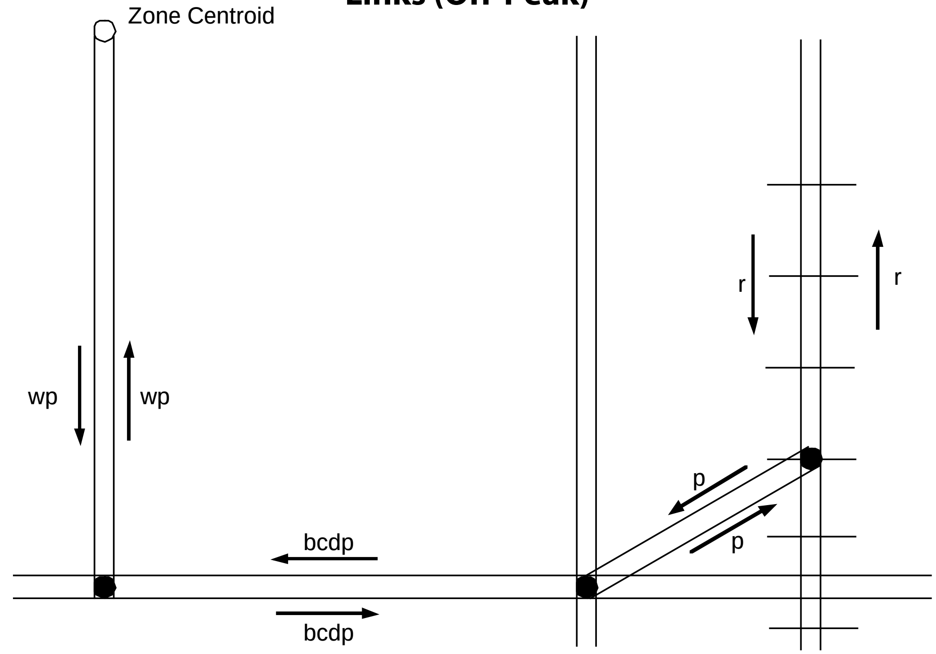
Figure C1a: Sample Mode Coding on Base Network Links (PM Peak)



LEGEND

Symbol	Mode Represented
a	Auto Access (Directional Link)
b	Bus
a	Car
d	Dual Power Bus
p	General Pedestrian Link
r	Rail
w	Walk Access (Directional Link)
x	Park and Ride Lot Connection Link

Figure C1b: Sample Mode Coding on Base Network Links (Off-Peak)



LEGEND

Symbol	Mode Represented
a	Auto Access (Directional Link)
b	Bus
a	Car
d	Dual Power Bus
p	General Pedestrian Link
r	Rail
w	Walk Access (Directional Link)

Route Headways

PM peak and off-peak headways are specified for each route in each transit service network. The PM peak headway reflects the number of trips between 3:00 and 6:00 PM, and the off-peak headway reflects the base headway between 9:00 a.m. and 3:00 p.m. For the base-year network, headways are determined directly from the printed bus schedules from the transit agencies.

A future 2030 ST baseline model was developed based on the "Build Network" definition from the latest 2030 North Link Model that was submitted to FTA. Route alignments and headways for the future baseline were based on this North Link model. Route patterns and headways for other future alignments will be based on the specific descriptions for each alternative.

Link Speeds and Bus Speeds

For fixed guideway facilities, link speeds representing travel time between two successive stations are calculated as part of the operating plan development that is unique to each alternative under consideration. Bus speeds under mixed operation with general traffic are calculated as follows:

> ***For the base year:*** link speeds are coded so that they result in network bus travel times equal to observed bus travel times.
>
> ***For future years:*** base-year link speeds are degraded according to the change in general roadway congestion level estimated by the PSRC model for arterial and freeway facilities and by geographic area.

Since the ST model's development in the early 1990s by the RTA future-year link speeds have been estimated using a constant degradation rate of seven to nine percent per decade. This degradation rate is consistent with historic trends in bus speeds. FTA staff, however, recently expressed concern about extrapolating historical trends in bus speed degradation into future projections. Instead, the FTA suggested basing link speeds degradation on roadway congestion estimated by the PSRC multi-modal model. Subsequently, a number of experimental analyses were performed in consultation with PSRC and City of Seattle travel modeling staff. As a result of this effort, analysis results and a recommended procedure were developed and documented by Sound Transit staff in a memorandum to the FTA. A copy of this memorandum follows.

C.2 Transit Fares

Historically, most transit agencies in the Puget Sound Region have increased transit fares at the rate of inflation. Consequently, transit fares are kept unchanged (in constant dollars) in the ST model between the base year (2004) and a future year. Transit fares for future years have been recently updated to reflect prevailing transit fares in 2010. Base year 2004 and future year (e.g., 2030) transit fares used in the ST model are presented in Tables C2a and C2b.

Table C2a: Base Year 2004 Peak and Off-Peak Transit Fares (in 2004 Constant Dollars)

ORIGIN	DESTINATION	North Everett 1	South Everett 2	Lynnwood 3	North Creek 4	Shoreline 5	Ballard 6	North Seattle 7	University District 8	Queen Anne 9	Capitol Hill 10	Seattle CBD 11	W Seattle 12	Rainier 13	Sea-Tac 14	Renton 15	Federal Way 16	Kent 17	Kirkland 18	Redmond 19	West Bellevue 20	Bellevue 21	Issaquah 22	North Tacoma 23	South Tacoma 24	Lakewood 25	Puyallup 26
North Everett	1	$0.75	$0.75	$1.00	$1.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
South Everett	2	$0.75	$0.75	$1.00	$1.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Lynnwood	3	$1.00	$1.00	$1.00	$1.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
North Creek	4	$1.00	$1.00	$1.00	$1.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Shoreline	5	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Ballard	6	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
North Seattle	7	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
University District	8	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Queen Anne	9	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Capitol Hill	10	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Seattle CBD	11	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$0.00	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
W Seattle	12	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Rainier	13	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50
Sea-Tac	14	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00
Renton	15	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00
Federal Way	16	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00
Kent	17	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.00	$2.00	$2.00	$2.00
Kirkland	18	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.50	$2.50	$2.50	$2.50
Redmond	19	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.50	$2.50	$2.50	$2.50
West Bellevue	20	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.50	$2.50	$2.50	$2.50
Bellevue	21	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.50	$2.50	$2.50	$2.50
Issaquah	22	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$2.50	$2.50	$2.50	$2.50
North Tacoma	23	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.50	$1.25	$1.25	$1.25	$1.25
South Tacoma	24	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.50	$1.25	$1.25	$1.25	$1.25
Lakewood	25	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.50	$1.25	$1.25	$1.25	$1.25
Puyallup	26	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.00	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.50	$1.25	$1.25	$1.25	$1.25

Table C2b: Future Years Peak and Off-Peak Transit Fares (in 2004 Constant Dollars)

