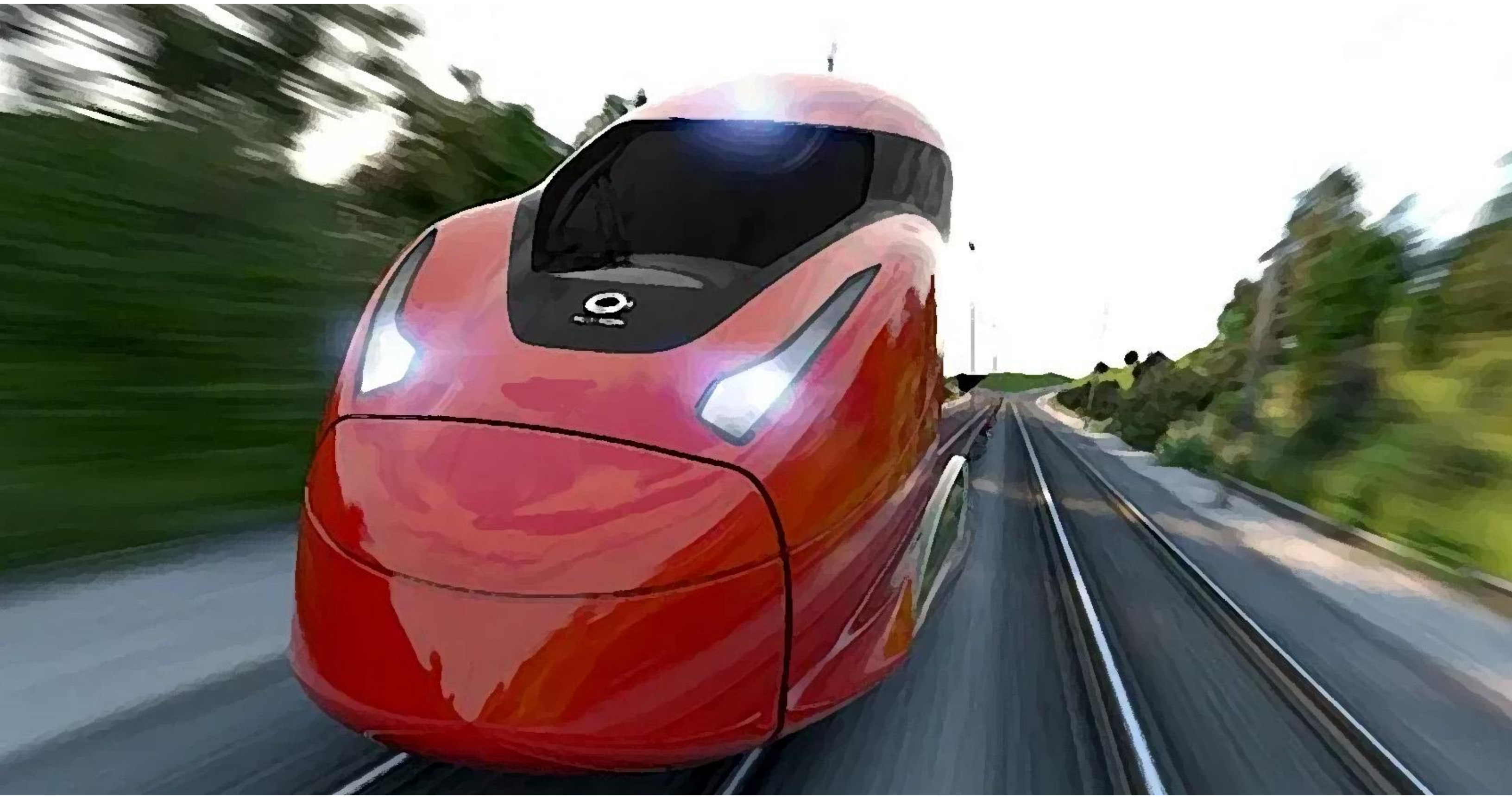
Cascadia High Speed Rail:
Service Development Plan
Portland to Seattle Segment



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1. RATIONALE, GOALS, AND OBJECTIVES

This Service Development Plan (SDP) report lays out the overall approach for implementing the proposed Cascadia Ultra High Speed Rail project for the Cascadia Corridor (Portland, OR to Seattle, WA segment) over the next 30 years. It will provide key results for ridership, revenue, financial and economic analyses. This plan for implementing ultra high-speed service will dramatically transform mobility in the Cascadia region. It will serve as a catalyst for the rebirth of passenger rail in the region, and for local efforts to leverage passenger rail investments to spark new economic development around stations and in the communities served by the system. Chapter 1 of this report sets out the background and purpose of the Cascadia Ultra High Speed Rail project, including outlining the Vision for the corridor, the project scope, and the methodologies used.

1.1 BACKGROUND

The Cascadia High Speed Rail (CHSR) Corridor, shown in Exhibit 1-1, has been recognized as a potential high-speed rail corridor since the early 1980's, when it was identified by USDOT FRA as one of the 11 best high-speed rail corridors for development. This was driven by the fact that the core of the corridor from Seattle, WA to Portland, OR is one of the densest in the US and as such, has sufficient population density, to sustain a high-speed rail service. The market for high-speed rail between Vancouver, British Columbia and Eugene, Oregon is substantial. The corridor contains a population of over 9.5 million people and on a stand-alone basis would be the world's 30th largest economy. This was also recognized by the widely acclaimed America 2050 study which noted that not only was the population dense, but it was hemmed in between the parallel Coastal and Cascade Mountain ranges, which forces development into the form of a linear corridor.

America 2050 developed six criteria to identify corridors in the U.S. where high-speed rail would be most successful. The criteria includes metropolitan size, distance, transit connections, economic productivity, congestion, and megaregion. Cities located in one of the 11 megaregions identified by America 2050 are more likely to be part of a network of interconnected cities with the appropriate density to support high-speed rail systems. The Cascadia megaregion emerged as one of the 11 megaregions with the characteristics most appropriate to support high-speed rail.

Exhibit 1-1: CHSR Corridor

The major cities of the CHSR corridor are too close to each other to be effectively served by air service, which economically needs at least 400 miles due to high energy costs associated with landing and taking off. However, the corridor cities are at an ideal distance for a passenger rail service.

Early experiments with passenger rail provided tangible evidence that this was the case, with ridership responding favorably even to minor improvements in a slow Amtrak service. For example, while with every rail improvement offered, such as the introduction of Talgo trains, the result has considerably improved ridership and revenue each time. As a result, the corridor from Seattle, WA south to Eugene, OR offers great potential for high-speed passenger rail. An extension north to Vancouver, BC also has great ridership potential, but due to the more difficult geographic terrain north of Seattle as well as the need for an international border crossing, it may require a different type of financing structure than that of the main spine from Seattle to Portland.

Heading south from Seattle, WA, the corridor links SEA-TAC Airport, which is the most important international airport and Asian gateway in the Northwest, Tacoma (the second largest city of Washington state), Olympia (the capital of Washington state), Centralia, Kelso, Vancouver, WA (a growing suburb of Portland), Portland Airport (the first passenger and freight airport of Oregon) and downtown Portland at the Rose Quarter (a major hub of the Portland transportation system). In the future it may be extended farther south to Salem (Oregon’s capitol), Albany, and Eugene, as well as north to Vancouver, BC.

The corridor is connected by Interstate 5 (I-5), but this highway is chronically congested from ever-increasing volumes of traffic. Everett, WA has some of the worst traffic congestion in the United States. Vancouver, BC; Seattle, WA; and Portland, OR, have the fourth, sixth, and tenth-most congested roads in North America, respectively. The need for continued additional transportation infrastructure investment in the Cascadia megaregion is clear—crowded roads, congested airports and limited intercity rail service constrain the mobility of residents, businesses, and tourists. Airport delays are making air travel increasingly unreliable, and the travel time and frequency of intercity rail service are not competitive for most trips, especially for business travel.

While government has considered directly funding highway improvements and/or using tolls to shift demand, major capacity expansions of urban freeways has been found impractical, due both to the significant costs and severe environmental impacts that highway expansion would have on densely built areas of cities. WSDOT has estimated that adding a lane in each direction to Interstate 5 in Washington would cost approximately $108 billion in 2018 dollars. Current plans for expansion at the region’s airports may not be sufficient to accommodate an expected doubling of demand.

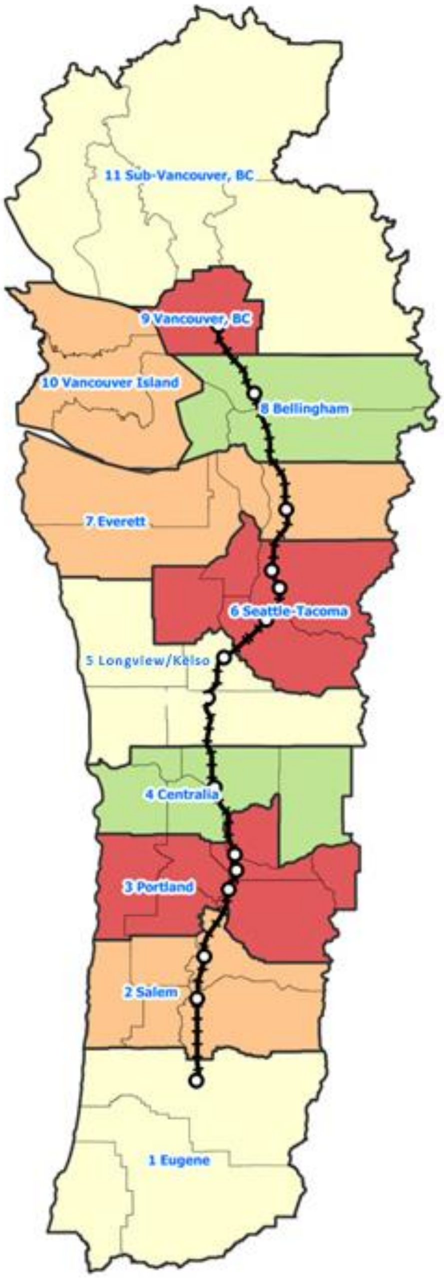
Amtrak’s Cascades rail service shares an alignment with freight rail and Sounder transit operations, which limits the opportunity to reduce travel times and improve frequencies. However, the success of major local initiatives to raise public funds for new transit development (such as the 2016 Sound Transit ballot initiative) demonstrates a public willingness to invest in new train systems.

As a result, the value proposition for developing an electrified, high-speed rail system is built on speed, time, and the monetary value that travelers place on their time. High-speed trains have a sustainable competitive advantage for inter-city trips between 100 and 500 miles. This makes high-speed rail the mode of choice for both intercity and commuter trips. A public/private partnership for developing a high-speed rail corridor in the Pacific Northwest would create significant new business opportunities for business and housing development opportunities around the station areas.

Exhibit 1-2 shows the Pacific Northwest corridor extending from Vancouver, BC to Seattle, WA, Portland, OR and ultimately to its southern terminus in Eugene, OR. 174 county level and urban TAZ zones were used for the demand analysis. The results were combined into 11 super zones, and then further combined into 4 regional aggregations. These zones have been further refined to investment-grade level environmental studies that are needed for further development in the corridor.

A rapidly growing economy and population of the Cascadia megaregion shares similar values, a skilled workforce and has an appetite for innovation. Cascadia's push for enhanced interconnectivity would maximize public transportation benefits.

Exhibit 1-2: CHSR Super-Zones



*Colors indicate the different Super zones defined by TEMS

However, the issues of increasing congestion, lack of capacity and unreliable existing transportation networks has led to a need to set out a vision to unlock a globally competitive, equitable, and sustainable Cascadia megaregion.

High-speed rail systems are an efficient transportation mode that can promote greater economic interconnectivity and innovation within megaregions. It does this by substantially enhancing increased connectivity between people, goods and services, promotes trade, tourism, housing, and employment options. Centralized, interconnected and efficient transportation hubs provide opportunities to generate economic development and jobs for businesses within the CHSR corridor.

In addition to economic development, several needs or drivers form the basis and rationale for Washington State and its partner stakeholders to study the potential for CHSR. These include (but are not limited to) the following:

- Robust population and economic growth in the Cascadia megaregion that encompasses the Vancouver, BC, to Portland, Oregon, travel market will substantially increase travel demand and generate additional congestion that further reduces automobile, transit, and air travel reliability using existing and committed transportation infrastructure.
- Automobile collisions and the resultant injuries, loss of life, and property damage decrease the safety of driving as a transportation mode and contribute to non-recurring congestion that reduces travel time reliability and increases delays for travelers.
- Current intercity passenger rail service operating capacity and speed constraints limit regional mobility, and economic development and global competitiveness.
- Declining air quality and greater climate instability associated with greenhouse gas emissions from increased travel demand and congestion require more environmentally sustainable modes of travel.
- Natural hazards, such as flooding, landslides and wildfires are common in the Cascadia megaregion and can result in prolonged closure or disruption to major transportation infrastructure including Interstate 5 and the BNSF/Amtrak rail line, with no other viable route options available.

Cumulatively, these driving factors negatively impact quality of life for residents, businesses, and visitors of the Cascadia megaregion. However, this analysis will show that CHSR can be among the most effective transportation investment solutions to promote the economic health and growth of the Cascadia megaregion. CHSR offers an opportunity to transform mobility beyond what current travel modes can provide. The reduced journey times—comparable to air travel—improved reliability, and the potential for direct downtown-to-downtown connections would enable residents and visitors to easily and quickly access the region's major cities and towns. Investment in CHSR can provide the following key benefits or outcomes:

- A better-connected megaregion resulting from faster journeys, increased capacity, and reduced congestion − CHSR would achieve this by integrating the megaregion's major commercial hubs and population centers including intermediate stations along a new transportation spine using a greener, environmentally advanced travel mode.
  - Travel times between each of the three major cities would be less than an hour for each segment, with connections to other transportation modes at all stations.
  - There is a clearly stated willingness of travelers in the region to shift to CHSR from other modes and support greener modes of travel that provide shorter travel times and more reliable service with a significant reduction in greenhouse gas emissions.
- A stronger, more productive megaregion as more businesses/jobs locate in the Cascadia megaregion due to the dramatically improved access to housing, jobs, schools, and entertainment centers. Once implemented, CHSR would catalyze the transformation of the Cascadia regional economy into a more dynamic, globally competitive, megaregion.
- A more affordable megaregion as residents benefit from easier access to more affordable housing and to higher-paying jobs. This would improve mobility for residents throughout the megaregion and support a commitment to developing an equitable network connected to other transportation modes.
- A cleaner environment by connecting trips to more sustainable modes, reducing carbon emissions and environmental impacts on wildlife.
- A better value infrastructure investment giving more value to the region than alternative projects such as interstate highways or airport expansion.
- Broad support from businesses, stakeholders, and travelers given its ability to unlock sustainable high quality growth, that is cost effective and provides safer journeys compared to existing road or air options.
- A modern delivery approach drawing on proven governance and procurement models plus innovative funding mechanisms.
  - These include lessons learned from other similar infrastructure projects related to funding mechanisms, phasing approaches, private investments, risk management, governance structure, and public accountability.
  - Recent trans-border and international models include the Gordie Howe International Bridge, Vancouver's Canada Line, Montreal's REM, UK HS1/Channel Tunnel, and London's Crossrail.

1.2 PROJECT DESCRIPTION: THE "VISION" FOR DEVELOPMENT OF THE CHSR CORRIDOR

The implementation of the proposed infrastructure improvements in the initial Seattle to Portland segment of the Cascadia High Speed Rail (CHSR) corridor will cost approximately $20 billion, or $121 million per mile for the 166-mile double tracked main line. In addition to this, spur lines would be developed both into SEA-TAC and Portland Airports; of which $1.5 billion would be CHSR's share of the cost. A description of the specific envisioned improvements and costs can be found in the Capital Improvement Plan section of this Service Development Plan.

These improvements will expand travel options between the some of the largest cities in the Pacific Northwest, improve operational efficiency as compared to today's slow Amtrak service, increase the number of passenger trains, increase the number of stations, maintain on-time performance, and attract new riders into the system. The result will be a significant reduction in highway traffic congestion, reduction in carbon emissions and an improvement in air quality.

The US Department of Commerce estimates that every $1 billion dollars of new rail investment creates 20,000 person-years of work. Using this methodology, the total capital cost of approximately $20 billion will create 400,000 person-years of work or 80,000 jobs over the 5-year construction period of the project. In addition, Transit Oriented Development opportunities will be enhanced at each station stop along the line, creating additional jobs and economic development activity. A description of the specific economic impacts can be found in the Public Benefits Analysis section of this Service Development Plan.

The "Vision" for the CHSR would be is to establish a true high-speed rail system that would fully integrate the Pacific Northwest region including linkages north to Canada as well as south to Oregon and, in the long-term, California.

To support and further develop the Cascadia High Speed Rail project, a number of institutional developments are critical. These include:

- Development of a public/private partnership with the states of Washington and Oregon.
- Development of a funding framework between federal, state, and private sectors to move the project forward.
- Further public and stakeholder outreach to the communities of the Cascadia corridor to identify any issues and to show the benefits of the project to each community.
- Completion of the Tier 2 EIS to provide a detailed understanding of the environmental issues and benefits of developing the Cascadia High Speed Rail corridor.

1.3 PROJECT RATIONALE

1.3.1 PROJECT PURPOSE

The purpose of the project is to develop new, dedicated ultra high-speed rail infrastructure and passenger rail service and intermodal connections within the Pacific Northwest, which will promote economic integration, growth, development, enhance energy efficiency and environmental quality. The project will allow for 220-mph or faster high-speed rail operations, while providing a safe, convenient, and reliable alternative mode of travel. The study area's transportation network has many links and facilities that are functionally inadequate. The Pacific Northwest is one of the most densely populated areas of the country and its major roadways and air traffic corridors experience chronic congestion. This has led to delays and reliability problems for all modes of transportation. Intercity trips are one of the most rapidly growing trip types in the study area and present the greatest transportation mode opportunity by shifting future riders from less efficient, more congested vehicle travel to rail.

Linking the larger cities together with high-speed passenger rail will enable the study area to function as an integrated economic unit in spite of existing State and National boundaries. The rail system will serve key destinations within the corridor and also address growing express freight capacity needs, which are necessary for continued economic growth. The project will serve as a beneficial economic stimulus at proposed station locations. It will act as a catalyst for integrating the existing transit systems and enhancing regional economic growth and development opportunities in a way that is consistent with smart growth and long-term sustainability.

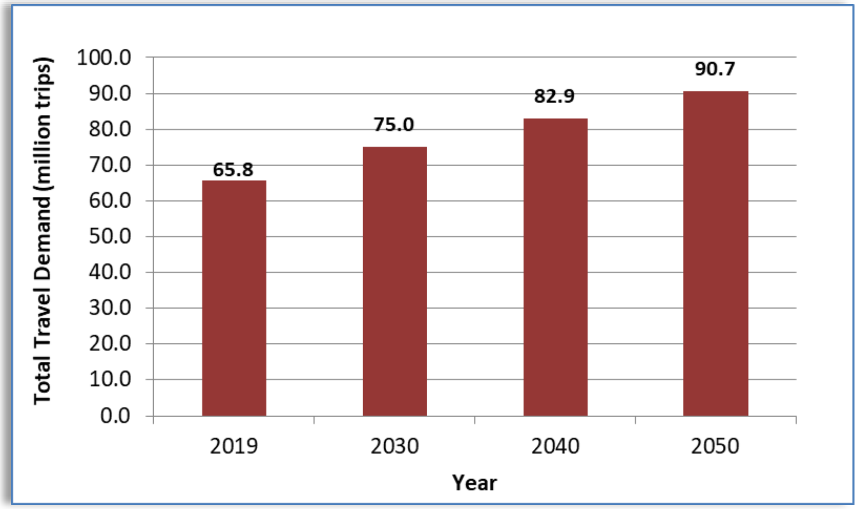
The CHSR corridor presents a great opportunity to link together a string of livable downtowns and neighborhoods. Many station locations already boast a vibrant mixture of land uses in compact and walkable nodes of activity, supported by effective transit systems that will be advanced by enhanced intercity rail service. Investment in high-speed rail will reinforce these communities as economic, residential, and cultural hubs of their respective areas and will lay the foundation for continued private sector investment in and around station locations.

With high levels of forecasted ridership, rail will be one of the most energy efficient means of passenger transportation. Shifting ridership from automobile to rail will provide congestion relief on highways and result in a corresponding reduction in greenhouse gases. Additionally, rail investments promote compact growth patterns, which is consistent with national, state, and local planning goods and policies that encourage smart growth.

1.3.2 PROJECT NEED

The Cascadia region has extensive multi-modal transportation systems of highways, airports, that link to intercity, commuter rail, and public transit that serves all major cities and many intermediate markets. However, after significant investment over decades in all modes, the study area still faces major congestion and capacity constraints. These constraints, if not addressed, have the potential to curtail future mobility, which will lead to slower economic growth. With forecasted demographic growth, coupled with growing capacity constraints on highways and at major airports, a 38% increase in total trip making as shown in Exhibit 1-3 could easily lead to doubling passenger rail ridership, even if no improvements are made to the rail system. This would overwhelm the capacity of the existing rail system even at the same time as all the other transportation modes likewise become saturated.

Exhibit 1-3: Total Intercity Travel Demand for the Cascadia Mega-Region



The need for the project is based on current and projected traffic congestion and safety concerns in the Interstate corridors, resulting from a lack of an integrated rail alternative to air travel, automobile, and truck usage. The CHSR Project would provide an attractive alternative mode of transportation for travel, within the Cascadia corridor, by providing direct connections to the two major passenger and freight airports and would provide effective connections to destinations outside the region as well. The project is part of an integrated, multi-modal vision that supports the transportation goals of the states in the project area and would be more cost effective and environmentally sensitive than attempting to meet the transportation demand by investing in highways expansion. Without the CHSR, the ability to develop a truly integrated intercity transportation system in the Pacific Northwest will not be possible.

1.3.3 PROJECT RATIONALE

Interstate 5 provides a critical commerce corridor and connections for the movement of people and goods linking Eugene, Portland, Seattle and Vancouver, BC. However, traffic congestion is routinely experienced on I-5 particularly in and around the urban areas of Portland and Seattle which experiences some of the worst traffic congestion in the country. However, the CHSR plan will provide an attractive option for intercity and commuter travelers in the Study Area that would offer service that faster than driving; accordingly, it will have the ability to effectively start to reduce automobile usage. The electrified double track proposal for this new high-speed rail line will add the capacity equivalent of a 6-lane freeway.

As highways and airports become increasingly more gridlocked and the costs of most transportation modes have been rising due to increasing energy costs and rising costs from traffic congestion, environmental impacts, and pollution; the technology for intercity passenger rail has been steadily improving and costs have been falling compared to those of other modes. In considering the cost of transportation in the corridor, one significant factor is the price of gasoline. The International Energy Agency (IEA) suggests that, under its “central case”, gas prices will rise to at least $5 per gallon by 2050 in real terms. This makes auto use increasingly expensive and options like passenger rail more competitive over time.

To meet its mobility needs in the future, “The Vision” has also recognized the potential for developing a “green” energy efficient, environmentally friendly travel option for the CHSR corridor that can achieve a 1-hour travel time between Seattle and Portland. High-speed rail is well-known for being an energy efficient transportation mode. Furthermore, it encourages and supports much more compact and higher density patterns of urban development rather than the “sprawl” that is more typical of auto dependent development patterns. At a time when it is difficult to expand highways, increase air service, or build new bridges and tunnels, the proposed high-speed and enhanced intercity passenger rail will provide fast, efficient, and environmentally friendly travel to the urban core of major cities and communities of the Cascadia region and beyond. In this atmosphere of increasing transportation demands and rising energy costs, a new environmentally friendly mode of travel can offer fast and frequent downtown to downtown travel while also offering competitive fares and a high level of reliability even in peak hours. CHSR offers a unique opportunity to improve travel in the corridor for all existing and future travelers.

As of January 2018, just 11 round-trips operated along the existing rail corridor each day: two between Vancouver, BC and Seattle, two between Vancouver, BC and Portland, three between Seattle and Portland; one from Portland to Eugene, and three between Eugene and Seattle. Because of its complex and slow schedule and lack of frequency, this existing regional rail service cannot meet the needs of intercity/regional travelers and commuters. It simply lacks the capacity and speed to make a significant dent in auto travel.

The existing Amtrak service suffers poor on time performance due to heavy freight train traffic on the same rail line. The existing tracks cannot be upgraded to modern high-speed rail standards due to both geometric and capacity reasons. Freight rail companies will not allow added use of their corridors in cities.

Qualitative and quantitative assessments of all these factors will be presented in later sections of this SDP.

1.4 ORGANIZATION OF THE REPORT

CHAPTER 1 – RATIONALE, GOALS, AND OBJECTIVES: Chapter 1 lays out the overall approach for implementing the proposed Cascadia Ultra High Speed Rail system providing key results for ridership, revenue, financial and economic analyses. Chapter 1 of this report sets out the background and purpose of the Cascadia Corridor including outlining the Vision for the corridor, the project scope, and the methodologies used.