ORIGIN	DESTINATION	North Everett 1	South Everett 2	Lynnwood 3	North Creek 4	Shoreline 5	Ballard 6	North Seattle 7	University District 8	Queen Anne 9	Capitol Hill 10	Seattle CBD 11	W Seattle 12	Rainier 13	Sea-Tac 14	Renton 15	Federal Way 16	Kent 17	Kirkland 18	Redmond 19	West Bellevue 20	Bellevue 21	Issaquah 22	North Tacoma 23	South Tacoma 24	Lakewood 25	Puyallup 26
North Everett	1	$0.72	$0.72	$1.26	$1.26	$1.80	$1.80	$1.80	$1.98	$1.98	$1.98	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$2.52	$2.52	$2.52	$2.52	$2.52	$3.24	$3.24	$3.60	$3.06
South Everett	2	$0.72	$0.72	$1.26	$1.26	$1.80	$1.80	$1.80	$1.98	$1.98	$1.98	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$2.52	$2.52	$2.52	$2.52	$2.52	$3.24	$3.24	$3.60	$3.06
Lynnwood	3	$1.26	$1.26	$1.26	$1.26	$1.80	$1.80	$1.80	$1.98	$1.98	$1.98	$2.52	$2.52	$2.16	$2.52	$2.52	$2.70	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$3.24	$3.24	$3.60	$3.06
North Creek	4	$1.26	$1.26	$1.26	$1.26	$1.80	$1.80	$1.80	$1.98	$1.98	$1.98	$2.52	$2.52	$2.16	$2.52	$2.52	$2.70	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$3.24	$3.24	$3.60	$3.06
Shoreline	5	$1.80	$1.80	$1.80	$1.80	$1.62	$1.62	$1.62	$1.80	$1.80	$1.80	$1.98	$1.98	$1.98	$2.52	$2.52	$2.70	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$3.24	$3.24	$3.60	$3.06
Ballard	6	$1.80	$1.80	$1.80	$1.80	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.98	$1.98	$2.16	$2.16	$2.16	$1.98	$1.98	$1.98	$1.98	$3.24	$3.24	$3.60	$3.06
North Seattle	7	$1.80	$1.80	$1.80	$1.80	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.80	$2.16	$2.16	$2.52	$2.34	$1.98	$1.98	$2.16	$2.16	$2.16	$3.24	$3.24	$3.60	$3.06
University District	8	$1.98	$1.98	$1.98	$1.98	$1.80	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$2.16	$2.16	$2.34	$2.34	$1.98	$1.98	$1.98	$1.98	$1.98	$3.24	$3.24	$3.60	$3.06
Queen Anne	9	$1.98	$1.98	$1.98	$1.98	$1.80	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.98	$1.98	$2.16	$2.16	$1.98	$1.98	$1.80	$1.80	$1.80	$3.24	$3.24	$3.60	$3.06
Capitol Hill	10	$1.98	$1.98	$1.98	$1.98	$1.80	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.98	$1.98	$2.16	$2.16	$1.98	$1.98	$1.80	$1.80	$1.80	$3.24	$3.24	$3.60	$3.06
Seattle CBD	11	$3.06	$3.06	$2.52	$2.52	$1.98	$1.62	$1.62	$1.62	$1.62	$1.62	$0.72	$1.62	$1.62	$1.98	$1.98	$2.16	$2.16	$1.98	$1.98	$1.80	$1.80	$1.80	$3.24	$3.24	$3.60	$3.06
W Seattle	12	$3.06	$3.06	$2.52	$2.52	$1.98	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.80	$1.80	$1.80	$1.80	$1.98	$1.98	$1.98	$1.98	$1.98	$3.24	$3.24	$3.60	$3.06
Rainier	13	$3.06	$3.06	$2.16	$2.16	$1.98	$1.62	$1.80	$1.62	$1.62	$1.62	$1.62	$1.62	$1.62	$1.80	$1.80	$1.98	$1.98	$1.98	$1.98	$1.98	$1.98	$1.98	$3.24	$3.24	$3.60	$3.06
Sea-Tac	14	$3.06	$3.06	$2.52	$2.52	$2.52	$1.98	$2.16	$2.16	$1.98	$1.98	$1.98	$1.80	$1.80	$1.62	$1.80	$1.80	$1.80	$2.34	$2.34	$2.34	$2.34	$2.34	$2.52	$2.52	$2.52	$2.52
Renton	15	$3.06	$3.06	$2.52	$2.52	$2.52	$1.98	$2.16	$2.16	$1.98	$1.98	$1.98	$1.80	$1.80	$1.80	$1.62	$1.80	$1.80	$1.80	$1.80	$1.80	$1.80	$1.80	$2.52	$2.52	$2.52	$2.52
Federal Way	16	$3.06	$3.06	$2.70	$2.70	$2.70	$2.16	$2.52	$2.34	$2.16	$2.16	$2.16	$1.80	$1.98	$1.80	$1.80	$1.62	$1.80	$2.34	$2.34	$2.34	$2.34	$2.34	$2.52	$2.52	$2.52	$2.52
Kent	17	$3.06	$3.06	$2.52	$2.52	$2.52	$2.16	$2.34	$2.34	$2.16	$2.16	$2.16	$1.80	$1.98	$1.80	$1.80	$1.80	$1.62	$1.80	$1.80	$1.80	$1.80	$1.80	$2.52	$2.52	$2.52	$2.52
Kirkland	18	$2.52	$2.52	$2.52	$2.52	$2.52	$2.16	$1.98	$1.98	$1.98	$1.98	$1.98	$1.98	$1.98	$2.34	$1.80	$2.34	$1.80	$1.62	$1.62	$1.80	$1.80	$1.80	$2.52	$2.52	$2.52	$2.52
Redmond	19	$2.52	$2.52	$2.52	$2.52	$2.52	$1.98	$1.98	$1.98	$1.98	$1.98	$1.98	$1.98	$1.98	$2.34	$1.80	$2.34	$1.80	$1.62	$1.62	$1.62	$1.62	$1.62	$2.52	$2.52	$2.52	$2.52
West Bellevue	20	$2.52	$2.52	$2.52	$2.52	$2.52	$1.98	$2.16	$1.98	$1.80	$1.80	$1.80	$1.98	$1.98	$2.34	$1.80	$2.34	$1.80	$1.80	$1.62	$1.62	$1.62	$1.80	$2.52	$2.52	$2.52	$2.52
Bellevue	21	$2.52	$2.52	$2.52	$2.52	$2.52	$1.98	$2.16	$1.98	$1.80	$1.80	$1.80	$1.98	$1.98	$2.34	$1.80	$2.34	$1.80	$1.80	$1.62	$1.62	$1.62	$1.62	$2.52	$2.52	$2.52	$2.52
Issaquah	22	$2.52	$2.52	$2.52	$2.52	$2.52	$1.98	$2.16	$1.98	$1.80	$1.80	$1.80	$1.98	$1.98	$2.34	$1.80	$2.34	$1.80	$1.80	$1.62	$1.80	$1.62	$1.62	$2.52	$2.52	$2.52	$2.52
North Tacoma	23	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$1.26	$1.26	$1.26	$1.26
South Tacoma	24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$3.24	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$1.26	$1.26	$1.26	$1.26
Lakewood	25	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$3.60	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$1.26	$1.26	$1.26	$1.26
Puyallup	26	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$3.06	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$2.52	$1.26	$1.26	$1.26	$1.26

SOUNDTRANSIT

MEMO

August 1, 2002

TO: Eric Pihl

FROM: Don Billen

SUBJECT: Updated Treatment of Bus Speeds in the Sound Transit Model

This memorandum describes the updated procedures for treating bus speeds in Sound Transit's incremental ridership forecasting process. This is in response to your request that Sound Transit rely on output from the PSRC multi-modal model to estimate changes in bus speeds over time.