CHAPTER 2 – IDENTIFICATION OF ALTERNATIVES: This chapter discusses the development of the three proposed alignment alternatives for the Cascadia corridor at different levels of development.

CHAPTER 3 – PLANNING METHODOLOGY: This chapter discusses the methodologies used for developing the engineering, economic and environmental assessments of the routes. Key to the analytical approach is the interactive analysis, which is a process of iterative refinement of each option for best fitting each option to the market need. This means, for example, that train capacity and ridership will be balanced so that train sizes and frequencies are appropriately matched to the market demand.

CHAPTER 4 – DEMAND AND REVENUE FORECASTS: This chapter is divided into subsections including the introduction, zone system, socioeconomic data, transportation network data, origin-destination data, stated preference surveys, results and analysis. This chapter describes the steps of developing the market data which includes developing a zone system, socioeconomic database of the Study Area, how the transportation networks were developed, how the origin and destination databases were obtained and validated, and the methodology used to conduct the stated preference surveys. This chapter also presents the analysis of the ridership and revenue results for all three options that were assessed for the Cascadia corridor.

CHAPTER 5 – OPERATIONS ANALYSIS: This chapter discusses the development of the Service and Operating Plan and includes a discussion of the track infrastructure and train technology options. This chapter also describes the operating plan, station stopping patterns, frequencies, train times and train schedules for each route and technology option.

CHAPTER 6 – STATION AND ACCESS ANALYSIS: This chapter assesses the population base and market hinterland for each of the proposed CHSR stations and compares the population demographics with the forecasted ridership of each station. It should be noted that the major endpoint stations of Portland, OR and Seattle, WA are significant trip attractors as well as trip generators. This amplifies the importance of these key endpoint stations as effective anchors for the high-speed rail system.

CHAPTER 7 – CONCEPTUAL ENGINEERING AND CAPITAL PROGRAMMING: This chapter discusses the development of the Capital Plan and includes a discussion of the capital cost methodology and the capital costs for the CHSR corridor including breakdowns by unit costs. The unit capital costs for infrastructure, equipment, and maintenance facility capital costs for each route and technology options are described. This chapter also presents the Capital Spending plan for the project.

CHAPTER 8 – OPERATING AND MAINTENANCE COSTS: This chapter describes the Operating Costs and Maintenance Costs that are calculated for each year using operating cost drivers such as passenger volumes, train miles, and operating hours.

CHAPTER 9 – PUBLIC BENEFITS ANALYSIS: This chapter presents a detailed economic analysis for all three Cascadia alternatives, including key financial measures such as Operating Surplus and Operating Ratio. A detailed Economic Analysis was carried out using the Cost Benefit and financial criteria set out by the 1997 FRA Commercial Feasibility Study and BUILD grant requirements. Key economic measures such as NPV and Benefit/Cost Ratio at 3% and 7% discount rates were calculated along with projected supply-side economic impacts.

CHAPTER 10 – CONCLUSIONS AND NEXT STEPS: This chapter outlines the key findings of the study, and the next steps that should be taken to move the project forward.

APPENDICES:

APPENDIX A – *RightTrack*™ Passenger Rail Planning System

APPENDIX B – Zone System and Socioeconomic Data

APPENDIX C – *COMPASS*™ Model

2. IDENTIFICATION OF ALTERNATIVES

This chapter discusses the evaluation of the route and technology options leading to the development of the proposed route alignment for the CHSR Corridor (Portland, OR to Seattle, WA segment).

2.1 POTENTIAL ROUTE OPTIONS FROM PORTLAND TO SEATTLE

Any number of route options may be possible, but only a limited number of options are able to meet the Purpose and Need of the CHSR project. Only one existing rail corridor links Portland, OR with Seattle, WA, and it is used by the current Amtrak service. Within this corridor there are only short sections where existing rail alternatives may exist, for example the Point Defiance Bypass in Tacoma for passenger trains. In this case, Washington DOT has already made a decision to develop the Bypass for passenger trains at a cost of $165 million. As such, the Point Defiance route is included as part of the "No Build" or Base Case option in this SDP.

For development of new or "greenfield" options[1] there are many more possibilities. Geometric requirements determine the location choices available since permissible grades and curves ultimately determine the speed capability of the alignment. The use of existing rail and highway alignments can reduce the need for securing property, but ultimately the geometric and speed requirements drive the route selection:

- While an existing alignment segment may be very straight in some sections, unfortunately often obstructions exist where the alignment curves. To utilize the straight portion, these obstructions often cannot be avoided. This can make the "cure" worse than the "disease."
- Development of a "greenfield" option affords more flexibility in shifting the alignment to avoid obstacles. While the overall property taking impact can be greater, environmental impacts can be lessened by taking advantage of the flexibility in location that a greenfield alignment can afford. New alignments afford much more flexibility in meeting the geometric requirements of high-speed service, while preserving the ability to shift the alignment to avoid impacts on sensitive environmental areas.

The decision whether or not to use a segment of existing alignment is very situational and localized. If it is possible to easily transition into and out of an existing alignment, such an existing right-of-way is likely to be used. However, options like Alternative 1 and 2 that make greater use of existing alignments often compromise the geometric standards, reducing the speed capability of the alignment.

An "Improved Amtrak" option based on a "Shared Use" concept was not developed in this study, because some segments of the existing rail line have extremely poor geometry.[2] In concept, this study's Alternatives 1 and 2 are the most similar to an "improved Amtrak" option, since these options have been developed as an incremental improvement that closely follows the existing BNSF right-of-way. However, Alternatives 1 and 2:

- Are based on 100% passenger dedicated track that will not have any freight train interaction.
- For bypassing the most difficult sections, some segments of new "greenfield" alignment have been included in Alternatives 1 and 2.

Alternatives 1 and 2 can therefore be characterized as high-speed (exceeding 125 mph) options. Only Alternative 3 rises to the standards of an ultra high-speed alignment (clean geometry for 220 mph or better).

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[1] A Greenfield is a brand-new proposed rail line where no rail line ever has existed. This contrasts with upgrades to an existing rail corridor, or the restoration of an abandoned rail corridor, since the locations of existing or abandoned alignments are known for sure.

[2] These segments have curves too sharp or closely spaced to allow them to be eased to the standards for High-Speed operations. Such an option cannot be characterized as a "High-Speed" option consistent with the Purpose and Need of this study.

In summary, three high-speed rail alternatives have been developed for this assessment, along with a Base Case “Do Nothing” alternative:

- **“Do Nothing”** – assumes that existing Amtrak service simply continues at a maximum speed of 79 mph on the existing rail line using conventional trains. Under this alternative, public transportation services would continue to be limited to the existing Amtrak intercity rail service, providing minimum service, and not offering a true modal choice compared to automobile and airline transportation. Transit options would remain poorly integrated. The speed and frequency of existing trains are insufficient to provide a convenient option for many intercity passengers. In addition, the current service does not provide an efficient connection to either SEA-TAC or Portland International Airport (PDX). Amtrak’s limited services cannot attract enough ridership to significantly impact or affect travel options in the corridor for passengers, or the traffic volume on highways in the Study Area. As a result, congestion in the Study Area would be expected to increase along with a corresponding reduction in air quality, increase in greenhouse gas emissions and loss of economic competitiveness. The “Do Nothing” alternative does not meet the Purpose and Need. It is included in this document for the purpose of baseline comparison.
- **Alternative 1 (improved infrastructure)** – This alternative uses the same alignment as Alternative 2, non-electrified for tilting diesel trains. It would improve the existing Amtrak diesel service and raise the average speed to 90 mph. North of Lakewood, the existing BNSF/Amtrak alignment would be upgraded to provide access to Seattle. An upgraded existing rail alignment would receive grade separations and dedicated track and be shared with Sounder commuter trains. Due to the limited train frequencies required by a diesel option, Alternative 1 would be mostly single track with a few long passing and station sidings. It would be similar to the Brightline diesel service now being developed in Florida.
- **Alternative 2 (Ultra High-Speed, low infrastructure)** – In 2016, CHSR proposed[3] to improve the existing BNSF alignment as much as possible between Portland, OR to Lakewood, WA, including some segments of new alignment where the BNSF geometry is very poor. This alternative uses the same alignment as Alternative 1 but electrified and fully double tracked for tilting electric trains. As an option that was originally based on improving an existing rail corridor, the alignment permits only short stretches of high-speed running (less than 20 miles at 220 mph); and results in a 118-mph average speed. The service it could offer would be similar to that of Acela in the Northeast corridor.
- **Alternative 3 (Ultra High-Speed, high infrastructure) –** A brand new end-to-end alignment with improved geometry would allow super express operations of electric trains with an average commercial speed of 171-mph. While it parallels the BNSF alignment, it would only minimally share the right-of-way, mostly in the Olympia area. It has no sharing of track with BNSF or other rail systems whatsoever, and it has no rail or highway crossings at grade. This is a new alignment option developed by CHSR Company in 2020 and 2021 as a true ultra high-speed rail system. The service it could offer would be similar to that of the latest TGV in France or Shinkansen in Japan with over 130 miles of 220 mph operation. Furthermore, it should be noted that the Alternative 3 route has been designed to allow 250-mph train operations, as it is possible that high-speed train commercial speed will increase to 250 mph in the next few years. If this is the case, Alternative 3 train times could be improved by up to 10 minutes against the currently proposed timetables.

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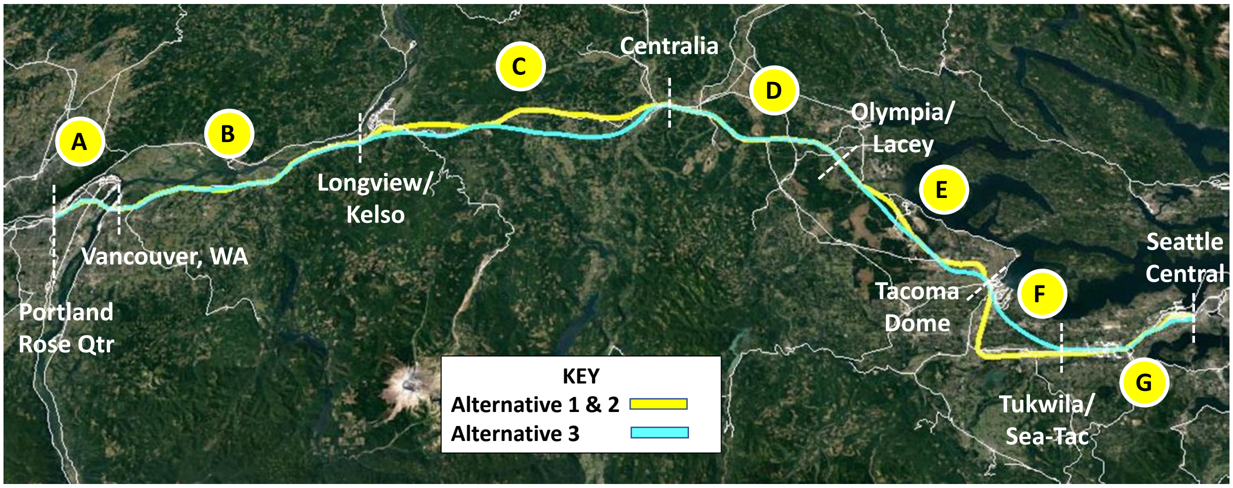
[3] See Docket #FRA-2016-0014 at: https://www.regulations.gov/document/FRA-2016-0014-0005 and https://www.regulations.gov/document/FRA-2016-0014-0006

2.2 POTENTIAL ROUTE OPTIONS FROM PORTLAND TO SEATTLE

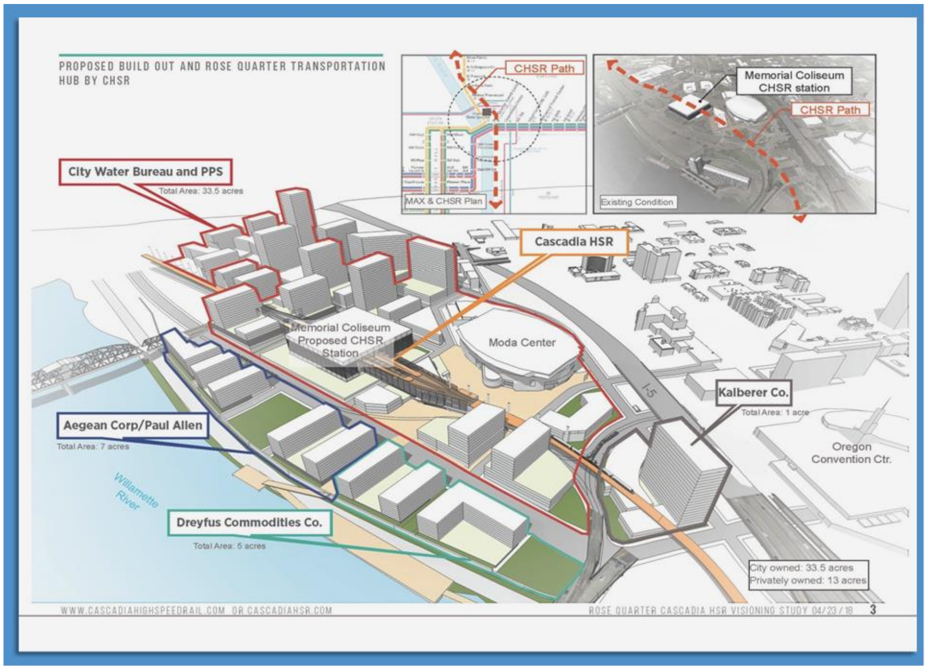
The alignments of Alternative 1 and Alternative 2 are identical, except diesel Alternative 1 can use the existing BNSF Columbia River Bridge at Vancouver, WA, and it can continue to use the existing King Street station in Seattle. The costs for the electric Alternatives 2 and 3 include a new Columbia River Bridge as well as a new Seattle Central train station. The alignment alternatives from Portland to Seattle are shown in Exhibit 2-1, which subdivides the route into seven segments, to be further detailed below.

Exhibit 2-1: High-Speed Rail Alternatives for the Portland to Seattle Corridor



SEGMENT A: PORTLAND ROSE QUARTER TO VANCOUVER, WA – In Portland, all options would start at a new station in the Rose Quarter (Exhibit 2-2) and utilize an elevated structure for getting around Union Pacific's Albina freight yard. (Exhibit 2-3). A new tunnel would parallel Union Pacific's existing Mock's Crest tunnel to emerge on the north side of the river bluff. From here the alignment would connect either with the existing Columbia River BNSF Railroad Bridge (in Alternative 1) or with a new Cascadia Multi-Modal Bridge (in Alternatives 2 and 3).

Exhibit 2-2: Proposed New CHSR Station as part of New Rose Quarter Transportation Hub



All alternatives from the proposed Portland Rose Quarter Transportation Hub follow the UP corridor and would be elevated around UP's freight yard and intermodal facility. A new Mocks Crest tunnel is needed to connect the route to the new Cascadia Multi-Modal Bridge over the Columbia River. The yellow line shows the location of the originally proposed 2016 alignment (identified as Alternatives 1&2) which was subsequently refined in Alternative 3 (see Exhibit 2-4) for reducing impacts on structures and on the Union Pacific rail yard.

Exhibit 2-3: Portland Rose Quarter to Vancouver, WA

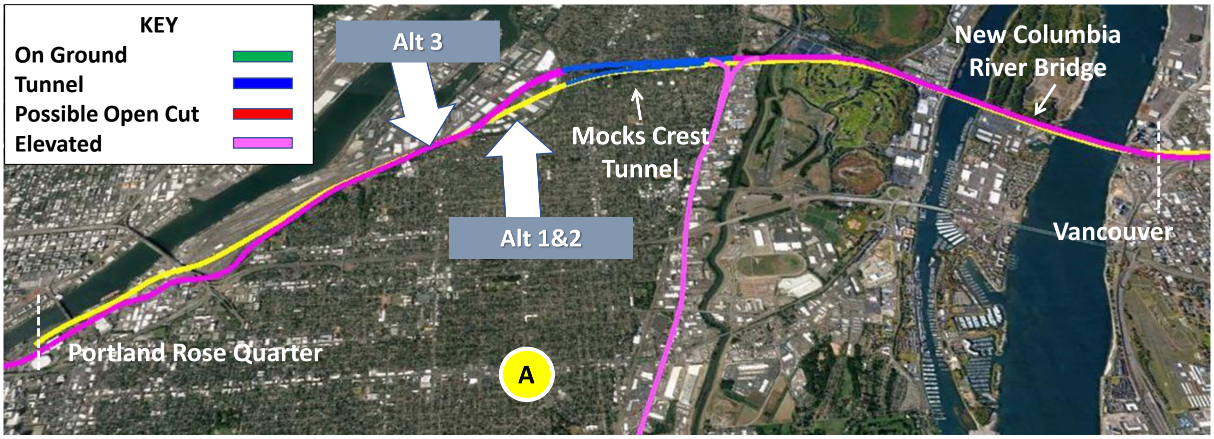
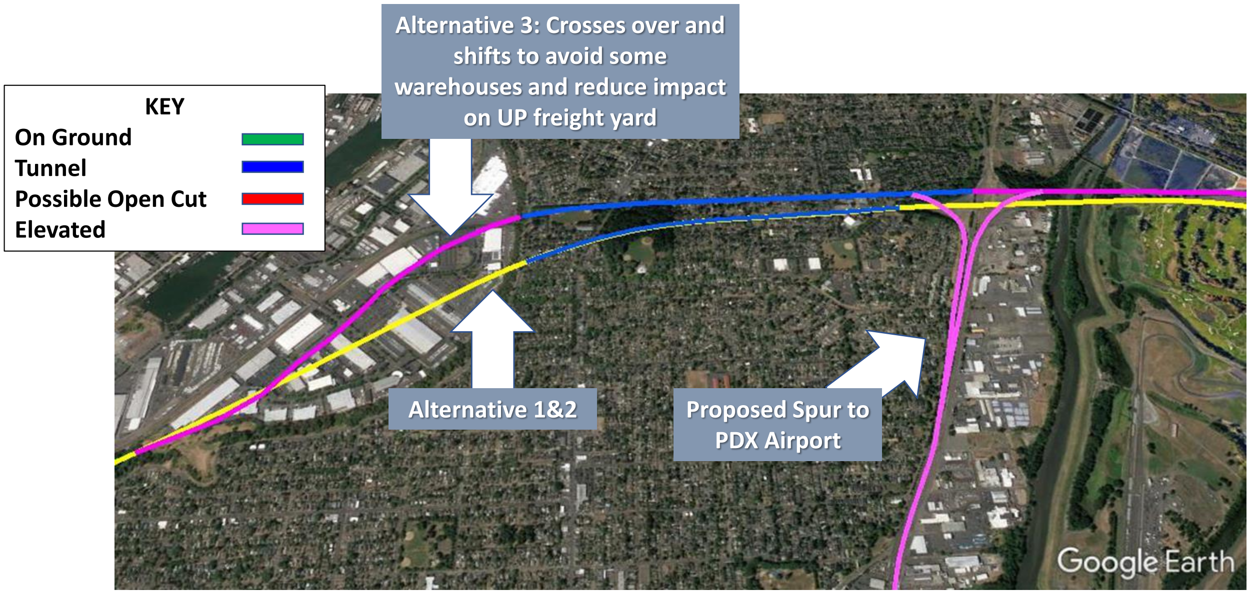
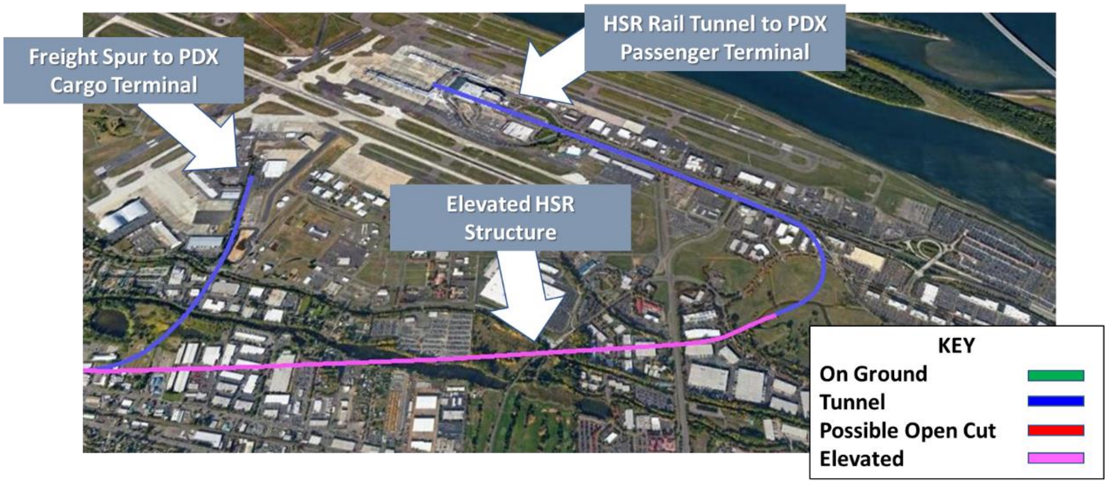


Exhibit 2-4: Alignment Refinements in the Mocks Crest Tunnel Area



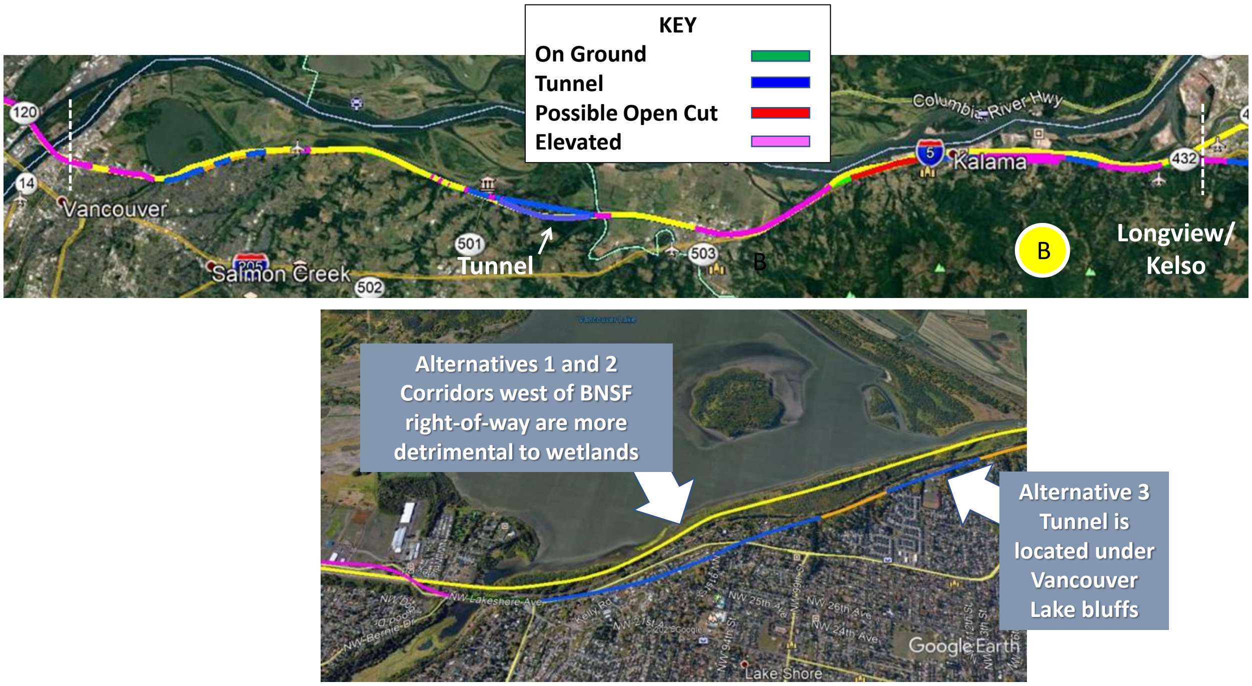
Segment A also includes a connection to the PDX Airport, which extends east along Columbia Boulevard to the PDX Airport terminal, as shown in Exhibits 2-4 and 2-5. The alignment shown in Exhibit 2-5 is a placeholder showing possible access to the passenger and freight terminals. The specific alignments for the airport will be examined in detail in the Tier 2 EIS analysis.

Exhibit 2-5: PDX Airport Spur



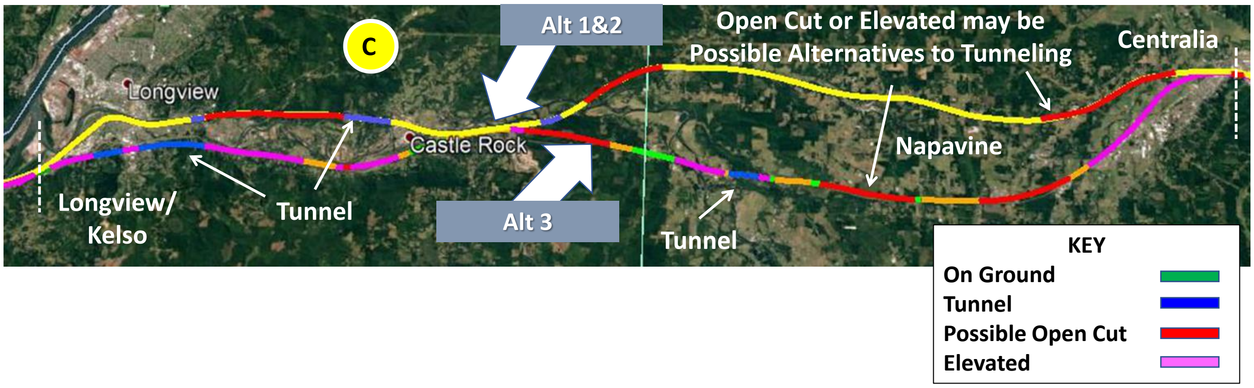
Segment B: Vancouver, WA to Longview/Kelso, WA – All alternatives closely follow the BNSF right-of-way in this stretch, with some curve easements and a tunnel under Ridgefield. As shown in Exhibit 2-6, Alternatives 1 and 2 tend to ease curves along the west side of the BNSF right-of-way which is very narrow and close to the Columbia River, having more detrimental environmental wetland impacts. Alternative 3 tends to be east of the BNSF right-of-way cutting or tunneling through the Vancouver Lake bluffs.

Exhibit 2-6: Vancouver to Longview/Kelso with a Zoom on the Vancouver Lake Area



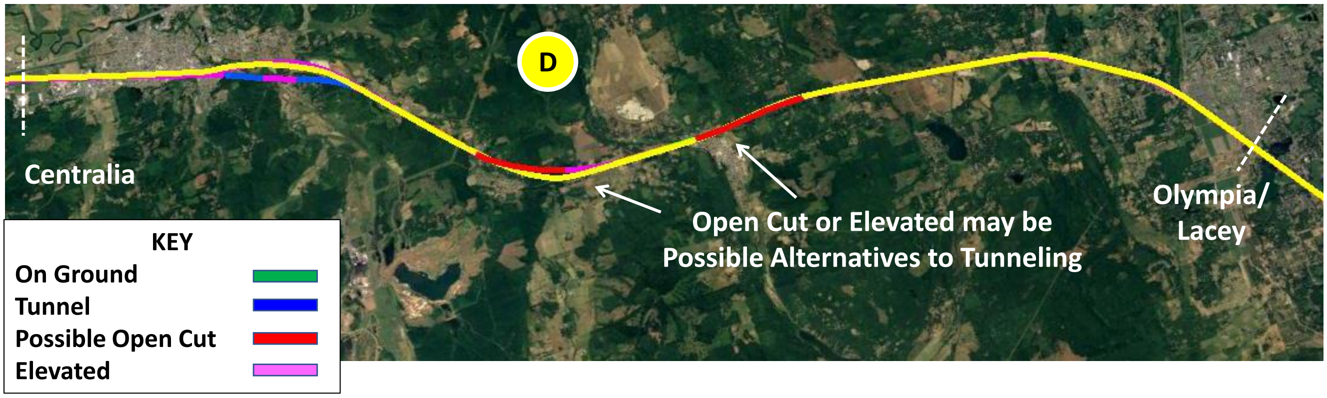
Segment C: Longview/Kelso to Centralia – The existing BNSF rail line has poor geometry in this rugged stretch of alignment that will be difficult to upgrade to HSR standards. As a result, two different (eastern and western) greenfield route alternatives have been developed. As shown in Exhibit 2-7, Alternatives 1 and 2 would follow a western route that roughly parallels but does not use BNSF right-of-way. Alternative 3 would follow an eastern alternative route with improved geometry that more closely follows I-5.

Exhibit 2-7: Longview/Kelso to Centralia



Segment D: Centralia to Olympia/Lacey – Since the existing BNSF line has good geometry in this stretch, all the alternatives closely follow existing BNSF right-of-way, with some curve easements as shown in Exhibit 2-8. Alternative 3 has more aggressive curve easements than do Alternatives 1 and 2. This is an area where the environmental advantages of utilizing an existing right-of-way will minimize the impacts of developing the high-speed rail system.

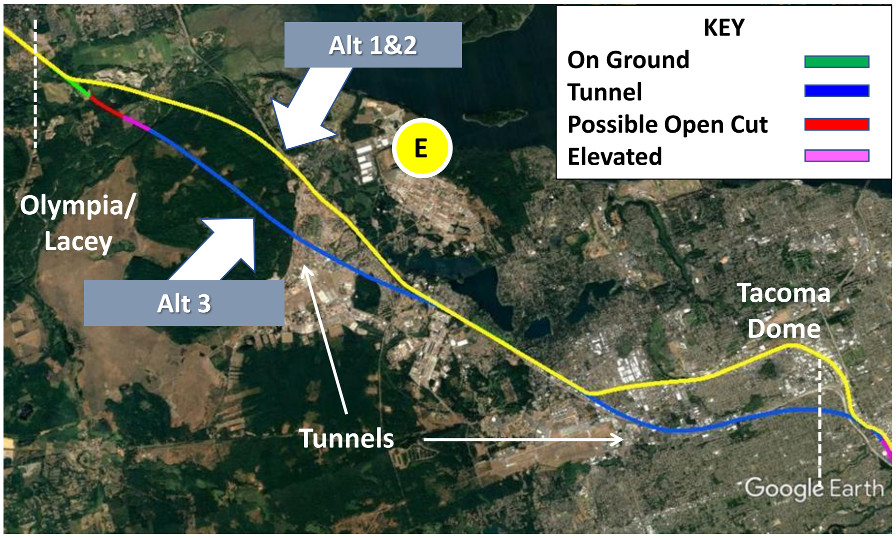
Exhibit 2-8: Centralia to Olympia/Lacey



Segment E: Olympia/Lacey to Tacoma Dome – The existing rail line between Nisqually Valley and Tacoma includes the Point Defiance Bypass, which was recently reactivated for Amtrak passenger service. However, this segment has 21 grade crossings as well as some sharp curves, particularly in the area of Dupont where the Amtrak accident occurred. The alignment for Alternatives 1 and 2 includes a short segment of new alignment to bypass the sharp curves at Dupont. North of Dupont, it rejoins the existing rail alignment, but to eliminate the grade crossings the track will be either elevated or tunneled through Lakewood.

However, as shown in Exhibit 2-9, Alternative 3 would develop shortcut tunnels under Lakewood and Nisqually. This would both reduce the length of the alignment and bypass geometric restrictions; it would minimize surface environmental impacts as well. The challenge in this segment is that the geometry of the existing rail alignment through Lakewood, although it may be acceptable for Amtrak service, falls significantly short of the requirement for a high-speed rail system. (This should have been made amply clear by the Dupont derailment.) None of the proposed CHSR 1, 2 or 3 alternatives include the site of that derailment. If it were decided to develop Alternative 3 with clean high-speed geometry, to avoid wasting the investment for improving the existing rail line, the corridor might be repurposed for extending Sounder commuter rail service farther south.

Exhibit 2-9: Olympia/Lacey to Tacoma Dome



SEGMENT F: TACOMA DOME TO TUKWILA/SEA-TAC – While all alternatives share a station at Tacoma Dome, the approaches they utilize for gaining access to that station are dramatically different. Alternatives 1 and 2 would utilize upgraded existing rail lines for both access to and egress from the Tacoma Dome station. However, for Alternative 3 the station may be underground since the approach would be tunneled on both sides of the station, although it might rise to grade through the station itself. The best approach has to be determined in future detailed engineering studies.

As shown in Exhibit 2-10, both Alternatives 1 and 2 would develop dedicated passenger tracks and would grade separate the BNSF corridor. As a result, there may be some capacity and curve issues in this corridor, which would have to be further considered in a Tier 2 Analysis. However, Alternative 3 would develop a shortcut tunnel under Lakeland, which although more expensive, would produce a faster alignment which would minimize the surface environmental impacts. In Exhibit 2-11, Alternative 3 elevates over the UP alignment for a short distance in Tukwila before entering the Lakeland Tunnel north portal. Exhibit 2-11 shows a placeholder potential alignment that will be considered in more detail in the Tier 2 EIS analysis.

Exhibit 2-10: Tacoma Dome to Tukwila/SEA-TAC

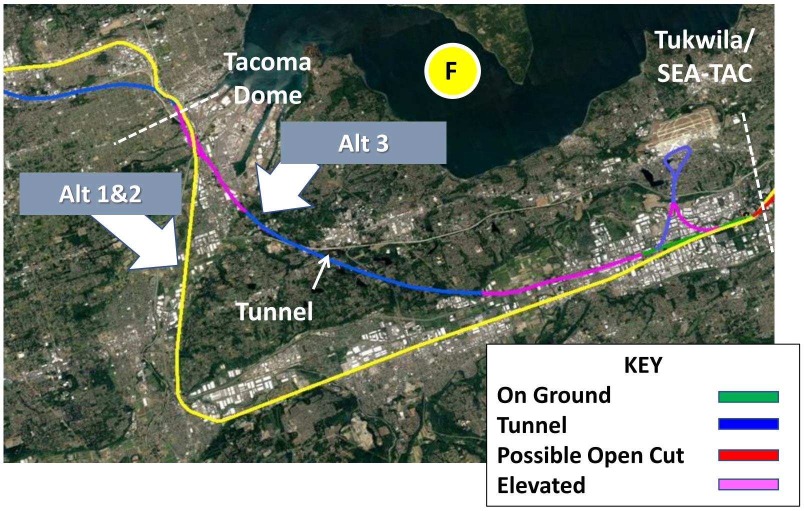
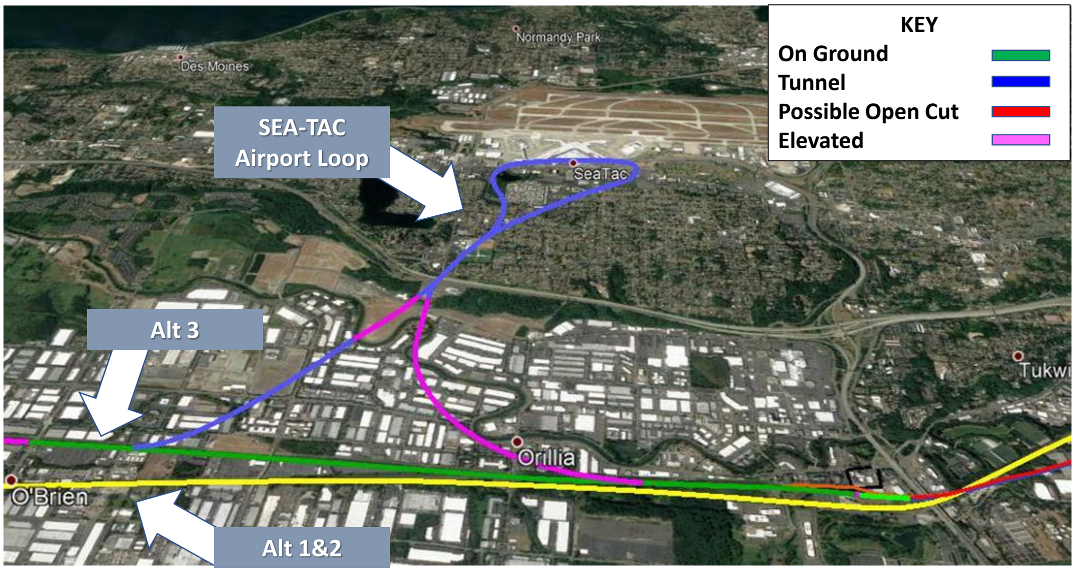


Exhibit 2-11: SEA-TAC Loop at Tukwila



SEGMENT G: TUKWILA/SEA-TAC TO SEATTLE CENTRAL – The final segment north of Tukwila (Exhibit 2-12) links the High-Speed Rail alignment into the Seattle station (Exhibit 2-13.) However, Alternative 1 (diesel) might continue using Seattle King Street, while Alternatives 2 and 3 (electric) would develop a new station called Seattle Central; The two alignments closely parallel in this stretch. Alternatives 1 and 2 would be developed within the existing BNSF right-of-way, whereas Alternative 3 would use a tunnel and an elevated structure on a new right-of-way east of the existing BNSF tracks, as shown in Exhibit 2-12.

Exhibit 2-12: Tukwila to Seattle

Exhibit 2-13: Seattle Central CHSR Station


SEATTLE CASCADIA HIGH SPEED RAIL - PROPOSED SITE PERSPECTIVE

PROPOSED DEVELOPMENT BOUNDARY

MAX GSF (3:1 FAR) = 15,300,000 SF

RECOMMENDED GSF (2:1 FAR)= 10,200,000 SF

EXISTING MAX FAR (1:1) = 5.1 mil. SF

ANKROM MOISAN ARCHITECTS
CASCADIA HIGH SPEED RAIL - VISIONING STUDY 06/05/18 6

2.3 STATION ALTERNATIVES

The proposed stations along the route are in the same cities as the current Amtrak stations; thus, no community would lose rail service as a result of the CHSR system being implemented. However, since some alternatives use different rail alignments, the exact location of stations within each community may vary. Drive time maps for each station will be presented in Chapter 6.

By their very nature, station site alternatives are limited to areas adjacent to the railroad tracks where there is good vehicular access, and where there would not be a conflict with an existing road grade crossing. Since the high-speed electric Alternatives 2 and 3 must be fully grade separated systems, grade crossing conflicts are not an issue with these Alternatives. Operations planning has been developed based on a reasonable set of initial station locations; however, the final station locations may be adjusted during preparation of the Tier II NEPA documents.

2.4 TRAIN TECHNOLOGY OPTIONS

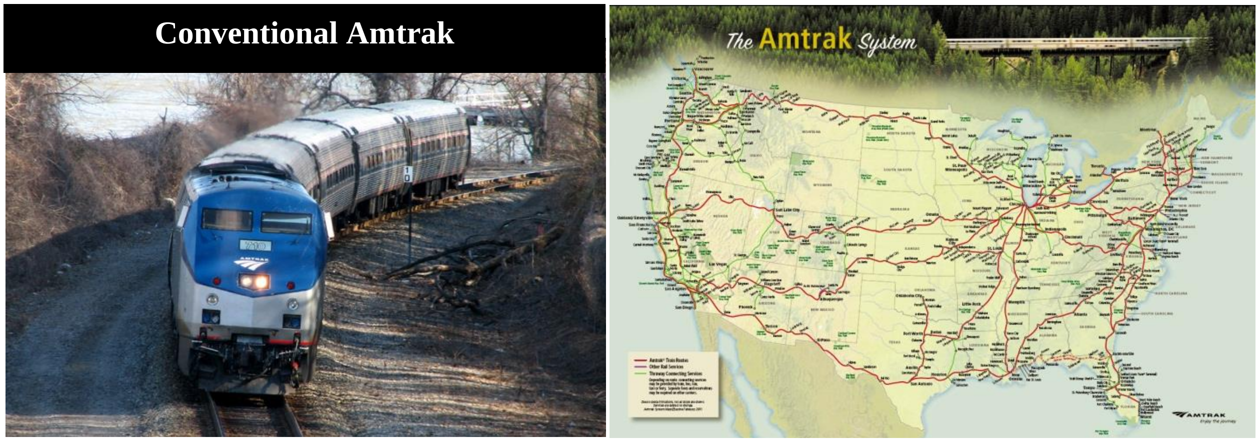
Developments in rail technology have been very rapid; while 150-mph technology was the best commercial speed possible thirty years ago, the latest electric technology allows speeds up to 220-250 mph. In rural areas, Greenfield routes can be developed with only very limited curvature and are thus ideal for the highest speed trains.

CONVENTIONAL RAIL – 79 MPH OR LESS: Conventional trains, as shown in Exhibit 2-14, typically operate at up to 79 mph on existing freight tracks. 79 mph represents the highest speed at which trains can legally operate in the United States without having a supplementary cab signaling system on board the locomotive. The key characteristics of these trains are that they:

- Are designed for economical operation at conventional speeds
- Can be diesel or electric powered
- Are non-tilting for simplified maintenance

Conventional rail is used for example by Amtrak in corridors across the country outside the Northeast corridor (Exhibit 2-14). Such trains do operate at up to 110 mph in developing corridors in Illinois and Michigan, but they need an extra locomotive in order to attain satisfactory acceleration or braking performance. The high center of gravity of the P-42 locomotive limits its safe speed around curves, as compared to higher speed trainsets, which are designed to have a lower center of gravity. The Cascadia corridor is currently served by conventional Amtrak service, so this is representative of the "Base Case" option in this study.

Exhibit 2-14: Conventional Rail – Representative Trains and Current Corridor Service



HIGHER SPEED RAIL – 110-130 MPH: A 110 to 130-mph service can often be incrementally developed from an existing conventional rail system by improving track conditions, adding a supplementary Positive Train Control safety system, and improving grade crossing protection. Tilt capability, built into the equipment can be used to allow trains to go around curves faster, and has proven to be very effective for improving service on existing track, often enabling a 20-30 percent reduction in running times. However, P-42 locomotives, as Amtrak operates with the Talgo trains in the Pacific Northwest today, have too high of a center of gravity and prevent tilt (such as the Talgo trains have) from being utilized to its full potential. Trains operating at 110 mph, such as those proposed for the Midwest, Ohio Hub and New York State systems (See Exhibit 2-15), have generally been found to be affordable, produce auto-competitive travel times, and are able to generate sufficient revenues to cover their operating costs.

Higher speed trains:

- Are designed for operation above 110 mph on existing rail lines and diesel trains can attain sustained speed of 130 mph on dedicated grade separated rights of way.
- Can be diesel or electric powered.
- Are usually tilting unless the track is very straight.

In the United States, 110-mph service has been seen to provide a low-cost infrastructure option by using existing lightly used railroad rights-of-way that have good geometry and quad-gating crossings, which are relatively low-cost options.

However, it may contradict some existing freight railroad passenger principles unless additional improvements are made. For example, while Norfolk Southern's passenger principles do not prohibit the operation of higher speed tilting trains, they do prohibit speeds above 79 mph on Norfolk Southern-owned rights of way. CSX policies have generally prohibited operations above 90 mph. Most importantly to the Cascadia Corridor, BNSF's passenger guidance does not appear to include any explicit speed limit[4]. Union Pacific's passenger policy allows up to a 110-mph speed limit but requires passenger and freight tracks to be separated by a minimum of 50 feet.[5] If geometry allows 110-mph speeds or higher on a high-density freight corridor, an alternative arrangement, such as purchasing a parallel strip of right way or right-of-way easement and separate ownership of the track, may be needed to comply with the requirements of the freight railroads. This type of arrangement can be very expensive if capacity mitigation is needed, especially if this is accompanied by speed restrictions due to geometry or freight rail policies. This combination of high cost and poor performance limits the applicability of this concept on lines like the BNSF corridor from Portland to Seattle. This "double whammy" can undermine the economics of the incremental approach to passenger rail development. In such cases, moving directly to greenfield alignment, as is proposed by this study, can provide a more cost-effective approach in segments of the corridor where the existing track is curvy and heavily used. This type of train would be used in Alternative 1 in this study.

Exhibit 2-15: High-Speed Rail Shared Use (Diesel) – Representative Trains and Corridor Service

Diesel High-Speed Train – 130 mph

*Indiana DOT is evaluating additional passenger rail service to South Bend and to Louisville.
**In Missouri, current restrictions limit train speeds to 79 mph.

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[4] See: https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=App%20A_BNSF%20Rail%20Principles_ea9ad8b7-b473-439d-864e-9b517b03e2e6.pdf and

[5] See: https://ftp.dot.state.tx.us/pub/txdot-info/rail/east_texas.pdf, page 13.

HIGH-SPEED RAIL – 220-250 MPH: The costs of grade separation for 125 mph can easily double the capital cost of a project, as the number of public and private crossings can be as many as two per mile. This is why true high-speed rail is typically twice the cost per mile of higher speed rail. Once full grade separation has been accomplished however, speeds can be pushed up to 220-250 mph by electrification and the use of electric train systems. This will tend to improve further the economic return on capital investment.

Representative trains include the Amtrak Acela electric locomotive hauled train as well as the proposed California trainset shown in Exhibit 3-4. While initially the Acela speed was limited to 150 mph, it is now being tested at speeds of 160 mph. However, this concept has been superseded by the equipment procurements by Amtrak and the California High-Speed Rail Authority, as well as Amtrak's cancellation of its own intended Acela fleet expansion for the Northeast Corridor. It should be noted that in the last twenty years electric high-speed train technology has evolved rapidly from 150 mph maximum speed to 220-250 mph maximum speed. This revolution in train capabilities has been due to rapid advances in the design of the propulsion system of modern electric trains. New electric trains based on the new standards will be able to operate up to 220-250 mph on dedicated alignment and still be able to comingle with freight trains on the same tracks as needed, at speeds under 125 mph. Both Amtrak and California have produced feasibility and business plans showing the advantage of moving to 220-250-mph technology. This is the recommended approach for development of the Cascadia corridor, since this corridor has sufficient population demographics to support a true high-speed rail system; and the alternative of developing a lower performing "Higher" speed rail system by incrementally improving the existing rail lines in the corridor, is very expensive and not cost effective. The 160-mph tilting trains are assumed for Alternative 2, while the 220-250-mph ultra high-speed trains are assumed for Alternative 3.

Exhibit 2-16: High-Speed Rail Shared Use (Electric) – Representative Trains and Corridor Service


Electric HSR – 160 mph


Electric Greenfield HST – 220 mph

2.4.1 TRAIN TECHNOLOGY ASSUMPTIONS

The key element for developing an operating plan is the train technology selection from a range of alternative technologies available. In the case of the slower speed alternatives (79-110 mph), the most effective option is using existing railroad rights-of-way and where the volume of freight rail traffic is limited, to share tracks with freight traffic. As speeds and frequency of passenger rail service increase, the ability to share tracks with freight becomes more limited, although if wide enough the right-of-way may still be shared. For very high-speeds, the ability to even use existing railroad rights-of-way is typically lost. Of course, sharing track or using freight rail right-of-way may still occur (at lower speeds) in urban areas to gain access to downtown stations, but away from the urban area true high-speed service is likely to require a greenfield route – since high-speed rail operations needs long stretches of straight track and very gentle curves to achieve high-speed. Even sharing Interstate highway right-of-way may not be possible since they frequently have curves that are too tight for the faster trains. In general, faster systems have fewer stops. A compromise may be needed to ensure all key communities are served, but this results in a trade-off between end-to-end speed and connecting communities. Each station stop takes three to seven minutes (including deceleration, stop time and acceleration back to speed) so multiple stops soon dramatically increase end-to-end running times. A typical solution is to introduce an express/local service pattern of operations so that the local stations can still be served, but at a reduced train frequency as compared to the major endpoint stations.

A key study assumption that determines transit time is a passenger car's "tilt" or "non-tilt" design. The track in curves is typically banked (super-elevated) up to six degrees (6° or 6"), which results in designation of a balance speed for each curve (at which speed a vehicle occupant would feel no sideways force in the curve). However, up to four degrees (4° or 4") of imbalance (cant deficiency) is acceptable for passenger comfort. Beyond this, onboard hydraulic systems (active tilt) or car suspension designs (passive tilt) can permit even higher speeds, by lowering the centrifugal forces felt inside cars.

True high-speed trains typically do not include tilting mechanisms, because the allowable cant deficiency reduces to only 2.5 degrees (2.5° or 2.5") at 220 mph[6]. This limitation on cant deficiency at the wheel-rail interface eliminates the benefit of tilt for true high-speed rail. It should be noted that the geometric standards for interstate highway alignments generally allow speeds of 125-150 mph, which are in the effective range for tilting trains, but the curves are usually too sharp to support true high-speed trains (186 mph+). As a result, high-speed trains need very gentle curves, which are typically only obtained through development of new "greenfield" alignments. Tilting capability may still be beneficial to high-speed trains however, on shared segments of existing line on urban approaches, or for extended operations beyond the limits of the high-speed territory.

Another key issue for determining the suitability of train technology is compliance with FRA safety requirements. The FRA Tier I safety requirements allow speeds up to 125 mph. More stringent Tier II requirements are applied to passenger trains operating with speeds 125-150 mph. The FRA Railroad Safety Advisory Committee (RSAC) recently announced "Alternative Tier I" compliance standards[7] that could make it easier to adapt European train designs to meet United States requirements.