Sound Transit Incremental Ridership Model

Sound Transit uses an incremental model to forecast transit ridership consisting of three stages:

- Stage 1: Changes in demographics
- Stage 2: External changes in highway travel time (congestion) and costs (including parking costs), transit fares, and household income are taken into consideration.
- Stage 3: Incremental changes in the transit level-of-service (i.e. access, wait, and ride travel times) are taken into consideration.

The third stage of the forecasting process is where the effects of changes in bus speeds are captured. Base year link speeds in combination with transit travel time functions are used so that they result in network bus travel times equal to observed bus travel times. Individual transit routes are coded with transit travel time functions that account for acceleration/deceleration time, with bus speeds equal to the base year link speed for express portions of a route. Dwell time is similarly coded for individual transit routes, with zero dwell time for express portions of a route.

Future year link bus speeds are degraded relative to base year link speeds and according to the procedures described below. The transit travel time functions which account for acceleration/deceleration time are the same in the base year and future year. Dwell time similarly remains the same in the base and future year.

Since the model's development in the early 1990's by the Regional Transit Project, future year link speeds have been estimated using a constant degradation rate of seven to nine percent per decade. This degradation rate is consistent with historic trends in bus speeds. However, FTA staff have expressed concern about extrapolating historical trends into the future and suggested relating future bus speeds to road speeds in the PSRC multi-modal model.

Updated Procedure for Estimating Future Bus Speeds

Sound Transit and its ridership consultant have investigated several methods for relating road speeds in the PSRC model to bus speeds in the Sound Transit model. After reviewing these methods with Puget Sound Regional Council and City of Seattle modeling staff, we have arrived at the following procedure.

For arterial bus speeds, weighted average auto travel time within the PSRC model is calculated at an intra 26-district level for the base year and forecast year in the PM peak and off-peak. The ratio between the base year and forecast year intra-district times is calculated. This change in intra-district auto travel times is used to estimate the change in bus speeds and is applied to the base year link speed values in the ST model for each geographic district. Table 1 shows the resulting PM peak bus degradation rates for each of the 26 districts for the period of 1998-2020.

Table 1: PM Peak Arterial Degradation Rates

Comparative Analysis of 1998 to 2020 Weighted Average Intra-District Travel Times					
District		**1998**	**2020**	**2020/1998 Ratio**	**Change Per Decade**
North Everett	1	6.13	6.80	1.11	4.8%
South Everett	2	8.24	9.28	1.13	5.6%
Lynnwood	3	8.04	9.95	1.24	10.2%
North Creek	4	10.13	11.17	1.10	4.5%
Shorelin	5	6.47	6.79	1.05	2.2%
Ballard	6	6.32	6.79	1.07	3.3%
North Seattle	7	6.64	7.29	1.10	4.3%
University District	8	4.55	5.52	1.21	9.2%
Queen Anne	9	6.44	6.94	1.08	3.5%
Capitol Hill	10	4.86	5.07	1.04	1.9%
Seattle CBD	11	2.48	2.63	1.06	2.6%
W Seattle	12	7.28	8.63	1.19	8.1%
Rainier	13	9.17	9.92	1.08	3.6%
Sea-Tac	14	8.01	8.81	1.10	4.4%
Renton	15	10.00	11.58	1.16	6.9%
Federal Way	16	8.26	9.50	1.15	6.5%
Kent	17	9.99	11.16	1.12	5.2%
Kirkland	18	8.75	10.10	1.15	6.7%
Redmond	19	8.60	11.42	1.33	13.8%
West Bellevue	20	5.51	5.68	1.03	1.4%
Bellevue	21	8.85	9.69	1.10	4.3%
Issaquah	22	8.62	10.33	1.20	8.6%
North Tacoma	23	8.48	10.58	1.25	10.6%
South Tacoma	24	6.16	6.78	1.10	4.4%
Lakewood	25	8.30	9.72	1.17	7.4%
Puyallup	26	10.51	11.46	1.09	4.0%
External	27	16.97	19.70	1.16	7.0%
Destination Totals		19.33	22.34	1.16	6.8%

For freeway bus speeds, zone to zone travel times between major entry and exit points for buses along regional freeways are calculated for the base year and future year. As with arterial times, the ratio between the base year and forecast year times is calculated. This change in freeway auto travel times is used to estimate the change in bus speeds and is applied to the base year link speed in the ST model for each freeway segment. Table 2 shows the resulting bus degradation rates on two freeway segments in the light rail study area.

Table 2: PM Peak Freeway Degradation Rates

Comparative Analysis of 1998 to 2020 Freeway Travel Times					
Freeway Segment		1998	2020	2020/1998 Ratio	Change Per Decade
I-5: Seattle CBD to Northgate		15.50	18.07	1.17	7.2%
SR 520: Seattle to Overlake		22.15	25.12	1.13	5.9%

The resulting rates of degradation for both arterials and highways are somewhat lower than historic changes in bus speeds in the Central Puget Sound Region, so may underestimate actual degradation rates. However, the updated method offers the advantage of being sensitive to varying congestion rates over time and across geographic areas and to changes in these rates with alternative land use or highway network scenarios.

Alternate Method Investigated

Our ridership forecasting consultant originally proposed to simply average PSRC link speeds within a cross-classification of geography and facility type for a base and future year to estimate changes in bus speeds. (see Parsons Brinkerhoff memo of 12-2-01 from Youssef Dehghani to Don Billen).

Investigation of this method between 1998 and 2020 yielded results that varied greatly between geographic areas and on the aggregate showed changes in road times much lower than other analyses of PSRC model output. The average decline in speeds across all facilities was 1% per decade between 1998 and 2020 compared to previous analysis of zone-zone road skims that showed an average decline of 8% per decade (see Parsons Brinkerhoff memo of 11-19-01 from Youssef Dehghani to Don Billen). Furthermore, the change in arterial speeds in different geographic areas varied by factors as high as 16 to 23 times. For instance, major arterial speed degradation in the Eastside of King County was 17 times as high as in Snohomish County, even though both are high growth areas with very limited road expansion currently funded. (Table 3)

Upon review of these results with PSRC and City of Seattle modeling staff, we concluded that simple averaging of link speeds is inaccurate and that it would be better to rely on zone-zone skim times than link level times. The simple averaging of link speeds results in too much influence from low volume roadways and too little influence from highway volume roadways. Also, using link level rather than zone-zone travel time skims created the possibility for the results to be influenced by the density of road networks coded in a geographic area.

Table 3

Analysis of PM Peak Speed Degradation in PSRC Model By Facility Type and Area Type

(average change per decade from 1998 to 2020)

Facility Type		Area Type: All	Seattle CBD	Seattle	Eastside	Rest of King County	Snohomish County	Pierce County	Kitsap County
	All	1.5%	0.9%	0.7%	5.6%	3.0%	0.8%	1.8%	0.2%
	Freeway GP Lanes	6.3%	4.48%		8.8%	3.1%	14.4%	4.0%	6.1%
	Freeway HOV Lanes	1.2%	1.95%		4.2%	5.56%			
	Major Arterials	1.4%	3.4%	0.8%	6.8%	3.0%	0.4%	1.9%	0.2%
	Minor Arterials	1.8%	0.1%	0.2%	3.1%	2.7%	2.1%	0.3%	0.0%

Notes :- The data shown above represents the percentage speed degradation over a period of 22 years from 1998 to 2020.
- The percentage degradation in speed was obtained from the "slope" of the regression equation obtained from a linear regression analysis of PM peak link travel times for a particular facility type and area type.
- The regression analysis showed an R^2 of greater 0.9 for all the categories.
- Major arterials include all those arterials in the PSRC model that have a speed greater than 25 mph, e.g., MLK way, Rainier Avenue, NE 8th (in Bellevue etc.). Minor arterials are arterials with a speed less than 25 mph.

These concerns led PSRC and City of Seattle modeling staff to recommend the use of weighted average auto travel times from zone-zone travel time skims and to Sound Transit's development of the procedures described at the beginning of this memo.

CC: John Witmer, FTA Region X
Larry Blaine, Puget Sound Regional Council
Eric Tweit, City of Seattle
Tracy Reed, Ron Lewis, Mike Williams, Sound Transit

DB <Updated bus speed degradation method.doc>

Table C3a. PM Peak and Off-Peak Arterial Speed Degradation Rates

District		2030/2004 Ratio	
No	Name	PM Peak Period	Off-Peak Period
1	North Everett	1.20	1.18
2	South Everett	1.35	1.11
3	Lynnwood	1.35	1.29
4	North Creek	1.35	1.35
5	Shoreline	1.35	1.23
6	Ballard	1.35	1.26
7	North Seattle	1.35	1.15
8	University District	1.17	1.19
9	Queen Anne	1.22	1.18
10	Capitol Hill	1.17	1.13
11	Seattle CBD	1.23	1.30
12	West Seattle	1.07	1.03
13	Rainier	1.24	1.23
14	Sea-Tac	1.35	1.20
15	Renton	1.35	1.15
16	Federal Way	1.35	1.18
17	Kent	1.35	1.28
18	Kirkland	1.35	1.24
19	Redmond	1.35	1.24
20	West Bellevue	1.35	1.35
21	Bellevue	1.35	1.35
22	Issaquah	1.35	1.18
23	North Tacoma	1.35	1.35
24	South Tacoma	1.17	1.05
25	Lakewood	1.27	1.06
26	Puyallup	1.35	1.23
27	External	1.35	1.21

Table C3b: PM Peak and Off-Peak Freeway Speed Degradation Rates

	2030/2004 Ratio	
Freeway Segment	PM Peak Period	Off-Peak Period
I-5: Seattle CBD to Northgate	1.37	1.31
SR 520 & I-90: Seattle to Bellevue/Redmond/Issaquah	1.18	1.10

SOUNDTRANSIT

Appendix D

- FAZ-Level Land Use Forecasts
- Zonal Parking Costs

Table D-1
Total Households, Population, and Employment for 2004 and 2030

PSRC FAZ No.	Base Year 2004			Year 2030[1]			Growth Rate 2030 over 2004		
	Households	Population	Employment	Households	Population	Employment	House-holds	Popula-tion	Employ-ment
ST Area									
110	2,040	4,940	910	2,410	5,380	1,900	1.18	1.09	2.09
120	4,270	11,030	1,000	5,410	12,110	1,420	1.27	1.10	1.42
135	5,900	14,860	1,770	7,650	17,320	2,390	1.30	1.17	1.35
136	4,790	12,520	3,920	5,700	14,020	4,080	1.19	1.12	1.04
205	5,290	12,660	11,070	5,720	12,450	13,280	1.08	0.98	1.20
206	5,640	13,610	6,780	7,210	15,800	8,150	1.28	1.16	1.20
315	5,520	15,020	6,970	6,680	16,550	10,350	1.21	1.10	1.48
325	8,100	20,080	4,910	9,640	22,760	7,910	1.19	1.13	1.61
405	7,000	18,870	3,700	9,080	22,970	6,160	1.30	1.22	1.66
505	9,860	28,460	5,460	18,940	52,540	7,690	1.92	1.85	1.41
506	5,870	17,650	1,820	13,530	37,330	3,750	2.30	2.12	2.06
605	7,230	19,550	2,190	12,560	31,630	3,690	1.74	1.62	1.68
606	5,730	14,590	2,270	11,310	28,260	4,160	1.97	1.94	1.83
705	5,900	16,890	1,240	12,960	33,190	4,970	2.20	1.97	4.01
706	4,460	12,970	2,590	7,170	19,290	3,600	1.61	1.49	1.39
805	5,900	17,350	2,420	10,410	28,560	4,560	1.76	1.65	1.88
806	6,710	18,470	1,250	15,610	41,540	2,040	2.33	2.25	1.63
900	3,790	9,020	6,740	6,640	14,740	12,330	1.75	1.63	1.83
1000	3,560	9,470	1,120	4,890	11,850	2,300	1.37	1.25	2.05
1115	3,800	9,360	3,690	5,310	12,940	4,370	1.40	1.38	1.18
1116	6,020	14,760	6,630	8,070	18,090	9,460	1.34	1.23	1.43
1120	11,060	28,480	10,440	15,560	38,140	12,410	1.41	1.34	1.19
1130	2,110	4,320	1,820	3,070	5,830	4,070	1.45	1.35	2.24
1200	6,280	15,690	2,900	11,600	27,140	5,700	1.85	1.73	1.97
1310	9,690	27,280	4,100	11,140	27,860	5,420	1.15	1.02	1.32
1320	6,840	18,880	3,160	8,880	21,910	3,590	1.30	1.16	1.14
1330	7,110	22,830	3,020	9,270	26,460	3,740	1.30	1.16	1.24
1410	4,680	12,010	12,690	5,470	12,430	16,260	1.17	1.03	1.28
1420	4,600	12,440	12,230	6,150	14,610	16,970	1.34	1.17	1.39
1505	7,760	18,420	4,170	9,580	20,920	7,110	1.23	1.14	1.71
1506	8,750	21,780	2,920	10,570	24,060	3,760	1.21	1.10	1.29
1605	7,880	17,680	6,220	9,770	20,350	7,350	1.24	1.15	1.18
1606	5,550	12,960	1,530	7,160	15,270	2,270	1.29	1.18	1.48
1710	8,470	21,990	12,220	10,160	24,180	12,260	1.20	1.10	1.00
1720	10,780	26,370	5,640	13,180	29,110	6,720	1.22	1.10	1.19
1810	1,760	5,540	13,180	3,370	8,860	18,250	1.91	1.60	1.38
1820	4,380	6,870	20,040	6,740	9,610	26,770	1.54	1.40	1.34
1900	190	890	13,140	500	1,720	17,160	2.63	1.93	1.31

Table D-1
Total Households, Population, and Employment for 2004 and 2030 (continued)