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[6] *See: http://www.scribd.com/doc/24548877/High-Speed-Railway-Lines-en*

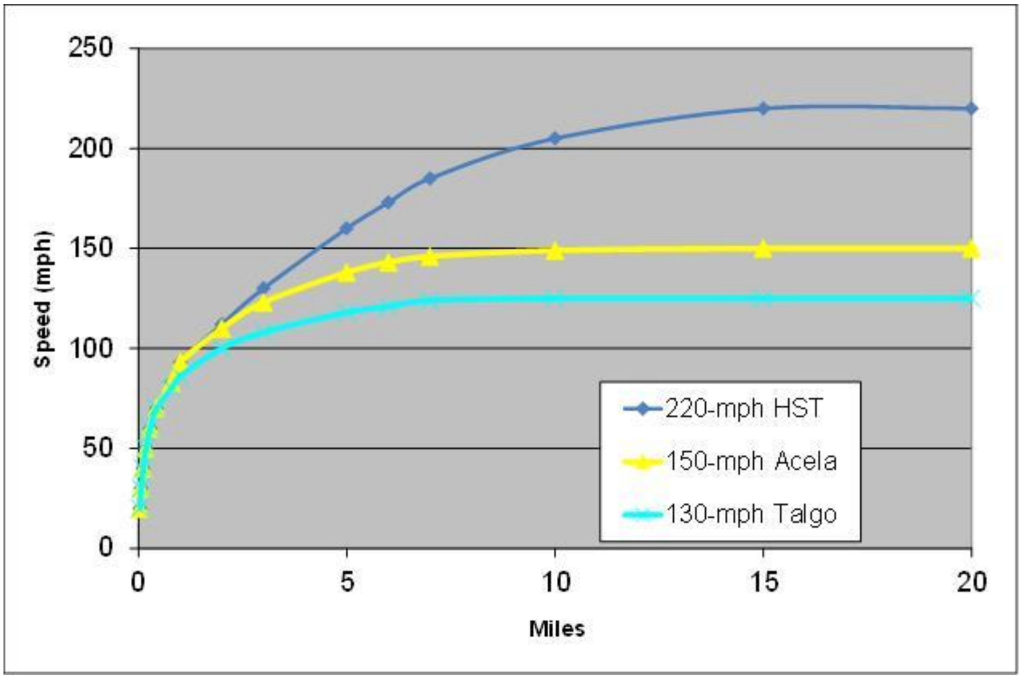
[7] Railway Track and Structures, http://www.rtands.com/index.php/track-maintenance/off-track-maintenance/rsac-recommends-passenger-rail-crashworthiness-standards-to-accommodate-hsr.html

In terms of assessing rail technologies, two main choices need to be considered: the type of propulsion and source of power:

- **Type of Propulsion: Trains can be either locomotive-hauled or self-propelled.** Self-propelled equipment has each individual railcar powered whereas conventional coaches rely on a separate locomotive to provide the power. Locomotive-hauled trainsets generally tend to be preferred on lines that have rail/highway grade crossings, due to the higher degree of protection they afford passengers in case of an accident.
- **Source of Power: Trains can be either diesel or electrically powered.** Diesel or electric power can be used with either the locomotive hauled or self-propelled equipment options. (Turbine power has also been considered for high-speed trains but does not offer any clear advantage over diesel at this time.) However, 125 mph is the practical upper limit for diesel power at the current times; for speeds higher than this, electric propulsion seems to be the only practical choice at the current time. As a rule, diesel locomotives are heavier than electric locomotives, because of the weight of the engine and also of the fuel. Electric equipment can be more powerful since it is not limited by the onboard generating capacity of the engine.

Train performance curves for representative equipment types are shown in Exhibit 2-17. The curves reflect the acceleration capabilities of three rail technologies with speed diesel 130 mph, electric locomotive hauled 150/160 mph and electric self-propelled (EMU) 220 mph.

Exhibit 2-17: Comparative Train Acceleration Curves[8]



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[8] Source: TEMS LOCOMOTION™ Equipment Database showing typical technology performance parameters, as developed, and validated over the course of previous rail studies.

Purpose-built diesel higher-speed trains, such as the Talgo T21, can offer considerably improved performance over conventional diesel trains that are based on freight-derived designs. Conventional locomotive-hauled diesel trains have a practical top speed of about 100 mph, whereas purpose-built high-speed diesel trains can achieve 125 mph to 135 mph and can accelerate much faster than a conventional diesel train. It should be noted that the Talgo trains in use in the Pacific Northwest corridor are not T21; they are hauled by conventional P-42 locomotives and thus do not have the acceleration or braking capabilities shown for high performance diesel trains in Exhibit 2-17. For speeds above 125 mph, electrified trains are needed. Some European diesel-powered 125-mph trains offer up to 500 seats, but if U.S. safety regulations were applied, the added weight (10-15 percent) would likely reduce the practical capacity of such trains down to 400-450 seats.

Up to its current top speed of 150 mph, Exhibit 2-17 shows that the Acela accelerates as fast as a 220-mph high-speed train due to its very high power to weight ratio. This implies that the Acela could go even faster if it were given a straight enough track to run on. Acela's weight penalty, however, expresses itself in terms of a higher operating cost and lower revenue generating capacity than a comparable 220-250-mph train. However, this is not a serious problem in the special environment in which the Acela operates (i.e., limited capacity and a very high level of demand.)

Most trains have the ability to stop a lot faster than they can accelerate by using the air brake system. Electric trains however may have the ability to use regenerative braking to recover braking energy and return it to the power system. New hybrid diesel locomotives with batteries will in the near future be able to do exactly the same thing. Rapid deceleration is extremely hard on the brakes and wastes a lot of energy, especially if there regenerative braking could be used. However, regenerative braking is limited by the capacity of the electrical system. To allow for this, we typically use braking curves that are a mirror image of the acceleration curve. Limiting the deceleration rates maximizes the electrical energy recovery and typically adds only a few seconds to the train running time. An allowance for this is built into the schedules. The operator would only use the more aggressive air braking curves if the train were behind schedule and needed to make up time.

The technology choices with characteristic trains are summarized in Exhibit 2-18:

Exhibit 2-18: Train Characteristics Table

Higher Speed	High-Speed	Ultra High-Speed
▪ 110 mph ▪ Diesel ▪ Tilting ▪ Talgo T21	▪ 160 mph ▪ Electric ▪ Tilting ▪ Acela Express	▪ 220-250 mph ▪ Electric ▪ Non-Tilting ▪ AGV


Diesel HrST 90-130 mph


Electric HST 160-220 mph

The following train technologies are shown:

- **Diesel Train – 130-mph Talgo T21:** the technical characteristics are hauled (non-powered) axles equipped with independent wheels to prevent hunting movement and to reduce wheel-track interaction; permanently steered axles by means of robust guiding bars that keep the wheels parallel to the track at all times; high-comfort tilting suspension, with natural car body tilting toward the interior of curves; Articulated couplings between adjacent cars with anti-overturning and anti-vertical hunting mechanisms; and maximum commercial speed of 140 mph[9]. However, the T21 is not the version of Talgo train that Amtrak is currently operating in the Pacific Northwest, because the P42 locomotive and BNSF track conditions constrain its performance capability. A Talgo or other type of tilting train with a Siemens Charger might be capable of better performance. This type of diesel train is assumed for Alternative 1.
- **Electric Train –** Modern high-speed electric trains are increasingly derived as variants of true high-speed types, even if they have certain modifications to specific operating environments. These trains are adapted to two main groupings, but only a single picture is shown since both the external and internal appearances of 160-250 mph high-speed electric trains tend to be very similar:
    - **150/160-mph Acela:** Acela express with standard gauge of 1,435 mm (4 ft. 8 1⁄2 in) and maximum operating speed 160 mph (256 km/h). This type of train is generally a tilting train that is adapted to maximize its performance on existing tracks and rights of way, which may have some curves. However, Amtrak decided not to order any more Acela equipment and instead has purchased new trains instead. The 2nd generation Acela train, Avelia Liberty may now be used to represent this class of trains in Alternative 2. Technically the new Avelia Liberty is rated as a 186-mph train, even though it is not expected to run that fast on existing track. This type of train is assumed for Alternative 2.
    - **220-250 mph High-Speed Train:** Trains that are certified to run 220-mph speed generally need new purpose-built rights of way. Characteristic examples include Siemens Valero, Bombardier Zefiro, and Alstom AGV. Chinese HSTs are even faster with speeds up to 240 mph. The trains are constructed from units comprising three cars, each with one transformer and two traction electronics packages located underneath the cars, and from single-car trailers. A 7-car unit has two 3-car modules separated by one trailer and seating for around 245, an 11-car unit has three 3-car modules with two trailer cars with seating for around 446. The maximum commercial speed is 360 km/h (220 mph)[10]. This type of train is assumed for Alternative 3.

It is important to note that especially the high-speed electric trains are very powerful and can easily handle grades that are far steeper than those that might be suitable for freight trains. Gradients of up to 4% are typical in modern high-speed rail construction.[11] The UIC standard gradient is 4 percent, but on some lines this is exceeded for example the recent Frankfurt-Cologne[12] line build by German railroads. Even higher grades of up to 7% can be used under exceptional circumstances.

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[9] http://www.talgo.com/pdf/TXXIen.pdf

[10] http://en.wikipedia.org/wiki/Automotrice_%C3%A0_grande_vitesse

[11] See Appendix H: http://rockymountainrail.org/documents/RMRAAppendi_Final_REV032410.pdf

[12] See: https://en.wikipedia.org/wiki/Cologne%E2%80%93Frankfurt_high-speed_rail_line

2.4.2 OTHER ROLLING STOCK AND OPERATIONAL ASSUMPTIONS

The design of the modern rail car offers onboard amenities that serve to make passenger rail travel superior to air travel. Seating can be bi-directional, (i.e., half the seats face one way and half the other way). The interior of the train can be divided into large flexible compartments with space for wheelchairs, bicycles, strollers and play areas for children. At each seat, there are receptacles for computers and other communications equipment, amenities that are very important to the business traveler. Some modern trains have a socket for a five-channel stereo system and an informational channel. The train has an electronic information system with displays in each passenger compartment providing continuously updated information on arrival and departure times. Special vibration-absorbing mountings and soundproofing contribute to a significant reduction in the noise level, which further adds to the comfort of the passengers.

Consistent with the assumptions customarily made in feasibility-level planning and Tier I EIS studies, the following general assumptions are proposed regarding operating requirements for rolling stock for the Cascadia Corridor:

- Trains will be reversible for easy push-pull operations (able to operate in either direction without turning the equipment at the terminal stations);
- Trains will be accessible from low-level station platforms for passenger access and egress, which is required to ensure compatibility with freight operations;
- Trains will have expandable capacity for seasonal fluctuations and will allow for coupling two or more trains together to double or triple capacity as required;
- Train configuration will include galley space, accommodating roll-on/roll-off cart service for onboard food service. Optionally, the trains may include a bistro area where food service can be provided during the entire trip;
- Onboard space is required for storing small, but significant quantities of mail and express packages, and also to provide for an optional checked baggage service for pre-arranged tour groups;
- Each end of the train will be equipped with a coupler that will allow for easy recovery of a disabled train by locomotives or other trains;
- Trains will not require mid-route servicing, with the exception of food top-off. Refueling, potable water top-off, interior cleaning, required train inspections and other requirements will be conducted at night, at the layover facilities located at or near the terminal stations. Trains would be stored overnight on the station tracks, or they would be moved to a separate train layover facility. Ideally, overnight layover facilities should be located close to the passenger stations and in the outbound direction so a train can continue, without reversing direction, after its final station stop; and
- Trains must meet all applicable regulatory requirements including:
    - FRA safety requirements for crashworthiness,
    - Requirements for accessibility for disabled persons,
    - Material standards for rail components for high-speed operations, and
    - Environmental regulations for waste disposal and power unit emissions.

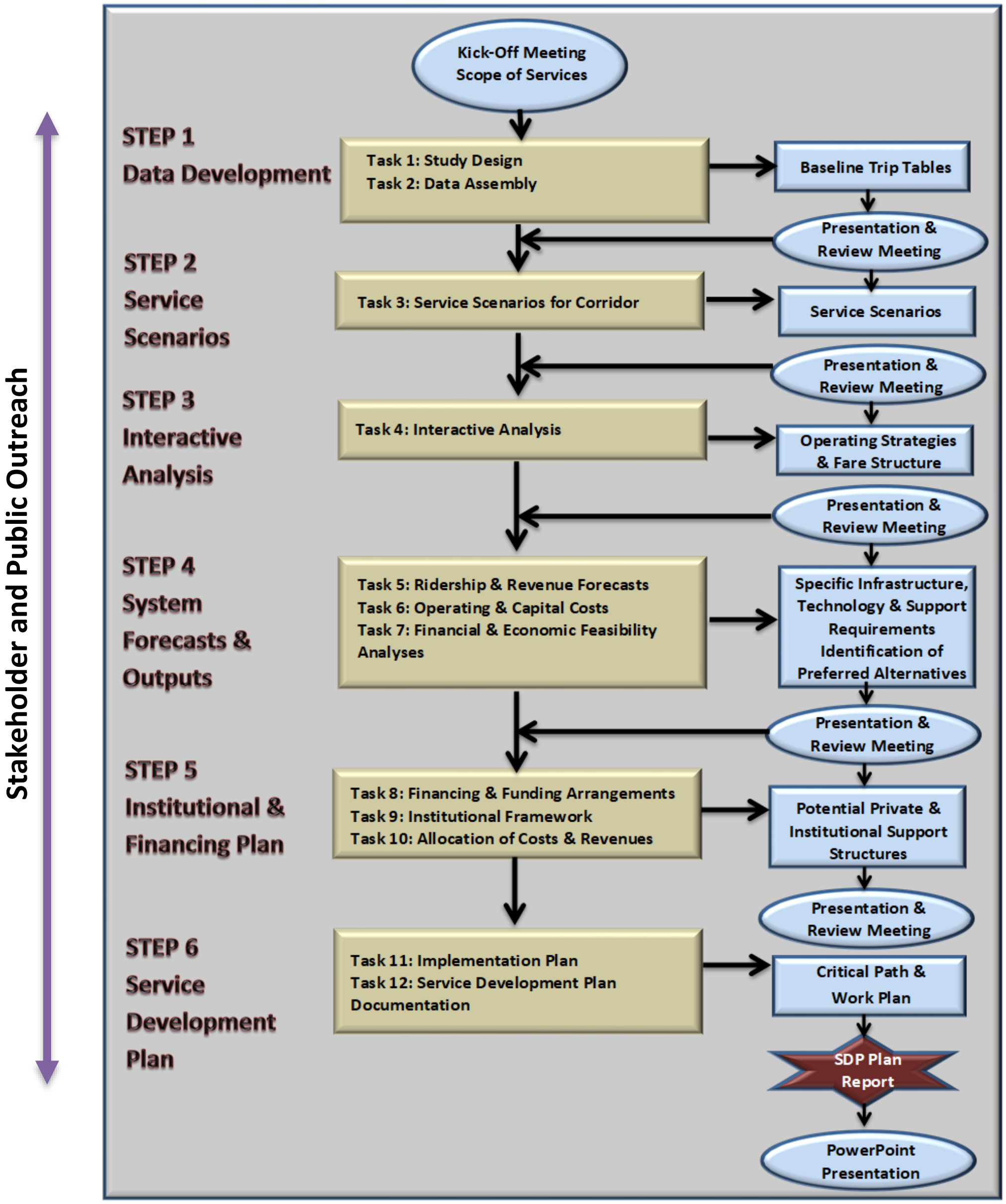
3. PLANNING METHODOLOGY

This chapter describes the planning methodology used to develop the Service Development Plan for the evaluation of Cascadia corridor alternatives. It describes the overall approach and methodology, the software, as well as the database, interactive analysis, public and stakeholder involvement.

3.1 PLANNING APPROACH

In order to prepare the Service Development Plan, and to efficiently evaluate the alternatives for the Cascadia High Speed Rail Corridor, the Study Team has used its Business Planning system. The development of a Service Development Plan for high-speed rail for the Cascadia corridor will involve a six-step process. At each step, the output is provided for Steering Committee and Stakeholder review and approval prior to the work proceeding to the next step. The process is shown in Exhibit 3-1.

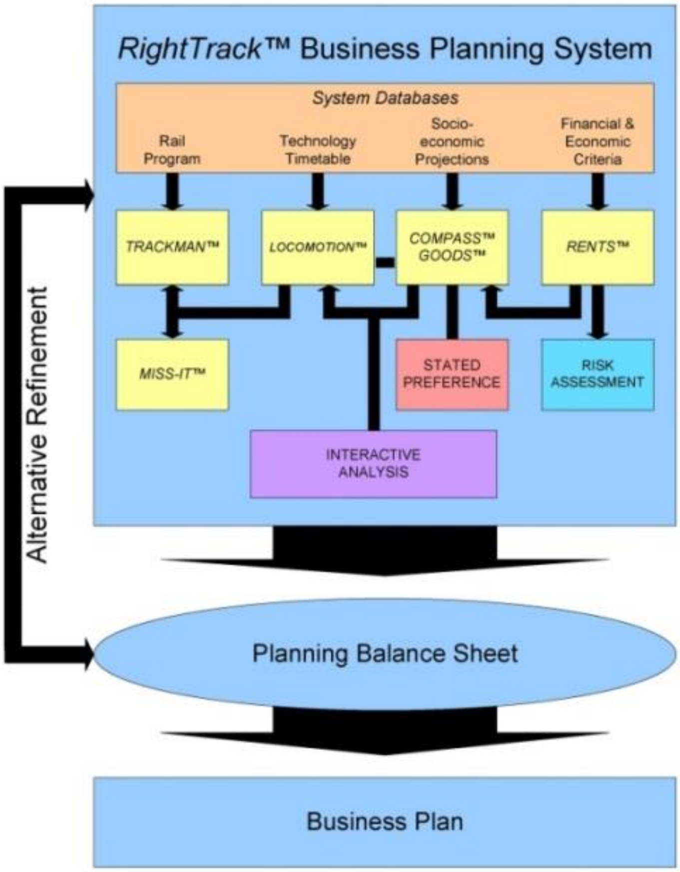
Exhibit 3-1: Service Development Plan Six-Step Process



3.2 SERVICE DEVELOPMENT PLAN ANALYSIS

To complete the initial Service Development Plan, the study team used its Passenger Rail Planning System *RightTrack™.* See Exhibit 3-2. The *RightTrack™* System is a comprehensive planning analysis software for high-speed transportation system evaluation that include engineering route analysis, alternatives analysis operations planning, passenger market analysis and USDOT financial and economic analysis. It uses a series of programs, *TRACKMAN™* for engineering and route planning, *LOCOMOTION™* for passenger and freight rail operations planning, *COMPASS™* for passenger ridership and revenue forecasting and *RENTS™* for financial and economic analysis. The programs are described in detail in Appendix A.

Exhibit 3-2: RightTrack™ Passenger Rail Planning System



SERVICE DEVELOPMENT PLAN - The development of the Service Development Plan has been guided and supported by the Study Steering Committee and key stakeholders through the evaluation, implementation planning, the financial analysis and USDOT economic analysis of the high-speed options. The Service Development Plan includes pro forma financial statements for use in pursuing public and private funding to support the capital needs and operational elements of the high-speed rail service. Equally important, the plan addressed the actual "implementation" of the high-speed rail service and the monitoring of activities as set forth in the Implementation Plan, thereby ensuring a smooth introduction of the new service.

For USDOT funding of further phases of work, the Service Development Plan for the project prepared financial and economic cash flows and returns for the most effective alternatives.

The deliverables consisted of a summary or executive report that can be used for general distribution, and a more detailed technical report with appendices and public outreach PowerPoint™ presentations.

REPORTS: The main outputs of the study were:

- Service Development Plan Executive Summary
- Service Development Plan Technical Report
- PowerPoint Presentation for use in stakeholder and public discussions.

3.3 SERVICE DEVELOPMENT PLAN ANALYSIS DATABASES

3.3.1 ENGINEERING DATABASE

The development of the Cascadia HSR Tier 1 EIS Service Development Plan uses three separate databases in order to assess the three alternatives developed for the study. These include:

- Engineering Database
- Technology Database
- Market Database

For the three (+) route Alternatives to be considered, the *TRACKMAN™* Track Management System was used as in previous Cascadia HSR feasibility study to provide a milepost-by-milepost record of the routes geography and its possible impact on the right-of-way. Key characteristics are curves, gradients, bridges, tunnels, elevated sections, stations, and limitations on passenger rail speeds. The data was recompiled from existing sources such as google maps, ordinance survey maps, geographic profiles and land stat photometry. The data will be reviewed and updated as required. This was achieved by a field review of the right-of-way and guideway in the corridor by the TEMS Engineering Team. Potential guideway upgrades and improvements for different passenger and freight operations were assessed and improvements were identified and listed. Engineering notes were developed and entered into the *TRACKMAN™* program to provide a clear understanding of basic route geometrics and conditions. The upgrades needed to support both passenger and freight speeds, were developed. A sample output from *TRACKMAN™* is given in Exhibit 3-3. A “helicopter ride” video was developed for each route to show its relationship to the geography and landscape of the route. See Exhibit 3-4.

DELIVERABLE

- Detailed right-of-way route characteristics including geometry, curves, gradients and infrastructure, train speeds and restrictions, station locations, and freight interaction

Exhibit 3-3: TRACKMAN™ Sample Output

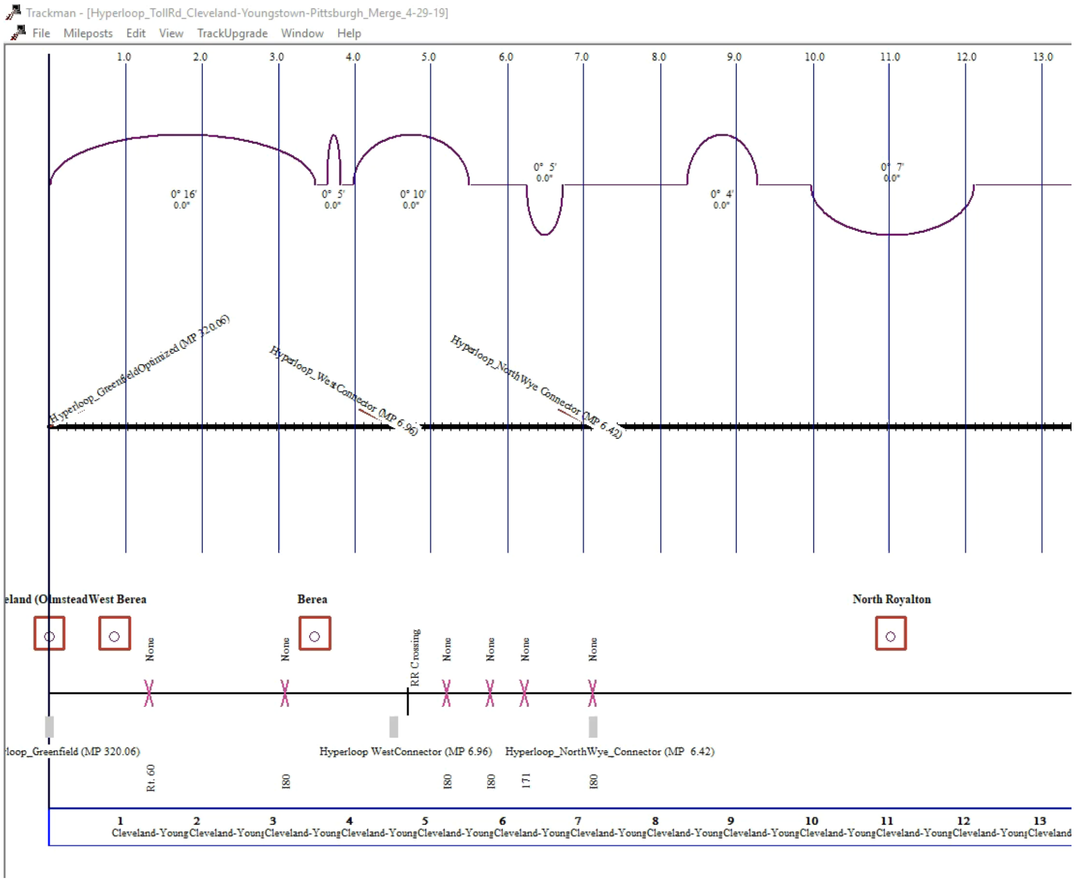
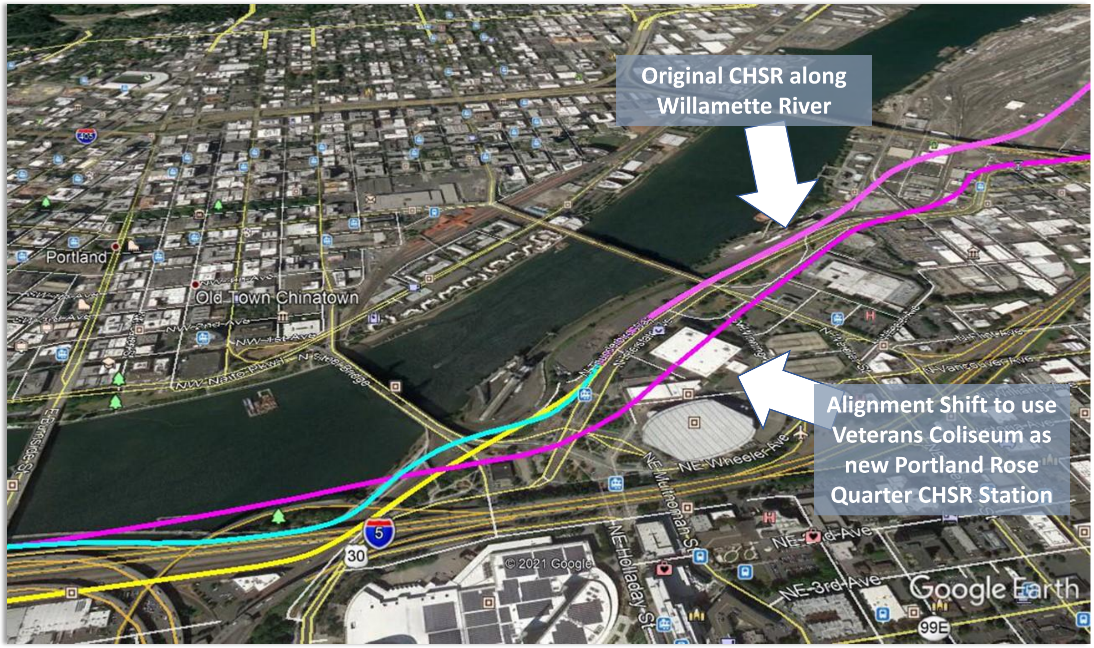


Exhibit 3-4: Helicopter ride showing Alignment Alternatives in the Rose Quarter Area


Original CHSR along Willamette River

Alignment Shift to use Veterans Coliseum as new Portland Rose Quarter CHSR Station

TECHNOLOGY DATABASE – The database for the different equipment options (110-mph Diesel, 160-mph Electric and 220-250-mph Electric) were developed by reviewing the literature of different technology options and soliciting information from manufacturers to update TEMS existing vehicle databank. This included Talgo, Bombardier, Siemens and Alstom. The data included key performance characteristics such as acceleration and deceleration, tilt capability, and climbing capability.

110-mph Diesel Train

220-250-mph Electric Train

DELIVERABLE

- High-Speed and Ultra High-Speed Vehicle performance characteristics

MARKET DATABASE – the market database consisted of two separate datasets that were used to forecast passenger ridership and express parcel traffic. For each route Alternative, four separate passenger and freight market databases were developed to identify the current nature of passenger travel and express freight movement in the corridor. Both the passenger and freight databases consist of four components – origin/destination data, socioeconomic data, network data, and stated preference.

- **Origin/Destination Trip Data:** As part of the original Cascadia HSR Feasibility Study, TEMS developed a comprehensive origin/destination database for the Cascadia corridor including the two US states of Oregon and Washington, as well as Canadian province of British Columbia. Fortunately, data is collected on a similar basis in Canada as in the US. The data are for travel by air, rail, bus and auto and are on a trip-purpose basis (business, commuter, and social / tourism). The data is aggregated on a county level in rural areas and a sub-city (TAZ) level for most urban areas. For this study, the data was refined to ensure it properly reflects 2019 travel demand in the study corridors. The study used 174 zones for the Cascadia corridor.

- **Socioeconomic Data:** As part of the original Cascadia Feasibility Study and the more recent Financial Prospectus Study an extensive socioeconomic database was developed for the Cascade corridor. The socioeconomic data were developed on the zone system shown in Exhibit 2-1. The data was developed from Federal Census and BEA data, state transportation data, as well as Woods and Poole socioeconomic forecasts and contains population, employment, and income forecasts on a county basis. These were reviewed and adjusted to the zone system to provide an effective database for the corridors. The passenger and freight analysis used the same disaggregate zone data.

- **Network Data:** Comprehensive modal networks will be developed for each mode of intercity travel and movement (**passenger:** auto, air, rail, and bus). The networks, which will identify access and egress times, and costs, will be built for business and non-business travel. A refined set of networks was developed for the proposed corridors to show the strength of modal competition and connections in the corridor.

- **Stated Preference Data:** Stated preference data for the corridor used data collected as part of the Midwest Regional Rail study, Detroit-Chicago EIS study, the Cascadia Feasibility study, and the Rocky Mountain High-Speed Rail study in Colorado. If a Tier 2 EIS Study is undertaken at a later date following the Tier 1 EIS, a specific corridor Stated Preference survey will be completed for the final ridership and revenues to be included in the Draft and Final Tier 2 EIS report.

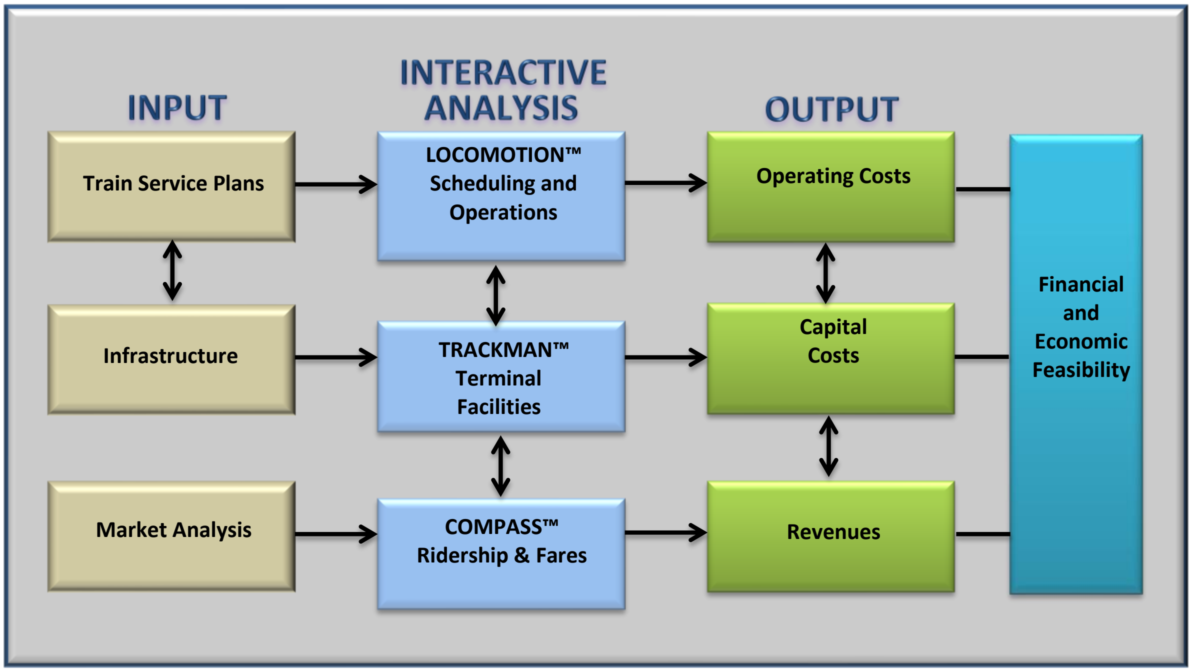
DELIVERABLE

- Base Year Passenger Analysis Data
- Base Year Freight Analysis Data

3.4 INTERACTIVE ANALYSIS

The next step in the process, once the major alternatives have been defined (see Chapter 4), and database developed is an Interactive Analysis to identify (based on FRA evaluation criteria) the optimum high-speed rail system that produces the best financial and economic results for the market. This analysis identifies the interaction between the Engineering and Technology and the Market for travel. Exhibit 3-4 shows the Interactive Analysis process that was used to develop the critical FRA performance metrics required for determining the value of the project[13].

Exhibit 3-4: Interactive Analysis Process



The Interactive Analysis is designed to develop the most efficient and effective Alternative(s) for each route, alignment, and service for each of the three (+) proposed routes and technology.

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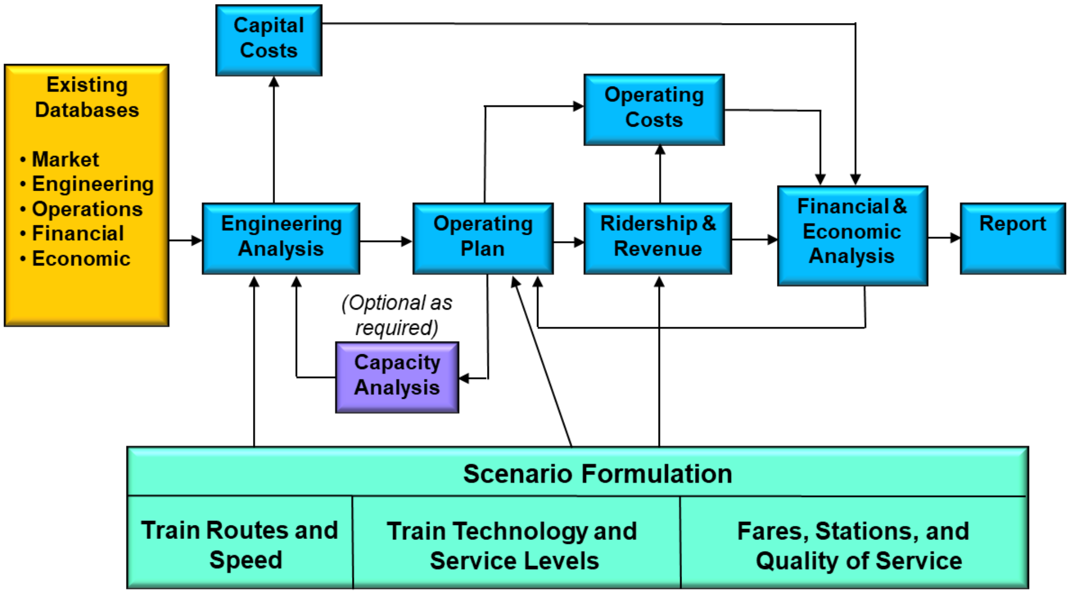
[13] Value of the project will be assessed by financial and economic analysis; this measures the cost benefit ratio and operating ratio.

The determination of appropriate passenger rail service depends on balancing the trade-off between revenues and costs for any given route and associated technology (See Exhibit 3-5). Higher levels of ridership generate higher revenues, which permit a greater level of infrastructure investment, and thus higher train speeds. Lower levels of ridership, and lower revenues require that infrastructure investment be minimized to be more cost effective. Each of the alternative service scenarios can be subject to a sensitivity analysis of route, train speed, train technology, train schedules and stops, and fare levels.

As a result, the TEMS Team used the Interactive Analysis as the most efficient means of screening options and developing an appropriate passenger rail service with the most effective infrastructure possible.

Exhibit 3-5: Interactive Analysis Sensitivity Analysis Process



The Interactive Analysis utilizes a number of computer systems from the *RightTrack™* package, permitting a rapid evaluation and re-evaluation of route, technology (see Exhibit 3-5), and/or ridership and freight factors –

- *TRACKMAN™* to assess the right-of-way guideway and route improvement options
- *LOCOMOTION™* Vehicle Performance Calculator to assess the performance of technologies
- *COMPASS™/GOODS™* Demand Models to assess passenger and freight ridership and traffic levels.

The result of the Interactive Analysis is an operating strategy for each route/alternative passenger rail technology option that optimizes the infrastructure, technology, and traffic levels.

3.4.1 OPERATIONS PLAN DEVELOPMENT

For the proposed corridor, the first step in the Interactive Analysis is to identify for each Alternative the most appropriate route alignment and vehicle speed. To achieve a desired vehicle speed, the route is examined, and specific infrastructure improvements are proposed for each mile of track. As part of the study, unit costs have been generated and used to develop cost estimates for infrastructure and improvements and operating costs. These costs were further reviewed, revised, and updated for use in the Tier 1 EIS analysis Service Development Plan.

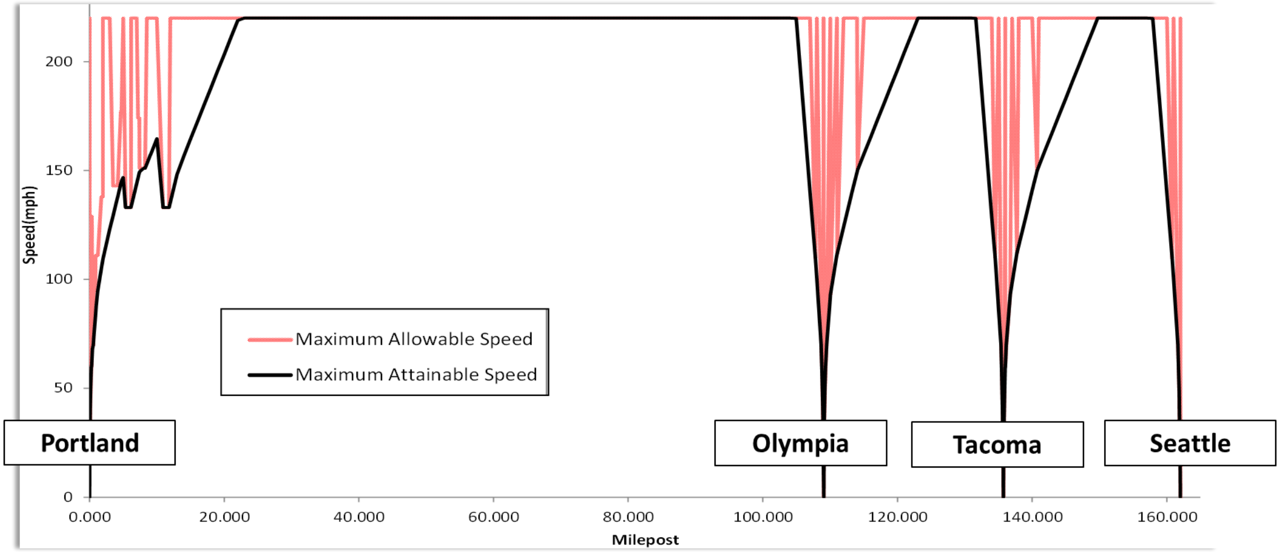
The actual operating speed of the high-speed trains along the tracks is calculated using *LOCOMOTION™*. Output from *LOCOMOTION™* was examined to identify specific bottlenecks, such as bridges, crossings, tunnels, and curves that restrict high-speed ground transportation system speeds unnecessarily and reduce the overall timetable performance of a specific technology.

The output of *LOCOMOTION™* provides an assessment of capsule running times for any given set of infrastructure proposals. By reviewing the timetables, the level of infrastructure improvements can be increased or reduced to meet specific timetable and thus specific ridership and freight traffic needs. In this way, the Interactive Analysis will result in the development of an operating strategy for each right-of-way/corridor and technology that best combines infrastructure requirements, operating speeds, frequencies, potential ridership and freight traffic.

A sample output of the train speed profile from *LOCOMOTION™* is given in Exhibit 3-6. Train speed can be plotted by milepost to show where train speed is reduced by speed restrictions along the track. It should be noted that the time saved by removing impedance factors will be different for different train technologies. For example, removing moderate curves is very important in maintaining average speeds at high levels for non-tilt trains.

Where restrictions are found, *TRACKMAN™* is used to identify the cost of upgrading the right-of-way. By using *LOCOMOTION™* and *TRACKMAN™* and *COMPASS™* programs together, a priority ranking of improvements can be developed. This consists of a cost per vehicle travel time minutes saved and cost-per-revenue dollar earned.

Exhibit 3-6: LOCOMOTION™ Example Speed Profile



The Interactive Analysis will identify key bottlenecks that prevent a given passenger rail technology from achieving its maximum capability, listing the priorities for each route, and estimating the civil engineering costs to overcome these bottlenecks. Equally, the analysis will be used to assess the effect of travel time and speed on ridership and freight traffic levels, and the cost of aligning the route to avoid locations with important environmental or cultural characteristics. In each case, the required infrastructure improvements will be quantified in terms of the full range of factors that affect infrastructure costs, including grading, guideway quality, and signaling, as well as engineering options like "tunnel" versus "cut and fill", which have very different capital costs.

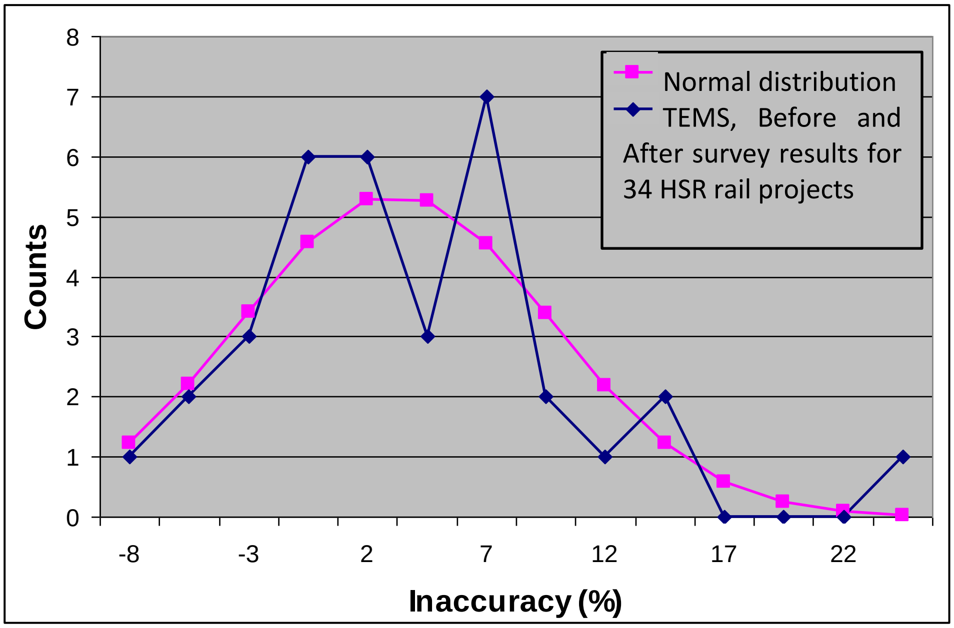
DELIVERABLES

- Interactive Analysis
- Base Year Traffic – OD
- Competitive modal schedules and times
- Alternative Operating Plans
- Alternative Route Infrastructure

3.4.2 MARKET ANALYSIS

The market analysis of passenger ridership and revenue has been completed using the *COMPASS™* demand model. The *COMPASS™* model is a discrete choice methodology approved by Academics, USDOT and Wall Street for Investment Grade high-speed rail forecasting. The *COMPASS™* model has been extensively used for high-speed rail analysis in Europe and North America, and for the 34 Investment Grade studies where "Before and After" surveys have been completed for passenger rail and high-speed passenger rail range for these corridors in terms of *COMPASS™* model error is less than plus or minus 20 percent. See Exhibit 3-7.

Exhibit 3-7: Distribution of TEMS' Forecast Error



Using a range of both rail alternatives and an assessment of the changes to the competitive character of other modes, a set of forecasts were prepared showing the market share of high-speed rail alternatives and the change in rail ridership and revenues over the life of the project. These forecasts were then used in the Interactive Analysis to refine each alternative and identify the most effective structure and character of the rail service for each alternative.

3.4.3 FINANCIAL AND ECONOMIC ANALYSIS

For the purposes of the development of a preferred alternative for the Cascadia High Speed Rail Corridor, the next step in the analysis is to show how each alternative measures up in terms of its financial and economic performance.

The financial and economic performance has been measured in the Cascadia High Speed Rail study using USDOT guidance on both Cost Benefit Analysis, as well as Public/Private Partnership. The Cascadia steering committee is seeking a 50/50 Public/Private Partnership, which requires the private sector to be able to operate the train service covering operating costs (as achieved by Amtrak in the Northeast corridor) as well as covering 50 percent of the Capital Costs of the project. To meet these needs and following the guidelines of the 1997 USDOT FRA "High-Speed Ground Transportation for America" the evaluation of each Alternative was made in both financial and economic terms.

- The Financial Analysis was made in "real terms" using a full twenty-five-year cash flow analysis and discount rates approved by the US Office of Management and Budget (OMB). This includes both a 3 percent and financial 7 percent discount rate. The results of the financial analysis is given as both an Operating Ratio, and a Net Present Value of the project over 25 years.
- The Economic Analysis follows USDOT guidance on Cost Benefit Analysis considering both the approved benefit criteria and the approved cost criteria for each alternative. Once again, the economic cash flows are discounted at rates approved by the OMB. The results of the Economic Analysis are presented in both a Cost Benefit Ratio and a Net Present Value calculated of the worth of the project over 25 years.

THE KEY DELIVERABLES

- Interactive Analysis
- Mapping of the most effective routes
- The Ridership and Revenue for each Alternative
- The Operating Plans for each Alternative
- The Capital and Operating Costs for each Alternative
- Financial and Economic Results

3.5 LEVEL OF PUBLIC INVOLVEMENT

Local stakeholders focusing on local and state government agencies have been engaged and made aware of service and infrastructure improvements planned for the CHSR corridor through a series of Webinars. Because the development of this plan has coincided with the timing of the COVID-19 pandemic in the United States, engagement has been in the form of newsletters, a web site, and webinars with local officials. It is anticipated that the scope of this outreach effort will be further expanded as the pandemic continues to recede.

A new Service NEPA Environmental Assessment (Service NEPA) is now advancing to evaluate the specific improvements planned for the Cascadia rail corridor under the three options defined in Section 2. The FRA will be the lead agency for this study. Additional public meetings, involvement and outreach are planned in conjunction with a continuation of the Service NEPA process and its eventual transition to a full NEPA process by the addition of formal Agency Coordination and additional Public Outreach tasks

A project website has been established which provides the public with project updates, notices of meetings and an opportunity to comment on the proposed projects. The address is: https://cascadiahighspeedrail.com/.

3.6 SUMMARY

It was clear early in the study that the SDP would need to need to focus on developing the critical Portland to Seattle segment of the Cascadia corridor first. Lack of capacity and poor geometry on the Portland to Seattle segment are well-known problems associated with the existing rail alignment. Although the line is adequate for supporting freight and can be expanded for adding commuter service, the combination of freight services, Amtrak, and commuter service will more than reach the capacity of a double tracked line between Portland

and Seattle. This is especially a concern if the two bottleneck areas between Seattle and Tacoma and at the Columbia River crossing are not addressed and remain only double tracked on a 150 year old railroad corridor.

Even Washington DOT's planned Seattle to Portland improvements do not effectively alleviate these bottlenecks, so as a result passenger service may continue to face significant delays and require added schedule time (pad) due to the lack of capacity.

As a result, it is clear that development of a new greenfield alignment from Portland to Seattle, and a capacity improvement plan that goes beyond Washington DOT's current shared-use plan, are absolute prerequisites to high-speed service in the Cascadia corridor. Without an alignment based on dedicated tracks that are free of freight train interference, high-speed service in the Cascadia corridor cannot be effective or successful.

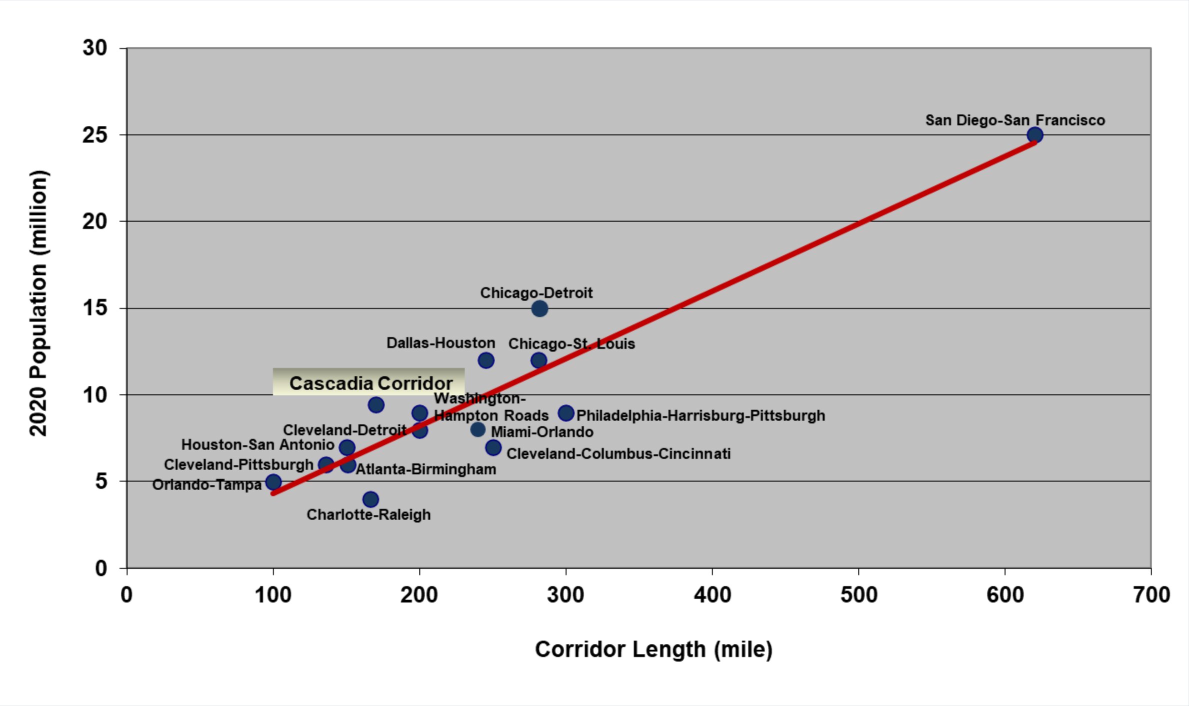
4. DEMAND AND REVENUE FORECASTS

This Market Analysis provides an assessment of the overall travel market and its comparison with other US high-speed rail corridors. It describes the development of the very high-quality travel demand model, its zones, and data sources used to develop forecasts. The socioeconomic growth projections and transport conditions for the corridor are also provided. A key input to the demand model was the Stated Preference Survey that estimated the responsiveness of the community to their travel options. Finally, the forecasts of ridership and revenue are described for each of the route and technology options.