PSRC FAZ No.	Base Year 2004			Year 2030[1]			Growth Rate 2030 over 2004		
	Households	Population	Employment	Households	Population	Employment	House-holds	Popula-tion	Employ-ment
2000	2,960	6,940	12,510	5,680	12,180	20,810	1.92	1.76	1.66
2100	6,980	18,560	1,480	9,470	23,340	2,960	1.36	1.26	2.00
2215	6,180	15,740	4,520	9,170	21,670	6,140	1.48	1.38	1.36
2216	5,900	17,120	2,220	8,710	23,400	3,370	1.48	1.37	1.52
2225	5,000	12,380	3,460	9,130	20,760	5,580	1.83	1.68	1.61
2910	880	2,580	640	1,510	4,110	770	1.72	1.59	1.20
2925	4,600	13,140	720	7,020	18,590	1,210	1.53	1.41	1.68
2926	8,120	23,930	800	11,720	31,850	1,520	1.44	1.33	1.90
2927	2,010	5,180	1,070	3,560	8,520	2,080	1.77	1.64	1.94
2935	4,640	23,830	30,080	3,670	19,140	27,700	0.79	0.80	0.92
2936	1,170	2,720	3,230	4,150	9,410	4,750	3.55	3.46	1.47
2940	4,820	14,200	1,300	6,330	17,530	1,990	1.31	1.23	1.53
3010	14,670	41,370	7,470	17,200	43,540	8,430	1.17	1.05	1.13
3020	9,430	22,660	20,130	11,330	25,550	25,020	1.20	1.13	1.24
3030	10,270	29,500	6,900	14,530	38,150	8,830	1.41	1.29	1.28
3045	10,020	25,990	2,360	12,400	29,280	3,450	1.24	1.13	1.46
3046	9,470	24,010	6,100	10,650	25,480	7,070	1.12	1.06	1.16
3110	2,770	8,160	2,160	5,470	14,070	3,320	1.97	1.72	1.54
3120	8,920	24,120	16,780	11,970	28,960	24,490	1.34	1.20	1.46
3130	6,990	16,660	17,630	9,410	19,830	27,160	1.35	1.19	1.54
3200	7,000	19,560	4,900	12,350	31,300	6,810	1.76	1.60	1.39
3310	4,630	13,550	1,610	8,630	22,760	2,910	1.86	1.68	1.81
3320	8,390	24,530	2,330	15,320	41,760	4,020	1.83	1.70	1.73
3330	4,490	12,380	820	5,770	14,720	1,460	1.29	1.19	1.78
3413	2,410	6,700	630	3,940	10,180	880	1.63	1.52	1.40
3414	8,190	23,920	1,970	9,810	25,930	2,350	1.20	1.08	1.19
3415	7,720	21,550	4,810	11,220	28,560	5,150	1.45	1.33	1.07
3416	7,750	21,020	2,830	10,280	25,210	3,640	1.33	1.20	1.29
3425	5,110	14,830	1,760	10,120	27,020	1,810	1.98	1.82	1.03
3426	5,250	16,490	2,200	10,300	29,860	2,240	1.96	1.81	1.02
3427	6,230	17,760	3,030	11,720	30,870	3,970	1.88	1.74	1.31
3505	14,250	33,990	14,600	17,490	39,230	20,130	1.23	1.15	1.38
3600	7,610	17,060	42,290	9,590	20,610	57,650	1.26	1.21	1.36
3705	11,950	31,290	33,390	14,630	34,950	40,940	1.22	1.12	1.23
3706	6,140	15,100	3,080	7,100	16,080	5,040	1.16	1.06	1.64
3815	8,000	18,770	9,080	10,780	23,330	8,850	1.35	1.24	0.97
3816	8,050	22,380	2,610	10,130	25,390	4,890	1.26	1.13	1.87
3825	6,570	17,240	5,570	8,850	21,240	7,130	1.35	1.23	1.28
3900	2,520	5,210	24,400	4,080	7,700	35,710	1.62	1.48	1.46
3905	3,400	8,750	17,240	3,820	8,650	26,020	1.12	0.99	1.51

Table D-1
Total Households, Population, and Employment for 2004 and 2030 (continued)

PSRC FAZ No.	Base Year 2004			Year 2030[1]			Growth Rate 2030 over 2004		
	Households	Population	Employment	Households	Population	Employment	House-holds	Popula-tion	Employ-ment
4005	4,460	11,550	1,460	5,800	13,640	2,830	1.30	1.18	1.94
4110	7,250	17,150	27,900	9,330	20,520	40,010	1.29	1.20	1.43
4120	7,620	17,430	2,890	9,370	19,840	3,980	1.23	1.14	1.38
4130	6,690	13,940	24,310	8,240	16,600	38,310	1.23	1.19	1.58
4210	6,560	16,120	2,490	11,410	26,290	3,730	1.74	1.63	1.50
4225	4,400	11,090	1,220	7,740	18,580	3,890	1.76	1.68	3.19
4226	5,880	14,860	1,450	8,840	20,720	2,850	1.50	1.39	1.97
4230	3,370	9,540	980	4,190	10,840	920	1.24	1.14	0.94
4300	4,710	10,640	9,050	6,100	13,260	13,130	1.30	1.25	1.45
4400	8,590	22,490	7,500	10,570	25,340	7,920	1.23	1.13	1.06
4505	5,480	15,830	680	7,700	20,300	880	1.41	1.28	1.29
4506	6,490	15,980	26,240	8,270	18,790	35,290	1.27	1.18	1.34
4605	7,590	20,570	9,670	10,290	26,320	13,810	1.36	1.28	1.43
4606	7,620	21,620	1,910	10,280	27,780	4,160	1.35	1.28	2.18
4607	4,140	12,920	4,370	10,680	30,480	7,680	2.58	2.36	1.76
4706	4,080	13,590	1,140	6,040	17,310	1,350	1.48	1.27	1.18
4810	4,090	8,930	7,080	5,040	10,310	10,680	1.23	1.15	1.51
4820	3,420	7,040	4,810	4,420	8,560	5,250	1.29	1.22	1.09
4900	2,880	3,590	34,910	12,390	17,460	77,510	4.30	4.86	2.22
5010	8,150	18,410	15,300	9,890	20,570	18,600	1.21	1.12	1.22
5020	9,770	24,780	6,550	11,140	25,700	8,010	1.14	1.04	1.22
5100	2,730	7,340	1,060	3,010	7,450	1,540	1.10	1.01	1.45
5205	5,370	11,790	28,390	10,060	19,720	41,250	1.87	1.67	1.45
5305	10,350	23,510	18,570	13,330	27,430	33,110	1.29	1.17	1.78
5306	9,690	22,120	15,960	13,100	27,420	21,370	1.35	1.24	1.34
5415	5,890	14,270	48,410	10,610	22,140	67,440	1.80	1.55	1.39
5425	14,950	35,640	25,340	22,720	48,940	43,510	1.52	1.37	1.72
5426	5,520	14,980	9,540	8,460	21,370	14,510	1.53	1.43	1.52
5515	9,010	23,830	2,780	11,220	26,770	4,070	1.25	1.12	1.46
5525	5,010	12,240	5,310	7,990	18,660	6,180	1.59	1.52	1.16
5535	8,250	20,460	4,460	10,460	24,400	6,460	1.27	1.19	1.45
5545	3,820	11,960	2,640	6,010	16,790	6,220	1.57	1.40	2.36
5546	5,600	16,070	8,760	7,930	20,490	14,100	1.42	1.28	1.61
5600	5,310	12,870	10,540	7,570	16,960	15,500	1.43	1.32	1.47
5715	7,340	16,580	880	7,920	16,380	2,060	1.08	0.99	2.34
5716	9,160	25,100	4,970	9,830	24,310	5,610	1.07	0.97	1.13
5720	16,890	33,870	7,590	18,220	34,510	9,980	1.08	1.02	1.31
5815	1,860	5,080	21,850	1,940	4,840	28,470	1.04	0.95	1.30
5825	1,010	2,680	38,000	1,630	4,010	54,730	1.61	1.50	1.44
5826	2,160	4,350	6,050	2,570	4,910	9,220	1.19	1.13	1.52