4.1 OVERVIEW OF EXISTING TRAVEL MARKET

The Cascadia Corridor is one of the top intercity corridors in the U.S., being comparable with California's San Francisco-San Diego, Florida's Miami-Orlando, Texas' Dallas-Houston, and Midwest's Chicago-St. Louis and Chicago-Detroit corridors; all of which are above the average red line shown in Exhibit 4.1. It can be seen that it is much stronger than many other corridors like Ohio's 3C Corridor, Philadelphia-Pittsburgh or Charlotte-Raleigh (Exhibit 4-1). As such, the Cascadia corridor has independent utility as a high-speed corridor.

Exhibit 4-1: Corridor Comparison



Like many intercity passenger rail corridors, the demand for travel in the corridor is strong. In 2020 the Cascadia Corridor had a population of more than nine million. The corridor also hosts large number of finance and business services, research and high-tech industry, and government agencies. In 2020 the total employment in the corridor was over five million and average household income was $134,140. Projections indicate that the corridor's demographic and economic growth will continue over the next several decades, the population is projected to be nearly 12 million in 2040, employment will be 7.5 million in 2040, and average household incomes will grow to $191,758 in 2040 in 2019 dollars. As a result, the Cascadia Corridor has a high level of business and commuter travel between its urban areas together with significant social and tourist travel. The total number of annual intercity and interurban trips in the corridor is estimated to be 66 million in 2019. This means the average resident takes 6.9 intercity and interurban trips per year.

4.2 BASIC STRUCTURE OF THE COMPASS™ TRAVEL MARKET FORECAST MODEL

For the purpose of this study, the ridership and revenue forecast will be produced using the *COMPASS™* Travel Demand Model. The *COMPASS™* Multimodal Demand Forecasting Model is a flexible demand forecasting tool used to compare and evaluate alternative passenger rail network and service scenarios. It is particularly useful in assessing the introduction or expansion of public transportation modes such as air, bus or high-speed rail into markets. Exhibits 4-2 and 4-3 show the structure and working process of the *COMPASS™* Model. As shown, the inputs to the *COMPASS™* Model are base and proposed transportation networks, base and projected socioeconomic data, value of time and value of frequency from Stated Preference surveys, and base year travel data obtained from government agencies and transportation service operators.

The *COMPASS™* Model structure incorporates two principal models: a Total Demand Model and a Hierarchical Modal Split Model. These two models are calibrated separately. In each case, the models are calibrated for origin-destination trip making in the study area:

- The *COMPASS™* Total Demand Model provides a mechanism for replicating and forecasting the total travel market. The total number of trips between any two zones for all modes of travel is a function of (1) the socioeconomic characteristics of the two zones and (2) the travel opportunities provided by the overall transportation system that exists (or will exist) between the two zones. Typical socioeconomic variables include population, employment and income. The quality of the transportation system is measured in terms of total travel time and travel cost by all modes, and the induced demand is estimated by considering the change in quality of travel offered by all modes.
- The role of the *COMPASS™* Modal Split Model is to estimate relative modal shares of travel given the estimation of the total market by the Total Demand Model. The relative modal shares are derived by comparing the relative levels of service (as estimated by generalized costs) offered by each of the travel modes. Three levels of binary choice were used in this study (see Exhibit 4-3). The first level separates rail services from bus services. The second level of the hierarchy separates air travel, the fastest and most expensive mode of travel, from surface modes of rail and bus services. The third level separates auto travel with its perceived spontaneous frequency, low access/egress times, and highly personalized characteristics, from public modes (i.e., air, rail and bus). The model forecasts changes in riders, revenue and market share based on changes travel time, frequency and cost for each mode as measured by the generalized costs for each mode. A more detailed description of the *COMPASS™* Model is given in Appendix C.

Exhibit 4-2: Structure of the COMPASS™ Model

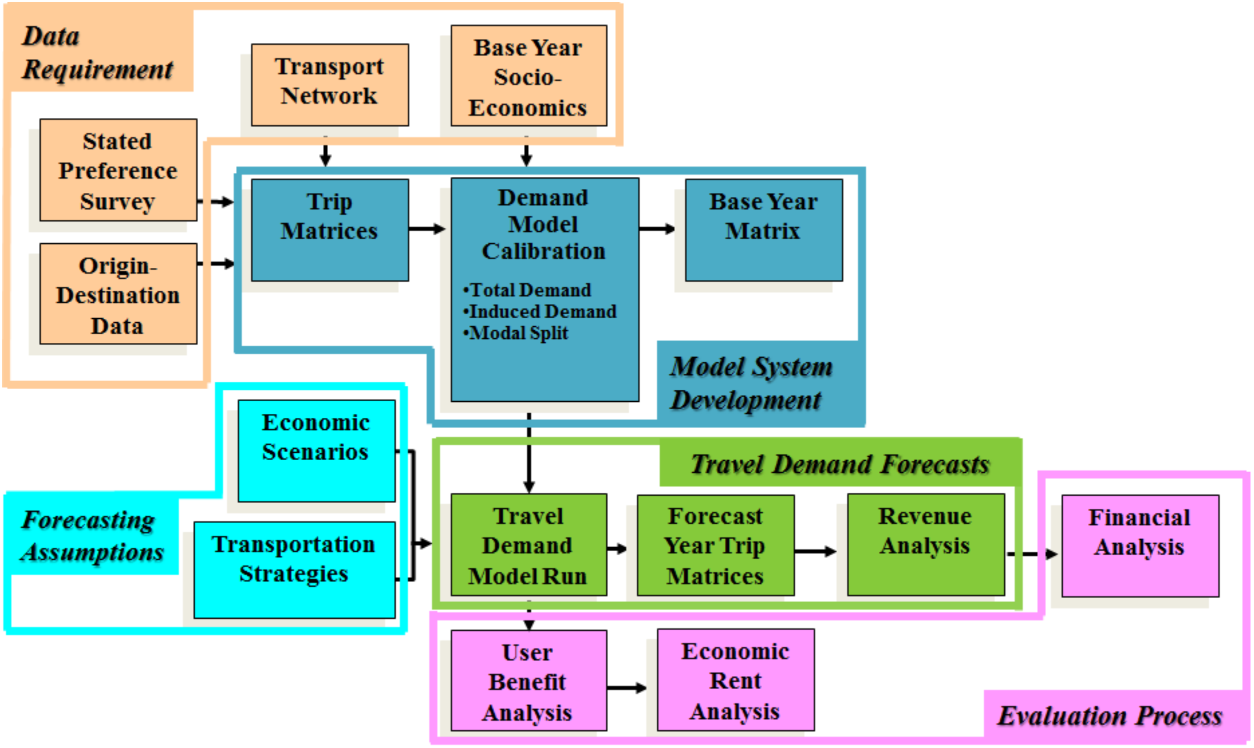
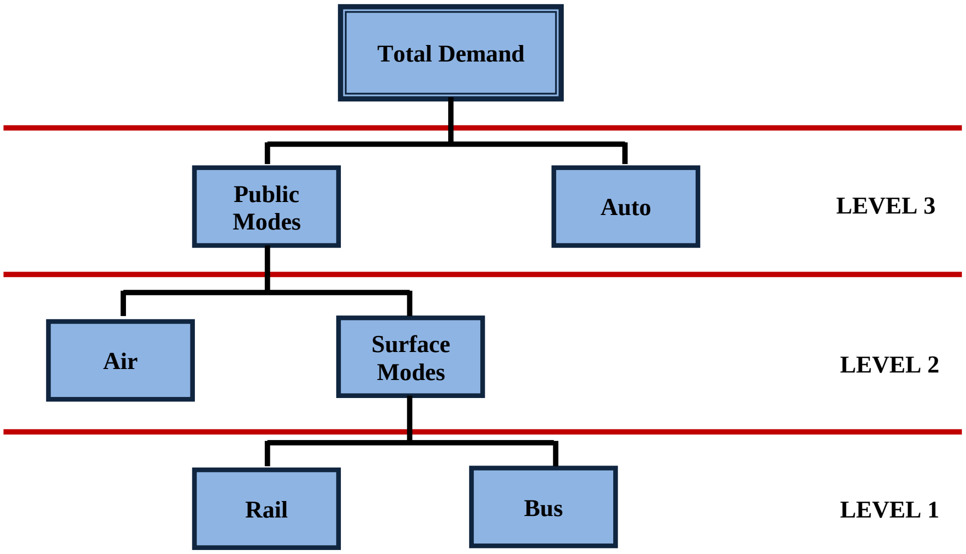


Exhibit 4-3: Hierarchical Structure of the Modal Split Model



A key element in evaluating passenger rail service is the comprehensive assessment of the travel market in the corridor under study, and how well the passenger rail service might perform in that market. For the purpose of this study, this assessment was accomplished using the following process:

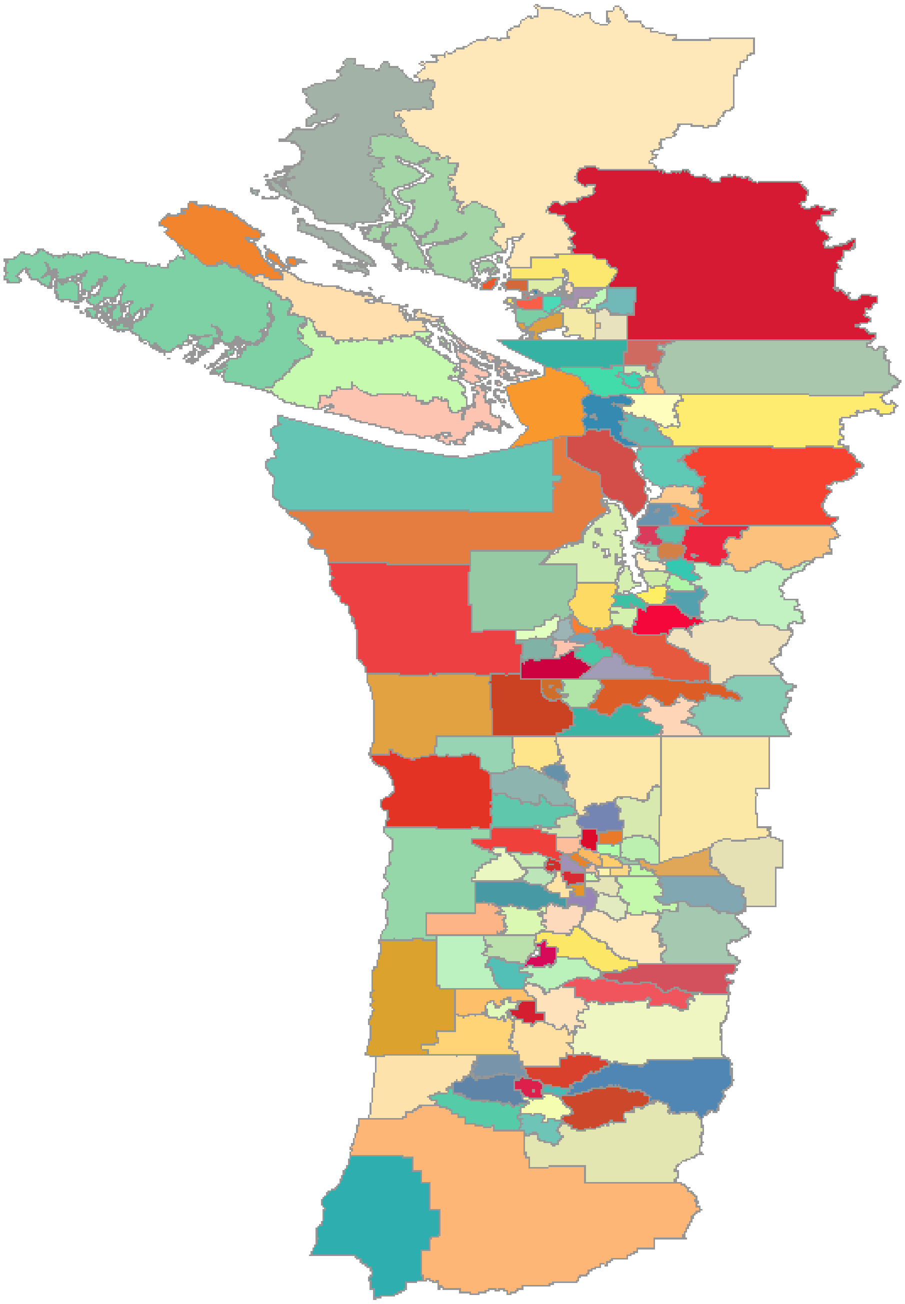
- Building the zone system that enables more detailed analysis of the origin-destination travel market and the development of base year and future socioeconomic data for each zone.
- Compiling information on the service levels (times, fares, frequency, costs) in the corridor for auto, air, bus, and the proposed passenger rail travel.
- Identifying and quantifying factors that influence travel choices, including values of time, frequency and access/egress time.
- Developing strategies that quantify how travel conditions will change, including future gas price, future vehicle fuel efficiency improvement, and highway congestion.
- Developing and calibrating total travel demand and modal split models for travel demand forecasting.
- Forecasting travel, including total demand and modal shares.

The following sections document the modeling process and the forecasting results.

4.3 ZONE DEFINITION

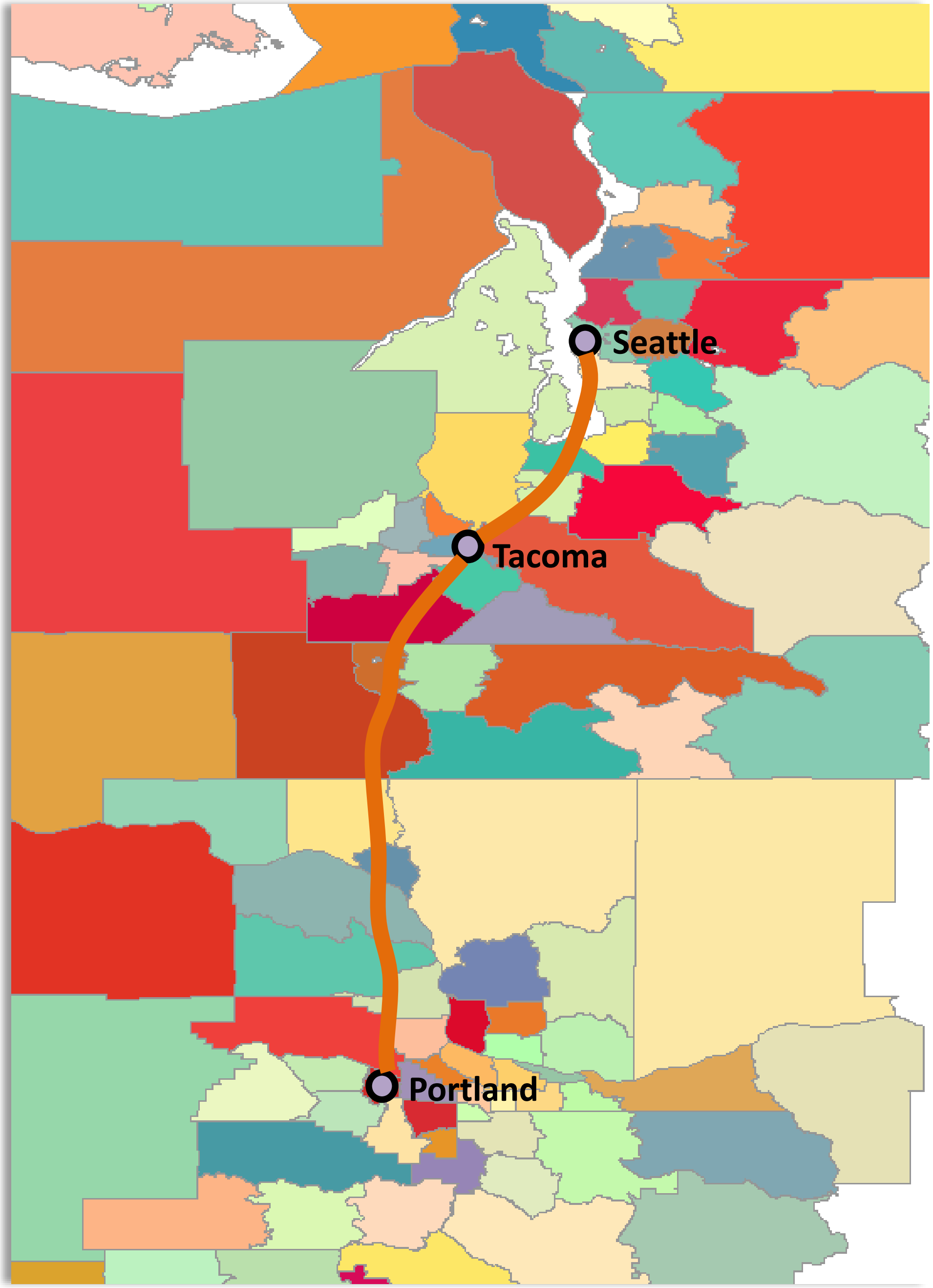
The zone system provides a representation of the market areas among which travel occurs from origins to destinations. For intercity and interurban passenger rail planning, most rural zones can be represented by larger areas. However, where it is important to identify more refined trip origins and destinations in urban areas, finer zones are used. To meet this need, a 174-zone system was developed for the Cascadia Corridor study area based on aggregation of census tracts and traffic analysis zones (TAZs) of local transportation planning agencies. Exhibit 4-4 shows the zone system for the whole study area. Exhibit 4-5 shows the zones between Seattle and Portland.

Exhibit 4-4: Study Area Zone System (174 Zones*)



*Colors indicate the different TAZ zones defined by TEMS

Exhibit 4-5: Seattle to Portland Area Zones*



*Colors indicate the different TAZ zones defined by TEMS

4.4 SOCIOECONOMIC BASELINE AND PROJECTIONS

The travel demand forecasting model requires base year estimates and future growth forecasts of three socioeconomic variables of population, employment and per capita income for each of the zones in the study area. A socioeconomic database was established for the base year (2020) and for each of the forecast years (2025-2055). The data was developed at five-year intervals using the most recent data from the following sources:

- US Census Bureau
- Woods & Poole Economics
- Bureau of Economic Analysis
- Puget Sound Regional Council
- Regional Transportation Plan – Oregon Metro
- Lane Council of Governments

Exhibit 4-6 shows the base year and projected socioeconomic data for the study. According to the data developed from these sources, the population will increase from 9.46 million in 2020 to 13.70 million in 2055, the total employment of the study area will increase from 5.52 million to 8.71 million in 2055, and average household income will increase from $134,140 in 2020 to $219,101 in 2055 in 2019 dollars.

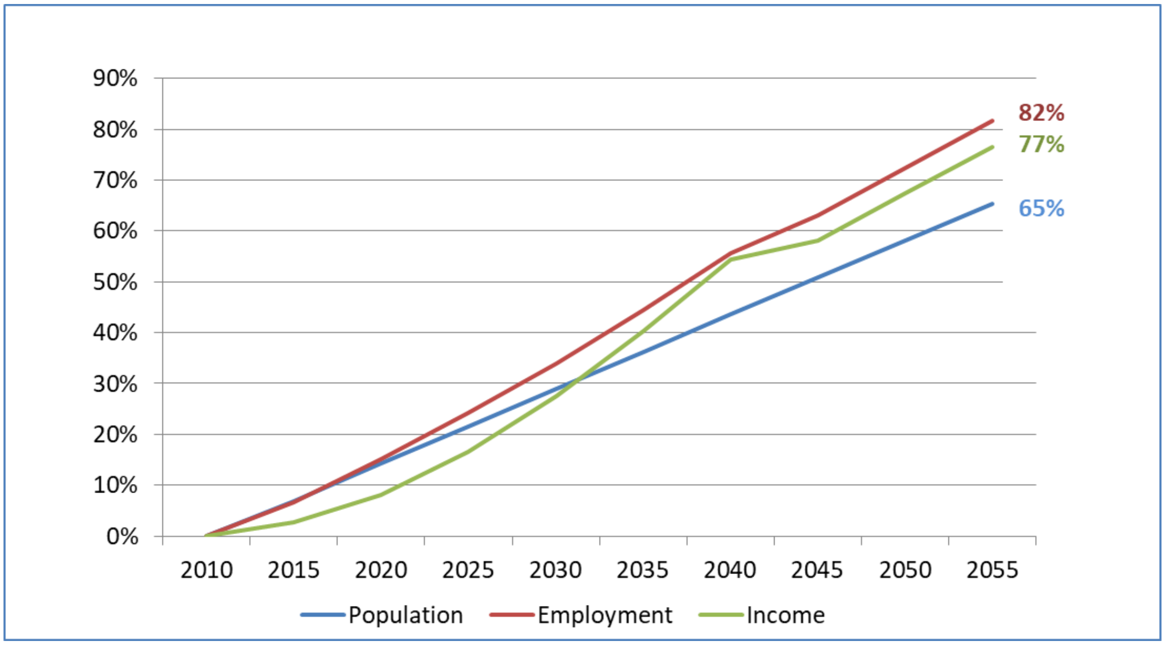
Exhibit 4-6: Base and Projected Socioeconomic Data for the Study Area

	2020	2025	2030	2035	2040	2045	2050	2055
Population	9,458,501	10,070,944	10,681,042	11,286,862	11,894,647	12,492,941	13,097,264	13,701,587
Employment	5,518,793	5,954,429	6,421,504	6,922,203	7,458,804	7,814,178	8,261,222	8,708,266
Average Household Income (2019 $)	134,140	144,809	158,268	174,095	191,758	196,319	207,712	219,101

Exhibit 4-7 shows the historical and projected socioeconomic growth for the study area. The exhibit shows that there is higher growth of employment than population, and income growth is in the middle. Furthermore, travel increases are historically strongly correlated to increases in employment and income, in addition to changes in population. Therefore, travel in the corridor is likely to continue to increase faster than the population growth rates, as changes in employment and income outpace population growth, and stimulate more demand for traveling.

The exhibits in this section show the aggregate socioeconomic projection for the study area. It should be noted that in applying socioeconomic projections to the model, separate projections were made for each individual zone using the data from the listed sources. Therefore, the socioeconomic projections for different zones are likely to be different and thus may lead to different future travel sub-market projections. A full description of socioeconomic data of each zone can be found in the Appendix B.

Exhibit 4-7: Socioeconomic Growth Projection for the Study Area



4.5 EXISTING TRAVEL MODES

In transportation analysis, travel desirability/utility is measured in terms of travel cost and travel time. These variables are incorporated into the basic transportation network elements that provide by mode the connections from any origin zone to any destination zone. Correct representation of the existing and proposed travel services is vital for accurate travel forecasting. Basic network elements are called nodes and links. Each travel mode consists of a database comprised of zones and stations that are represented by nodes, and existing connections or links between them in the study area. Each node and link is assigned a set of travel attributes (time and cost). The network data assembled for the study included the following attributes for all the zone pairs.

For public travel modes (air, rail, bus):

- Access/egress times and costs (e.g., travel time to a station, time/cost of parking, time walking from a station, etc.)
- Waiting at terminal and delay times
- In-vehicle travel times
- Number of interchanges and connection times
- Fares
- Frequency of service

For private mode (auto):

- Travel time, including rest time
- Travel cost (vehicle operating cost)
- Tolls
- Parking Cost
- Vehicle occupancy

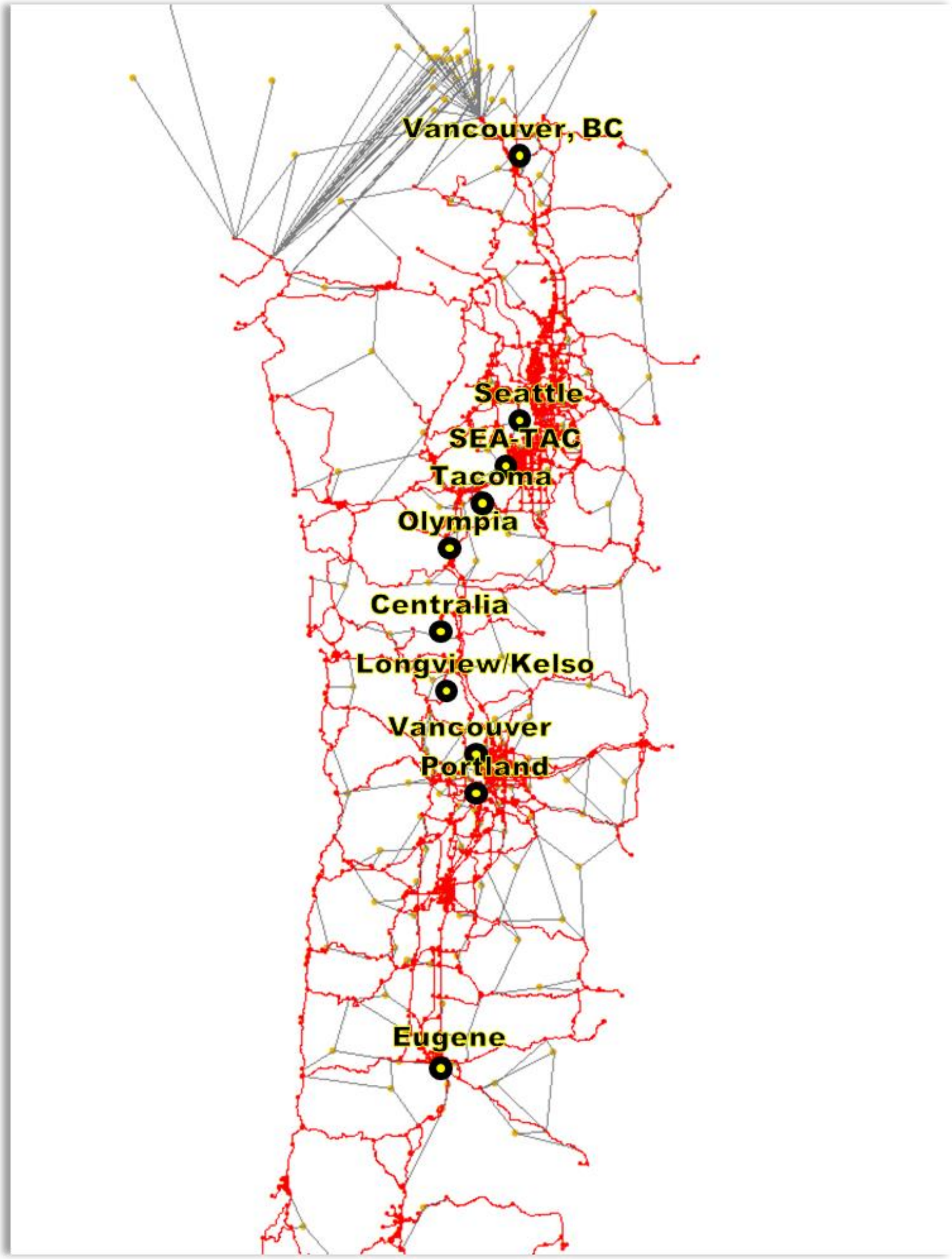
The transportation travel attribute or service data of different modes available in the study corridor were obtained from a variety of sources and coded into the *COMPASS™* networks as inputs to the demand model. The major sources are as follows.

The highway network was developed to reflect the major highway segments within the study area. The sources for building the highway network in the study area are as follows:

- State and Local Departments of Transportation highway databases
- Highway Performance Monitoring System (HPMS) database

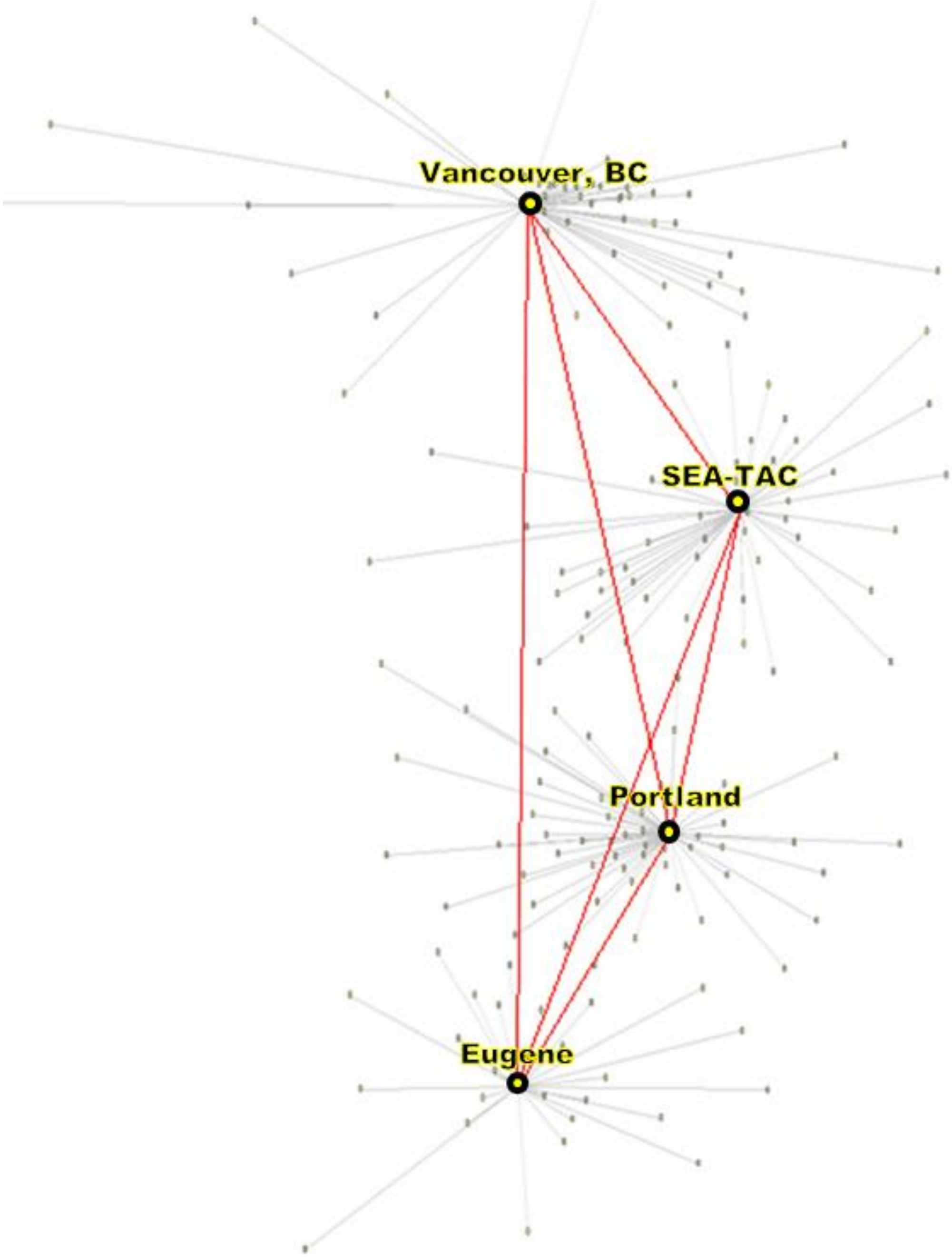
The highway network of the corridor area coded in *COMPASS™* is shown in Exhibit 4-8.

Exhibit 4-8: COMPASS™ Highway Network for the Study Area



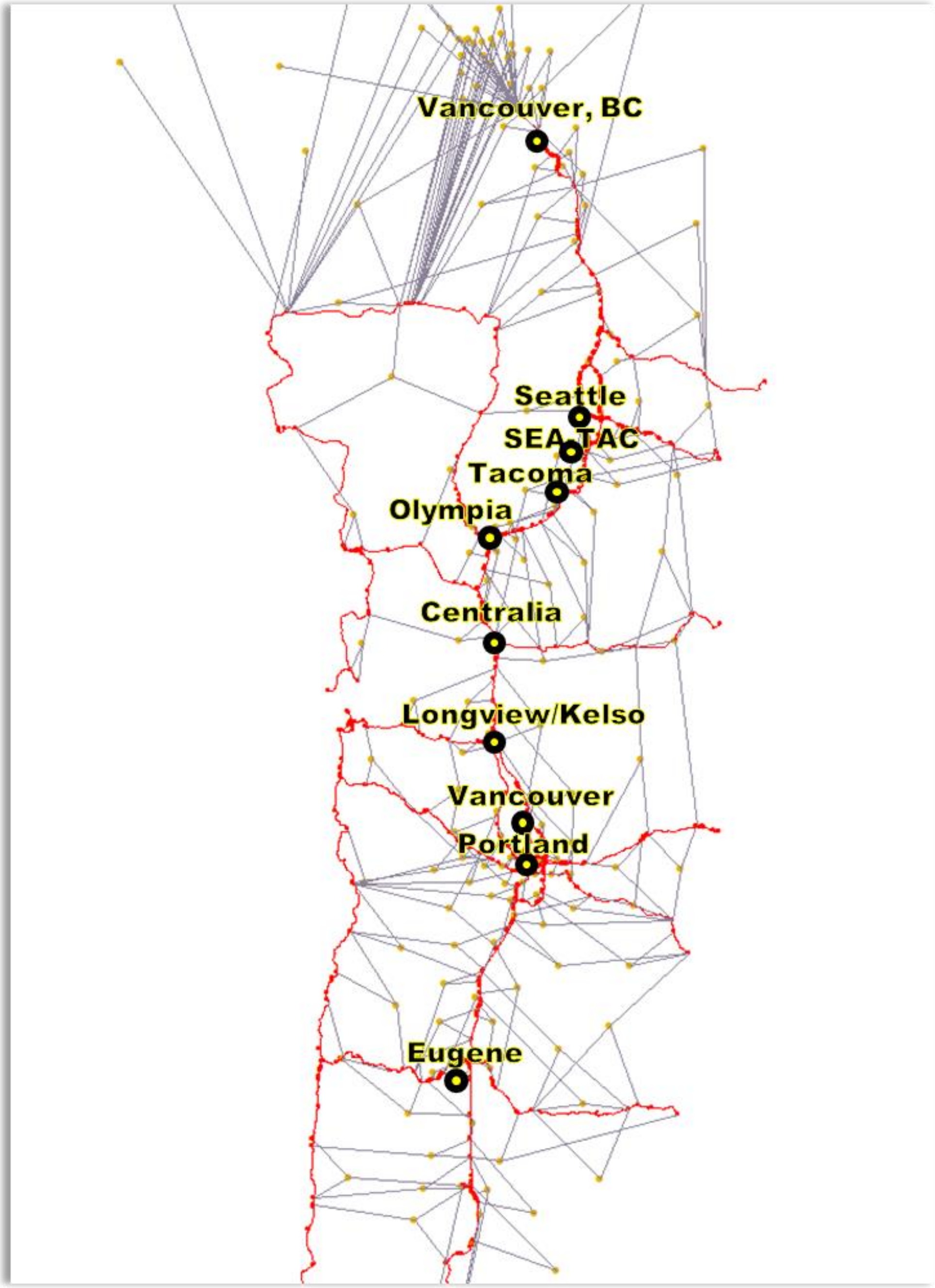
Air network attributes contain a range of variables that include time and distance between airports, airfares, and connection times. Travel times, frequencies and fares were derived from official airport websites, websites of the airlines serving airports in the study area, and the BTS 10% sample of airline tickets. Exhibit 4-9 shows the air network of the study area coded in *COMPASS™.*

Exhibit 4-9: COMPASS™ Air Network for the Study Area



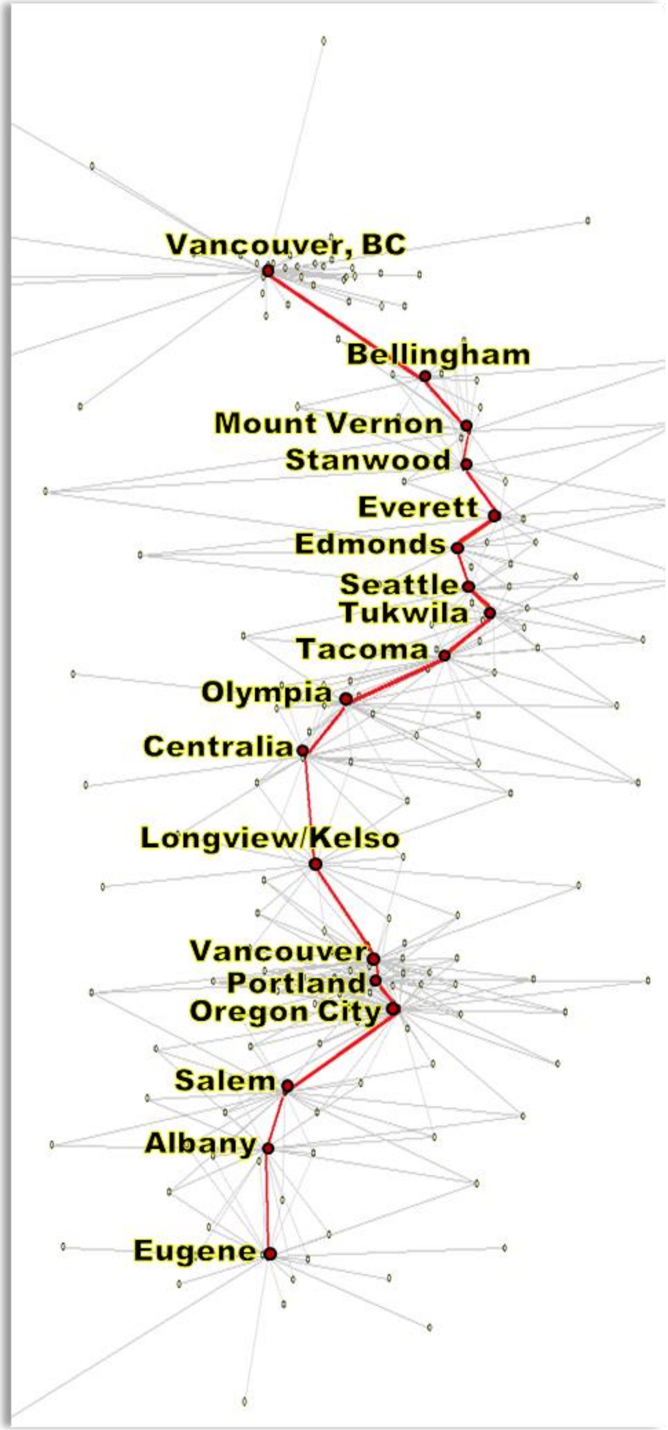
Bus travel data of travel time, fares, and frequencies, were obtained from official schedules of Greyhound. Exhibit 4-10 shows the bus network of the study area coded in *COMPASS™.*

Exhibit 4-10: COMPASS™ Transit Network for the Study Area



Current passenger rail travel data of travel time, fares, and frequencies, were obtained from official schedules of Amtrak. Exhibit 4-11 shows the Amtrak passenger rail network of the study area coded in *COMPASS™.*

Exhibit 4-11: COMPASS™ Amtrak Rail Network for the Study Area



4.6 ORIGIN-DESTINATION TRIP DATABASE

The multi-modal intercity travel analyses model requires the collection of base year 2019 origin-destination (O-D) trip data describing annual personal trips between zone pairs. For each O-D zone pair, the annual personal trips are identified by mode (auto, air, and bus) and by trip purpose (business, commuter, other). Because the goal of the study is to evaluate intercity travel, the O-D data collected for the model reflects travel between zones (i.e., between counties, neighboring states and major urban areas) rather than within zones.

TEMS extracted, aggregated and validated data from a number of sources in order to estimate base travel between origin-destination pairs in the study area. The data sources for the origin-destination trips in the study are:

- Washington DOT
- Oregon DOT
- Puget Sound Regional Council
- Regional Transportation Plan – Oregon Metro
- Lane Council of Governments
- Highway Performance Monitoring System (HPMS)
- British Columbia Ministry of Transportation
- Bureau of Transportation Statistics 10% Air Ticket Sample

The travel demand forecast model requires the base trip information for all modes between each zone pair. In some cases, this can be achieved directly from the data sources, while in other cases the data providers only have origin-destination trip information at an aggregated level (e.g., AADT data, station-to-station trip and station volume data). Where that is the case, a data enhancement process of trip simulation and access/egress simulation needed to be conducted to estimate the zone-to-zone trip volume. The data enhancement process is shown in Exhibit 4-12.

For the auto mode, the quality of the origin-destination trip data was validated by comparing it to AADTs and traffic counts on major highways and adjustments have been made when necessary. For public travel modes, the origin-destination trip data was validated by examining station volumes and segment loadings.

Exhibit 4-12: Zone-to-Zone Origin-Destination Trip Matrix Generation and Validation

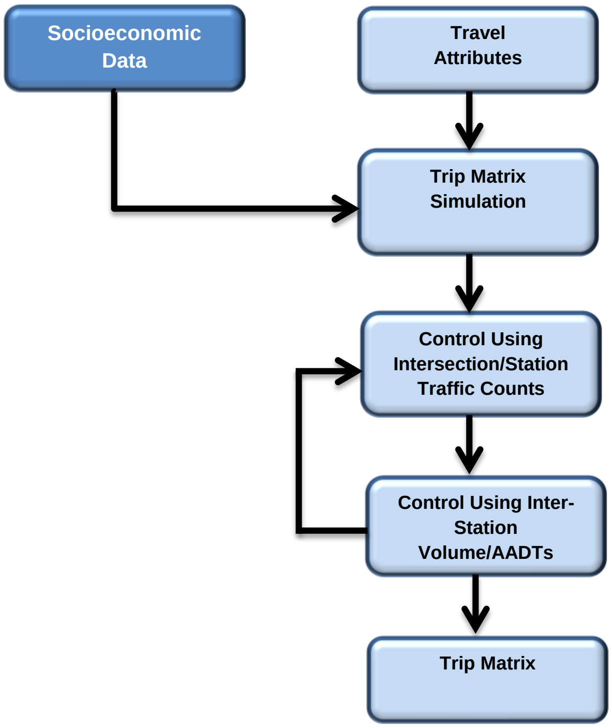


Exhibit 4-13 shows the base 2019 travel market share of rail, air, bus, and auto modes. It can be seen that auto mode dominates the travel market with more than 91 percent of market share. Public modes have 8.4 percent of travel market share.

Exhibit 4-13: 2019 Base Travel Market Share by Mode

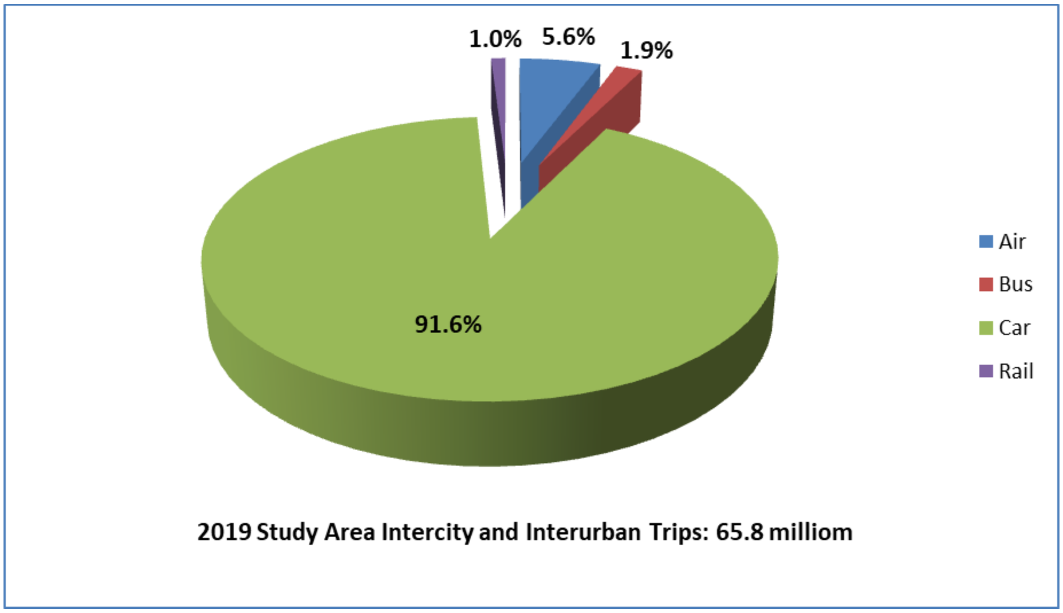
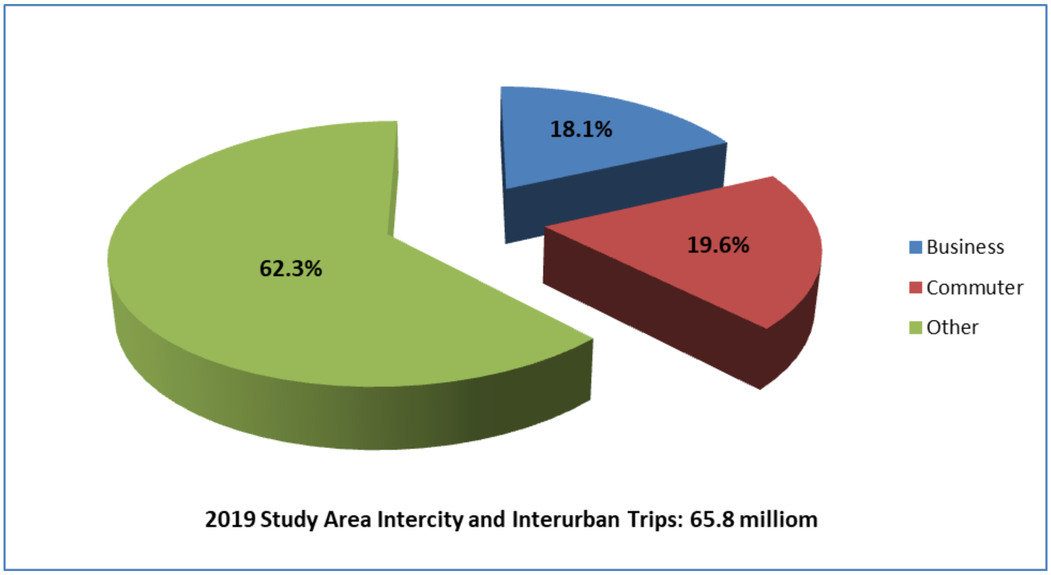


Exhibit 4-14 shows 2019 study area travel market share by travel purpose.

Exhibit 4-14: 2019 Base Year Travel Market by Travel Purpose



4.7 VALUES OF TIME, VALUES OF FREQUENCY, AND VALUES OF ACCESS TIMES

Generalized cost of travel between two zones estimates the impact of improvements in the transportation system on the overall level of trip making. Generalized Cost includes all the factors that are key to an individual's travel decision (such as travel time, fare, frequency) that are all included in the Generalized Cost equation for the *COMPASS™* Model. Generalized Cost is typically defined in travel time (i.e., minutes) rather than cost (i.e., dollars). Costs are converted to time by applying appropriate conversion factors such as Value of Time, derived from Stated Preference Surveys. The generalized cost (GC) of travel between zones i and j for mode m and trip purpose p is defined as follows:

$$GC_{ijmp} = TT_{ijm} + \frac{TC_{ijmp}}{VOT_{mp}} + \frac{VOF_{mp} * OH}{VOT_{mp} * F_{ijm}}$$

Where,

TT_{ijm} = Travel Time between zones i and j for mode m (in-vehicle time + station wait time + connection time + access/egress time), with waiting, connect and access/egress time multiplied by a factor (waiting and connect time factors is 1.8, access/egress factors were determined by ratios from the Michigan Detroit-Chicago SP survey) to account for the additional disutility felt by travelers for these activities.

TC_{ijmp} = Travel Cost between zones i and j for mode m and trip purpose p (fare + access/egress cost for public modes, operating costs for auto)

VOT_{mp} = Value of Time for mode m and trip purpose p

VOF_{mp} = Value of Frequency for mode m and trip purpose p

F_{ijm} = Frequency in departures per week between zones i and j for mode m

OH = Operating hours per week (sum of daily operating hours between the first and last service of the day)

Value of Time (VOT) is the amount of money (dollars/hour) an individual is willing to pay to save a specified amount of travel time, the Value of Frequency (VOF) is the amount of money (dollars/hour) an individual is willing to pay to reduce the time between departures when traveling on public transportation. Access/Egress time is weighted higher than in-vehicle time in generalized costs calculation, and its weight is derived from value of access stated preference surveys. Station wait time is the time spent at the station before departure and after arrival. On trips with connections, there would be additional wait times incurred at the connecting station. Wait times are weighted higher than in-vehicle time in the generalized cost formula to reflect their higher disutility as found in previous stated preference surveys.

Exhibits 4-15 and 4-16 shows the values of time and values of frequency obtained from the previous SP surveys.

Exhibit 4-15 VOT values by Mode and Purpose of Travel ($2019/hour)

Value of Time (VOT)	Business	Non-business
Auto	$30.06	$27.11
Bus	$22.35	$16.46
Rail	$42.87	$30.68
Air	$54.06	$42.97

Exhibit 4-16: VOF values by Mode and Purpose of Travel ($2019/hour)

Value of Frequency (VOF)	Business	Non-business
Bus	$5.82	$5.78
Rail	$11.42	$9.66
Air	$27.99	$20.14

The SP Surveys included:

- Rocky Mountain High Speed Rail SP Survey
- Baltimore-Washington High Speed Ground Transportation EIS Study
- Chicago-Detroit/Pontiac Environmental Impact Study
- Detroit/Windsor-Toronto High Speed Rail SP Survey
- Edmonton-Calgary High Speed Rail Study
- Los Angeles-Las Vegas High Speed Rail Study
- Texas A&M Value of Time Estimates

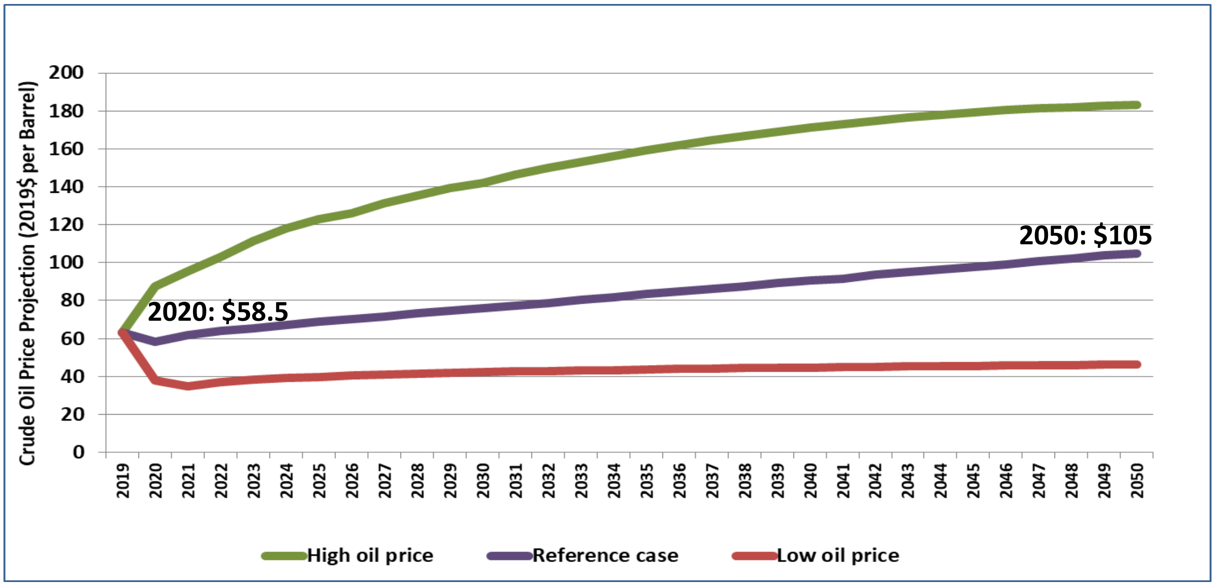
For the final Investment Grade Forecasts of the Cascadia Tier 1 EIS, a Cascadia Corridor Stated Preference Survey will be completed.