Table D-1
Total Households, Population, and Employment for 2004 and 2030 (continued)

PSRC FAZ No.	Base Year 2004			Year 2030[1]			Growth Rate 2030 over 2004		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
5915	7,000	20,870	4,190	8,630	23,200	6,310	1.23	1.11	1.51
5916	12,360	36,440	5,230	13,730	38,320	7,660	1.11	1.05	1.46
5925	9,670	25,730	14,400	12,120	29,450	18,850	1.25	1.14	1.31
6010	5,510	12,730	134,550	11,640	23,240	176,900	2.11	1.83	1.31
6020	8,680	12,260	43,790	19,970	27,280	66,740	2.30	2.23	1.52
6113	19,040	30,290	38,780	24,120	36,650	42,490	1.27	1.21	1.10
6114	14,190	30,750	16,340	17,490	36,000	19,050	1.23	1.17	1.17
6115	10,450	20,620	7,770	11,490	21,180	10,310	1.10	1.03	1.33
6123	8,120	13,360	48,580	19,710	29,710	68,020	2.43	2.22	1.40
6124	13,270	25,190	9,730	15,200	26,840	14,560	1.15	1.07	1.50
6125	4,950	9,390	7,850	5,400	9,950	11,880	1.09	1.06	1.51
6126	5,440	12,390	2,060	5,900	12,330	3,560	1.08	1.00	1.73
6213	9,100	16,650	11,600	10,330	18,040	17,450	1.14	1.08	1.50
6214	230	2,560	24,970	460	2,860	29,610	2.00	1.12	1.19
6215	11,120	28,200	12,540	14,230	32,610	17,920	1.28	1.16	1.43
6216	6,090	14,910	7,270	6,890	15,250	6,830	1.13	1.02	0.94
6223	12,070	26,020	5,740	14,040	28,780	8,940	1.16	1.11	1.56
6224	10,270	21,040	5,390	12,560	23,930	7,600	1.22	1.14	1.41
6225	9,030	18,480	14,600	12,390	23,260	20,620	1.37	1.26	1.41
6226	12,670	29,080	4,810	14,230	30,150	7,710	1.12	1.04	1.60
6316	13,310	25,770	13,390	15,960	28,900	16,630	1.20	1.12	1.24
6325	15,350	33,940	4,770	18,750	38,650	7,410	1.22	1.14	1.55
6326	10,630	23,070	8,840	13,350	26,910	11,240	1.26	1.17	1.27
6410	13,910	35,530	11,420	15,640	37,120	13,120	1.12	1.04	1.15
6420	12,650	32,560	6,110	13,870	33,150	6,950	1.10	1.02	1.14
6505	2,280	5,300	2,280	6,140	15,060	2,050	2.69	2.84	0.90
6506	5,270	14,010	3,460	7,230	17,810	5,290	1.37	1.27	1.53
6605	3,610	9,930	1,210	6,350	16,900	1,540	1.76	1.70	1.27
6606	1,770	4,950	770	2,810	7,230	1,240	1.59	1.46	1.61
6900	2,680	7,320	1,260	3,380	8,400	2,350	1.26	1.15	1.87
6910	1,220	3,140	650	2,370	5,570	730	1.94	1.77	1.12
7015	6,650	16,170	3,380	8,250	18,210	4,100	1.24	1.13	1.21
7025	8,600	19,240	6,830	11,930	24,530	8,810	1.39	1.27	1.29
7026	3,720	10,130	390	4,500	11,010	540	1.21	1.09	1.38
7100	8,050	20,890	7,570	10,460	24,510	10,390	1.30	1.17	1.37
7205	5,330	14,370	6,020	6,680	16,390	8,700	1.25	1.14	1.45
7206	7,140	17,600	11,510	10,080	22,490	20,830	1.41	1.28	1.81
7315	5,710	16,760	2,450	9,480	24,730	3,680	1.66	1.48	1.50
7316	6,740	18,940	2,310	10,180	25,780	3,870	1.51	1.36	1.68
7320	9,160	23,670	5,490	17,270	41,600	8,260	1.89	1.76	1.50

Table D-1
Total Households, Population, and Employment for 2004 and 2030 (continued)

PSRC FAZ No.	Base Year 2004			Year 2030[1]			Growth Rate 2030 over 2004		
	Households	Population	Employment	Households	Population	Employment	House-holds	Popula-tion	Employ-ment
7335	11,790	31,930	6,420	19,190	46,220	9,880	1.63	1.45	1.54
7340	7,990	23,190	2,040	12,850	34,000	2,760	1.61	1.47	1.35
7415	3,040	7,790	8,210	6,060	14,800	13,820	1.99	1.90	1.68
7425	6,830	20,590	1,050	13,490	38,030	2,470	1.98	1.85	2.35
7435	2,670	7,880	1,670	3,710	9,970	4,160	1.39	1.27	2.49
7436	2,030	5,860	640	3,210	8,620	1,510	1.58	1.47	2.36
7515	1,440	3,720	6,230	3,460	7,960	12,400	2.40	2.14	1.99
7525	5,440	15,590	1,160	7,880	20,190	2,980	1.45	1.30	2.57
7526	5,420	14,460	5,010	8,430	21,080	8,780	1.56	1.46	1.75
7535	6,760	15,260	3,670	16,250	34,420	7,950	2.40	2.26	2.17
7537	8,140	20,720	11,910	13,290	30,660	18,160	1.63	1.48	1.52
7605	680	1,950	390	790	2,100	650	1.16	1.08	1.67
7606	670	1,630	390	1,450	3,520	710	2.16	2.16	1.82
7700	3,310	8,690	3,920	4,810	11,430	6,240	1.45	1.32	1.59
7805	5,810	16,990	1,290	10,590	28,610	2,430	1.82	1.68	1.88
7806	1,510	4,290	650	2,980	7,640	1,610	1.97	1.78	2.48
7905	6,030	17,290	3,340	11,720	30,750	5,400	1.94	1.78	1.62
8000	4,250	11,560	28,530	7,170	17,310	36,670	1.69	1.50	1.29
8115	10,920	26,240	8,500	16,360	36,350	13,080	1.50	1.39	1.54
8125	6,130	15,820	4,300	8,100	18,810	5,910	1.32	1.19	1.37
8126	4,780	12,100	6,270	6,330	14,660	9,650	1.32	1.21	1.54
8210	3,940	9,390	16,650	6,080	13,260	25,410	1.54	1.41	1.53
8220	7,060	19,450	14,970	8,830	21,700	23,990	1.25	1.12	1.60
8310	11,010	29,630	7,470	17,000	41,080	9,920	1.54	1.39	1.33
8320	4,030	12,580	4,360	6,910	19,260	8,150	1.71	1.53	1.87
8405	4,190	12,320	270	8,770	24,900	490	2.09	2.02	1.81
8406	590	1,730	60	1,550	3,980	160	2.63	2.30	2.67
8500	5,310	13,840	7,740	10,840	26,810	13,770	2.04	1.94	1.78
8600	5,550	18,220	8,020	9,450	27,900	11,600	1.70	1.53	1.45
8905	2,810	8,210	270	3,750	10,010	400	1.33	1.22	1.48
8906	2,780	8,240	410	3,950	10,600	800	1.42	1.29	1.95
8910	5,340	14,600	1,380	8,640	21,440	1,790	1.62	1.47	1.30
8925	4,350	12,200	1,010	7,690	20,040	1,810	1.77	1.64	1.79
8926	4,680	13,100	810	6,860	17,470	1,370	1.47	1.33	1.69
8927	1,840	5,160	140	2,670	6,900	210	1.45	1.34	1.50
8935	3,690	10,290	3,340	6,720	17,290	5,310	1.82	1.68	1.59
8936	5,940	16,420	1,120	9,290	23,410	1,990	1.56	1.43	1.78
8937	3,560	10,170	2,980	5,720	14,530	6,480	1.61	1.43	2.17
Subtotal	**1,255,200**	**3,179,600**	**1,678,500**	**1,798,400**	**4,206,800**	**2,384,300**	**1.43**	**1.32**	**1.42**

Table D-1
Total Households, Population, and Employment for 2004 and 2030 (continued)

PSRC FAZ No.	Base Year 2004			Year 2030[1]			Growth Rate 2030 over 2004		
	Households	Population	Employment	Households	Population	Employment	House-holds	Popula-tion	Employ-ment
Rest of the Region									
6930	4,240	10,180	2,260	5,380	11,920	2,770	1.27	1.17	1.23
9002	8,590	22,840	7,480	11,850	29,350	8,230	1.38	1.29	1.10
9004	5,450	14,570	2,250	10,090	25,850	4,340	1.85	1.77	1.93
9005	1,950	5,510	80	3,510	8,830	220	1.80	1.60	2.75
9006	3,260	9,120	560	5,340	13,900	1,290	1.64	1.52	2.30
9009	1,680	4,400	490	2,890	7,060	1,200	1.72	1.60	2.45
9011	3,270	7,900	6,090	5,720	12,540	7,620	1.75	1.59	1.25
9015	5,170	14,340	880	7,250	18,190	1,360	1.40	1.27	1.55
9016	3,850	10,640	1,000	5,600	14,700	1,640	1.45	1.38	1.64
9017	1,300	3,400	190	1,940	4,560	450	1.49	1.34	2.37
9018	5,810	15,600	10,470	9,330	22,640	13,610	1.61	1.45	1.30
9019	5,340	13,670	1,840	9,410	22,630	3,340	1.76	1.66	1.82
9020	5,120	12,830	1,770	9,350	22,100	3,100	1.83	1.72	1.75
9900	2,970	7,110	1,460	4,080	8,830	2,370	1.37	1.24	1.62
9901	2,570	7,220	3,170	3,520	9,000	4,620	1.37	1.25	1.46
9902	9,950	26,120	28,090	12,060	27,560	34,550	1.21	1.06	1.23
9904	4,670	10,380	5,970	6,330	12,810	6,560	1.36	1.23	1.10
9908	1,340	7,630	8,820	1,510	8,580	6,690	1.13	1.12	0.76
9909	1,590	4,470	520	2,130	5,560	1,310	1.34	1.24	2.52
9913	2,580	5,430	4,000	4,210	8,400	4,250	1.63	1.55	1.06
9914	5,750	15,710	1,790	8,800	21,840	3,170	1.53	1.39	1.77
9915	5,350	15,060	2,610	6,260	15,890	2,880	1.17	1.06	1.10
9916	3,660	10,220	1,510	5,280	13,420	2,870	1.44	1.31	1.90
Subtotal	**95,500**	**254,400**	**93,300**	**141,800**	**346,200**	**118,400**	**1.48**	**1.36**	**1.27**
Four County Total	**1,350,700**	**3,434,000**	**1,771,800**	**1,940,200**	**4,552,900**	**2,502,700**	**1.44**	**1.33**	**1.41**

Source: PSRC's "2006 Small Area" land-use forecasts. These forecasts are currently available on their website - http://www.psrc.org/data/forecasts/saf/

[1] For FAZs 5205, 5415 and 5425, the 2030 land use forecasts are based on the recommendation from PSRC in their May 21, 2009 letter to Sound Transit. This recommendation follows the comprehensive plan changes that City of Bellevue and Redmond adopted at that time in Bel-Red and Overlake neighborhoods.

Table D-2
Zonal Parking Costs for 2004 and 2030 (in 2004 Constant Dollars)

	Daily		Hourly			Daily		Hourly			Daily		Hourly	
TAZ	2004	2030	2004	2030	TAZ	2004	2030	2004	2030	TAZ	2004	2030	2004	2030
15	$0.00	$3.86	$0.00	$2.32	115	$3.49	$5.84	$2.09	$3.50	148	$3.35	$4.94	$2.01	$2.96
16	$0.00	$3.86	$0.00	$2.32	116	$9.63	$14.18	$5.78	$8.51	149	$0.00	$0.00	$0.00	$0.00
43	$2.94	$4.34	$1.77	$2.60	117	$13.47	$19.83	$8.08	$11.90	150	$0.00	$0.00	$0.00	$0.00
44	$2.94	$4.34	$1.77	$2.60	118	$6.37	$9.38	$3.82	$5.63	153	$3.35	$4.94	$2.01	$2.96
47	$0.00	$3.86	$0.00	$2.32	119	$8.98	$13.22	$5.39	$7.93	154	$2.63	$3.87	$1.58	$2.32
58	$3.76	$5.54	$2.26	$3.33	120	$14.07	$20.72	$8.44	$12.43	155	$8.95	$13.18	$5.37	$7.91
59	$3.76	$5.54	$2.26	$3.33	121	$17.98	$26.48	$10.79	$15.89	156	$2.63	$3.87	$1.58	$2.32
60	$3.83	$6.41	$2.30	$3.85	122	$17.08	$25.16	$10.25	$15.10	157	$2.63	$3.87	$1.58	$2.32
62	$2.94	$4.34	$1.77	$2.60	123	$10.11	$14.89	$6.07	$8.93	158	$2.63	$3.87	$1.58	$2.32
64	$3.76	$5.54	$2.26	$3.33	124	$13.15	$19.37	$7.89	$11.62	159	$2.63	$3.87	$1.58	$2.32
65	$3.76	$5.54	$2.26	$3.33	125	$14.31	$21.07	$8.59	$12.64	162	$8.33	$12.26	$5.00	$7.36
69	$4.71	$6.93	$2.82	$4.16	126	$17.98	$26.48	$10.79	$15.89	163	$2.63	$3.87	$1.58	$2.32
70	$4.82	$8.07	$2.89	$4.84	127	$12.89	$18.98	$7.73	$11.39	240	$0.00	$3.86	$0.00	$2.32
71	$9.05	$15.15	$5.43	$9.09	128	$12.23	$18.02	$7.34	$10.81	255	$0.00	$3.86	$0.00	$2.32
72	$9.65	$16.14	$5.79	$9.68	129	$12.14	$20.32	$7.28	$12.19	262	$0.00	$1.94	$0.00	$1.16
73	$12.04	$20.15	$7.23	$12.09	130	$12.14	$20.32	$7.28	$12.19	263	$0.00	$3.86	$0.00	$2.32
94	$7.05	$10.38	$4.23	$6.23	131	$11.99	$17.66	$7.20	$10.60	264	$0.00	$1.94	$0.00	$1.16
95	$3.76	$5.54	$2.26	$3.32	132	$18.07	$26.62	$10.84	$15.97	280	$0.00	$15.44	$0.00	$9.26
96	$3.76	$5.54	$2.26	$3.32	133	$21.69	$31.95	$13.02	$19.17	281	$0.00	$3.86	$0.00	$2.32
97	$0.00	$0.00	$0.00	$0.00	134	$16.12	$23.74	$9.67	$14.24	283	$10.01	$15.10	$6.00	$9.06
98	$5.89	$8.67	$3.53	$5.20	135	$17.18	$25.30	$10.31	$15.18	284	$10.81	$16.31	$6.48	$9.79
99	$7.89	$11.62	$4.73	$6.97	136	$14.36	$21.15	$8.61	$12.69	309	$0.00	$3.86	$0.00	$2.32
100	$11.17	$16.45	$6.70	$9.87	137	$6.18	$10.35	$3.71	$6.21	310	$0.00	$3.86	$0.00	$2.32
101	$5.91	$8.71	$3.55	$5.22	138	$12.14	$20.32	$7.29	$12.19	325	$0.00	$3.86	$0.00	$2.32
102	$13.15	$19.37	$7.89	$11.62	139	$8.98	$15.02	$5.39	$9.01	351	$0.00	$3.86	$0.00	$2.32
103	$5.32	$8.90	$3.19	$5.34	140	$10.91	$16.06	$6.54	$9.64	355	$12.46	$18.35	$7.48	$11.01
104	$8.01	$11.80	$4.81	$7.08	141	$7.20	$12.04	$4.32	$7.23	356	$0.00	$3.86	$0.00	$2.32
105	$5.32	$8.90	$3.19	$5.34	142	$7.02	$11.75	$4.21	$7.05	357	$0.00	$3.86	$0.00	$2.32
106	$9.10	$13.40	$5.46	$8.04	143	$9.22	$15.44	$5.53	$9.26	361	$0.00	$1.94	$0.00	$1.16
107	$5.32	$8.90	$3.19	$5.34	144	$4.65	$7.78	$2.79	$4.67	362	$0.00	$7.18	$0.00	$4.31
108	$5.59	$9.35	$3.35	$5.61	145	$14.60	$21.50	$8.76	$12.90	363	$0.00	$3.86	$0.00	$2.32
109	$5.74	$8.46	$3.45	$5.07	146	$4.25	$7.12	$2.55	$4.27	364	$0.00	$1.94	$0.00	$1.16
114	$3.40	$5.01	$2.04	$3.01	147	$3.35	$4.94	$2.01	$2.96	372	$0.00	$0.00	$0.00	$0.00

Table D-2
Zonal Parking Costs for 2004 and 2030 (in 2004 Constant Dollars) (continued)

TAZ	Daily 2004	Daily 2030	Hourly 2004	Hourly 2030	TAZ	Daily 2004	Daily 2030	Hourly 2004	Hourly 2030	TAZ	Daily 2004	Daily 2030	Hourly 2004	Hourly 2030
385	$0.00	$0.00	$0.00	$0.00	488	$0.00	$6.48	$0.00	$3.89	629	$1.08	$1.40	$0.65	$0.84
392	$0.00	$3.86	$0.00	$2.32	501	$0.00	$7.73	$0.00	$4.64	630	$1.11	$1.63	$0.67	$0.98
395	$0.00	$0.00	$0.00	$0.00	503	$0.00	$3.86	$0.00	$2.32	631	$5.48	$8.07	$3.29	$4.84
398	$0.00	$3.86	$0.00	$2.32	504	$0.00	$6.48	$0.00	$3.89	632	$5.48	$8.07	$3.29	$4.84
418	$4.03	$5.93	$2.42	$3.56	505	$0.00	$3.86	$0.00	$2.32	633	$3.28	$4.83	$1.97	$2.90
423	$0.00	$1.94	$0.00	$1.16	511	$0.00	$4.05	$0.00	$2.43	634	$3.28	$4.83	$1.97	$2.90
430	$0.00	$1.94	$0.00	$1.16	512	$2.75	$4.05	$1.65	$2.43	635	$6.03	$8.88	$3.62	$5.33
436	$0.00	$7.73	$0.00	$4.64	513	$2.75	$4.05	$1.65	$2.43	636	$6.03	$8.88	$3.62	$5.33
448	$0.00	$3.86	$0.00	$2.32	522	$0.00	$3.86	$0.00	$2.32	637	$6.03	$8.88	$3.62	$5.33
451	$0.00	$0.00	$0.00	$0.00	535	$0.00	$3.86	$0.00	$2.32	638	$6.03	$8.88	$3.62	$5.33
452	$0.00	$0.00	$0.00	$0.00	537	$0.00	$3.86	$0.00	$2.32	639	$0.00	$0.95	$0.00	$0.57
453	$0.00	$0.00	$0.00	$0.00	561	$0.00	$3.86	$0.00	$2.32	657	$0.00	$3.86	$0.00	$2.32
466	$0.00	$3.86	$0.00	$2.32	564	$0.00	$3.86	$0.00	$2.32	672	$0.00	$5.78	$0.00	$3.47
467	$0.00	$1.94	$0.00	$1.16	585	$0.00	$0.00	$0.00	$0.00	673	$0.00	$5.78	$0.00	$3.47
468	$0.00	$3.86	$0.00	$2.32	586	$0.00	$3.86	$0.00	$2.32	713	$0.00	$4.04	$0.00	$2.43
475	$0.00	$3.86	$0.00	$2.32	587	$0.00	$3.86	$0.00	$2.32	734	$0.00	$3.86	$0.00	$2.32
476	$0.00	$6.48	$0.00	$3.89	598	$0.00	$1.94	$0.00	$1.16	735	$0.00	$1.94	$0.00	$1.16
484	$11.08	$16.31	$6.65	$9.79	603	$0.00	$3.86	$0.00	$2.32	737	$0.00	$3.86	$0.00	$2.32
485	$10.26	$15.10	$6.15	$9.06	609	$1.08	$1.40	$0.65	$0.84	777	$0.00	$7.18	$0.00	$4.31
487	$12.46	$18.35	$7.48	$11.01	610	$1.08	$1.40	$0.65	$0.84	778	$0.00	$1.94	$0.00	$1.16