4.8 FUTURE TRAVEL MARKET STRATEGIES

4.8.1 FUEL PRICE FORECASTS

One of the important factors in the future attractiveness of public modes is fuel price. Exhibit 4-17 shows the Energy Information Agency (EIA)[14] projection of crude oil prices for three oil price cases: namely a high world oil price case that is for an aggressive oil price forecast; a reference world oil price case that is moderate and is also known as the central case forecast; and a conservative low world oil price case. In this study, the reference case oil price projection is used to estimate transportation cost in future travel market. The EIA reference case forecast suggests that crude oil prices are expected to be $76 per barrel in 2030 and will increase to $105 per barrel in 2050.

Exhibit 4-17: Crude Oil Price Forecast by EIA



EIA has also developed a future retail gasoline price forecast, which is shown in Exhibit 4-18. The implication of this is a reference case gasoline price of $2.81 per gallon in 2030, with a high case price of $4.18 per gallon, and a low case price of $2.09 per gallon. The reference case gasoline price will increase to $3.43 per gallon in 2050. The impact of rising energy prices will clearly impact the competition between the modes of travel in the corridor.

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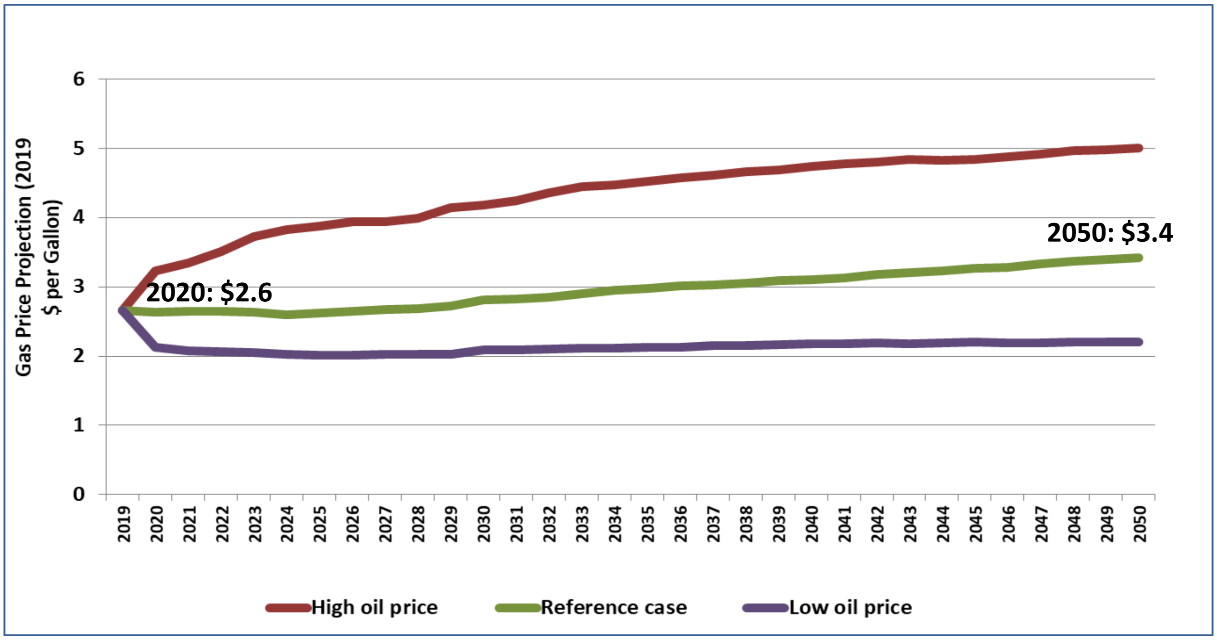
[14] EIA periodically updates historical and projected oil prices at www.eia.gov/forecasts/aeo/tables_ref.cfm

Exhibit 4-18: U.S. Retail Gasoline Prices Forecast by EIA



4.8.2 VEHICLE FUEL EFFICIENCY FORECASTS

Future improvement in automobile technology is likely to reduce the impact of high gas prices on automobile fuel cost with better fuel efficiency. The Oak Ridge National Laboratory (ORNL) Center for Transportation Analysis (CTA) provides historical automobile highway energy usage in BTU (British Thermal Unit) per vehicle-mile data for automobiles since 1970 (Exhibit 4-19).

Exhibit 4-19: ORNL Historical Highway Automobile Energy Intensities Data

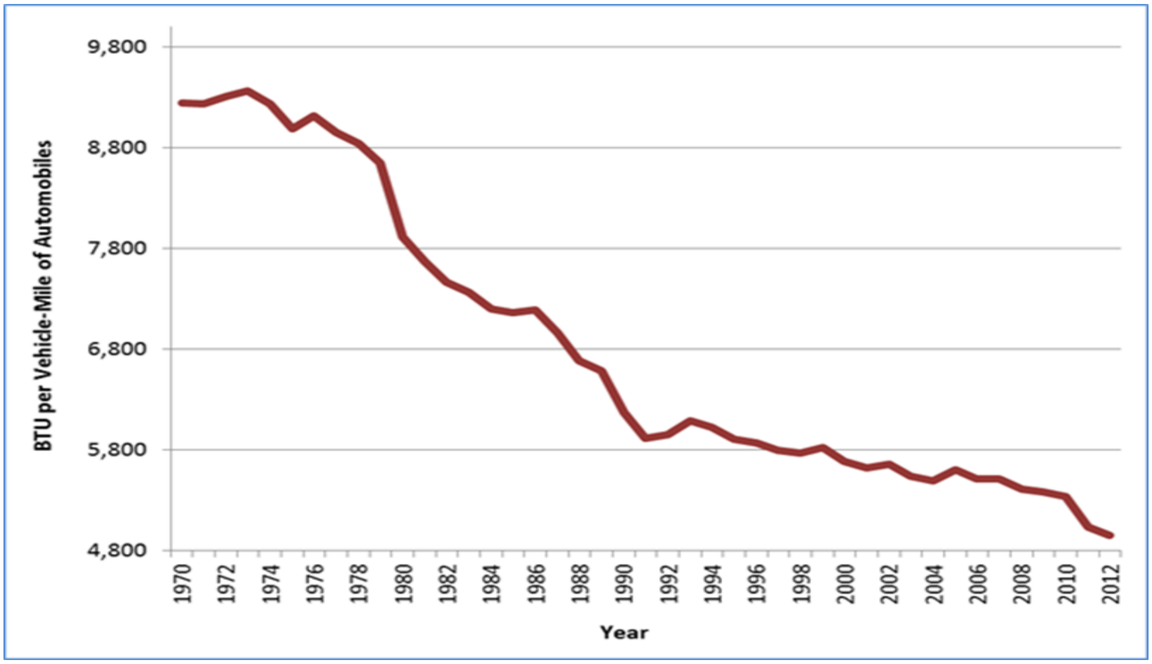
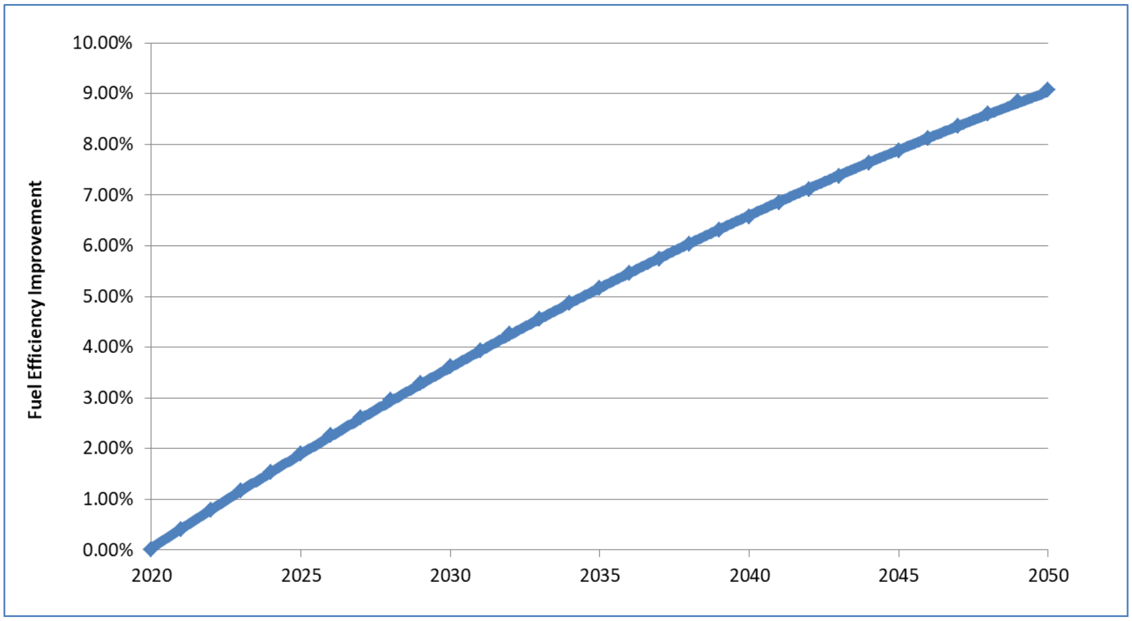


Exhibit 4-19 shows the historical highway automobile energy intensities from 1970 to 2012. It can be seen that automobile fuel efficiency has been improving gradually during the past few decades, but the improvement perhaps surprisingly has slowed down in recent years. Future automobile fuel efficiency improvement was projected by TEMS as shown in Exhibit 4-20. The TEMS forecast reflects the actual performance of the vehicle fleet, which is much lower and slower to be implemented than the regulated Corporate Average Fuel Economy (CAFE) standards for new cars. The auto fleet simply changes at a much slower pace than the standards for new cars. It was based on the historical automobile fuel efficiency data. The TEMS forecast shows a slow but consistent increase in car fuel efficiency to 2050, and beyond. It shows that the automobile fleet fuel efficiency is expected to improve by more than 9 percent by 2050 as compared to fuel efficiency of today.

Exhibit 4-20: Auto Fuel Efficiency Improvement Projections



4.8.3 HIGHWAY TRAFFIC CONGESTION

The average annual travel time growth in the corridor is estimated with the projected highway traffic volume data and the BPR (Bureau of Public Roads) function that can be used to calculate travel time growth with increased traffic volumes:

$$T_f = T_b * [1 + \alpha * \left(\frac{V}{C}\right)^{\beta}]$$

Where

T_f is future travel time,
T_b is highway design travel time,
V is traffic volume,
C is highway design capacity,
α , β are calibrated coefficients.

The projected travel times were calculated by computing travel time on each segment of the highway route between two cities. The key assumptions are as follows:

- $\alpha = 0.56$
- $\beta = 3.6$

The above two coefficients are from the Highway Capacity Manual, they determine how traffic volume will affect travel speed. Exhibit 4-21 shows the estimated travel time growths in 2050 for main city pairs in the corridor due to increasing highway traffic volumes.

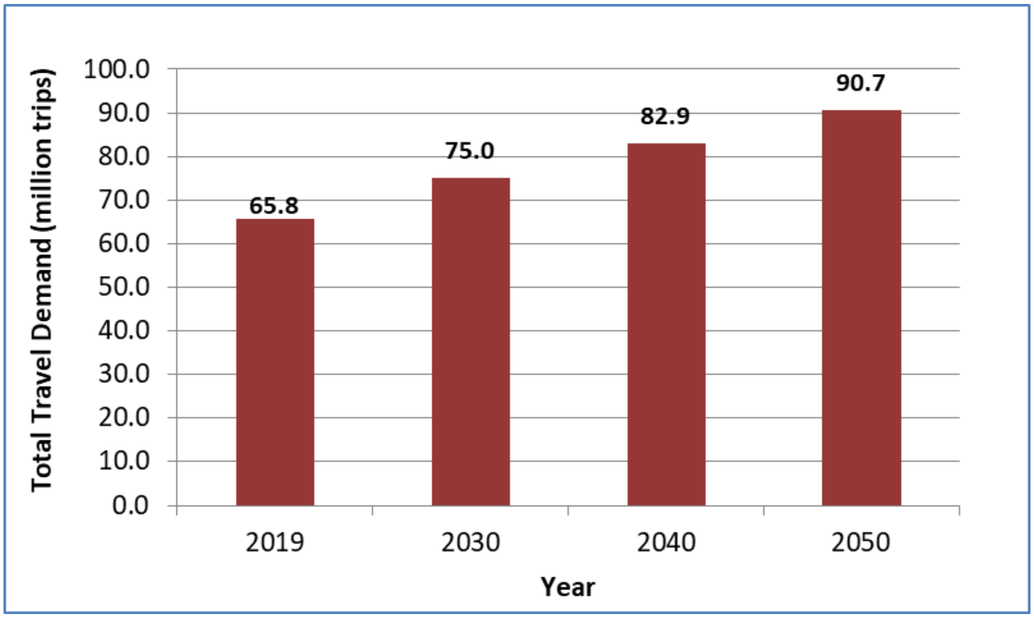
Exhibit 4-21: Highway Travel Time Projections

	2019 Travel Time	2050 Estimated Travel Time
Seattle, WA – Tacoma, WA	35 Min	43 Min
Seattle, WA – Portland, OR	2 Hour 45 Min	3 Hour 15 Min
Tacoma, WA – Portland, OR	2 Hour 10 Min	2 Hour 30 Min

4.9 CORRIDOR TOTAL TRAVEL MARKET DEMAND FORECAST

Exhibit 4-22 shows the CHSR Corridor total intercity and interurban Travel Demand Forecasts from 2019 to 2050 at five-year interval. These travel demands are potential travel market where high-speed rail will be competing with auto driving, air travel, and transit riding. It can be seen that the travel demand will increase from 65.8 million trips in 2019, to nearly 75 million in 2030, and increases to more 90.7 million in 2050. The average annual corridor travel market growth rate is 1.04 percent, which is in line with the socioeconomic growth within the travel market for the corridor.

Exhibit 4-22: CHSR Corridor Total Travel Demand Forecast



4.10 CHSR TRAVEL MARKET FORECASTS FOR HIGH-SPEED RAIL

The specific ridership and revenue is dependent on the level of high-speed rail service proposed. Three high-speed rail service alternatives were used for the high-speed rail ridership and revenue forecast:

- **Alternative 1 (Improved Infrastructure)** – Improves the existing diesel service and raises the top speed to 110 mph. The option would include CHSR's originally proposed improvements to the BNSF alignment from Portland to Lakewood; north of Lakewood, the alignment would be upgraded and shared with Sounder commuter trains.
- **Alternative 2 (Ultra High-Speed, low infrastructure)** – Same alignment as Alternative 1 but electrified for tilting trains. Although it uses Ultra High Speed equipment, the alignment permits only short stretches of 220 mph: it is more characteristic of a 160-mph alignment.
- **Alternative 3 (Ultra High-Speed, high infrastructure)** – A brand new end-to-end alignment with improved geometry would allow operations of electric trains at sustained 220-250 mph top speeds.

Exhibit 4-23 summarizes the running time and frequency for each alternative. In exhibit 4-23, running times are expressed in hours and minutes format (HH:MM) and "RT" signifies the number of round trips operated.

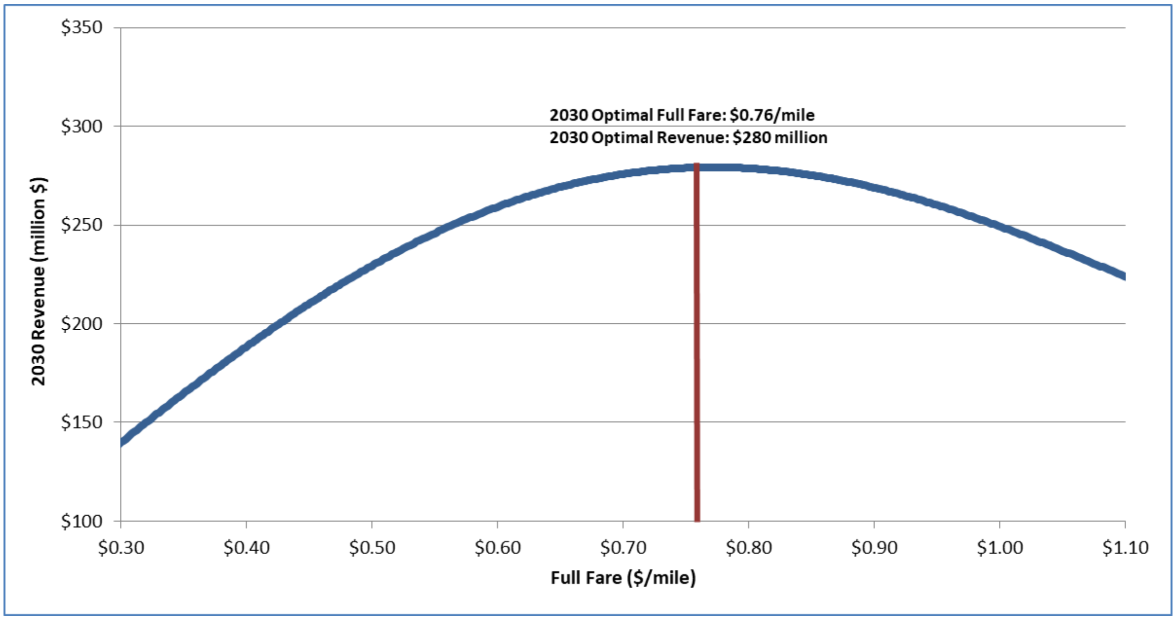
Exhibit 4-23: High-Speed Rail Schedules and Daily Round Trips (DRT)

	Express Train	Regular Train
Alternative 1 CHSR 110-mph Improved Infrastructure	1:56 Seattle to Portland, 6 DRT	2:09 Seattle to Portland, 6 DRT
Alternative 2 CHSR 220-mph Ultra High-Speed Low Infrastructure	1:28 Seattle to Portland, 10 DRT	1:43 Seattle to Portland, 8 DRT
Alternative 3 CHSR 250-mph Ultra High-Speed High Infrastructure	1:00 Seattle to Portland, 14 DRT	1:28 Seattle to Portland, 8 DRT

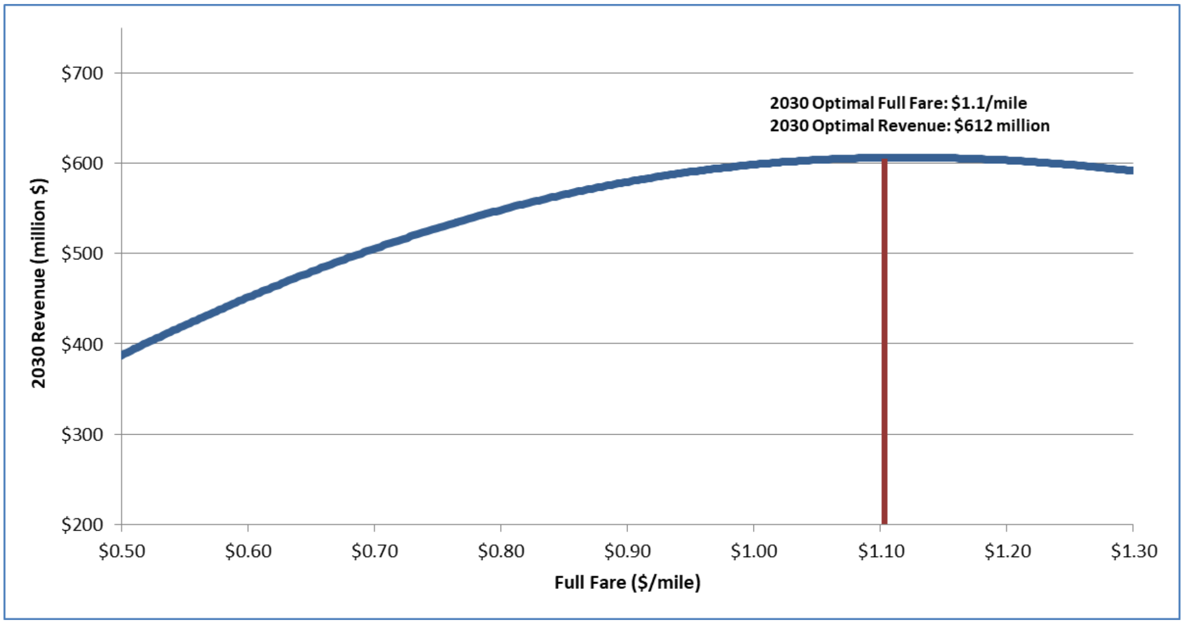
To find out the optimal fare that maximizes revenue for each high-speed rail alternative, a revenue yield curves were developed for each alternative as shown in Exhibit 4-24. It is shown that the optimal full fare for is $0.76 per mile for Alternative 1, $1.10 per mile for Alternative 2, and $1.20 per mile for Alternative 3. Full fare is charged for Business class travelers, and for Commuters and Other travelers, fare is half of the full fare rate. Exhibit 4-25 shows the fare rates by alternative and trip purpose.

Exhibit 4-24: Cascadia Corridor High-Speed Rail Revenue Yield Curves (2030)

Alternative 1 CHSR 110-mph Improved Infrastructure



Alternative 2 CHSR 220-mph Ultra High-Speed Low Infrastructure



Alternative 3 CHSR 250-mph Ultra High-Speed High Infrastructure

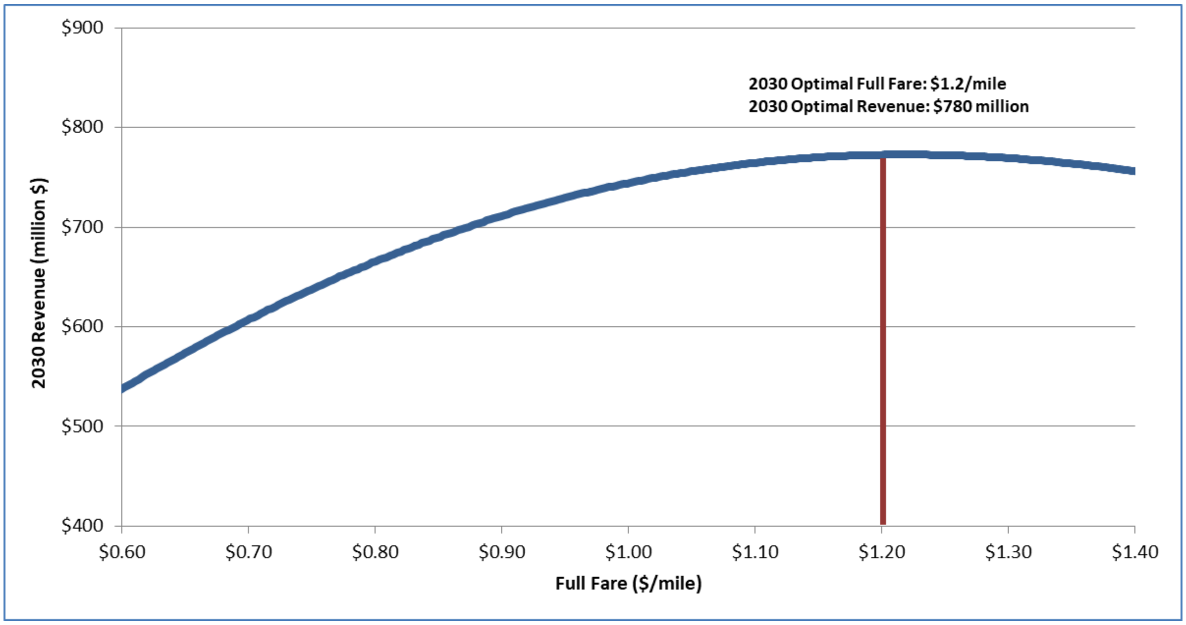


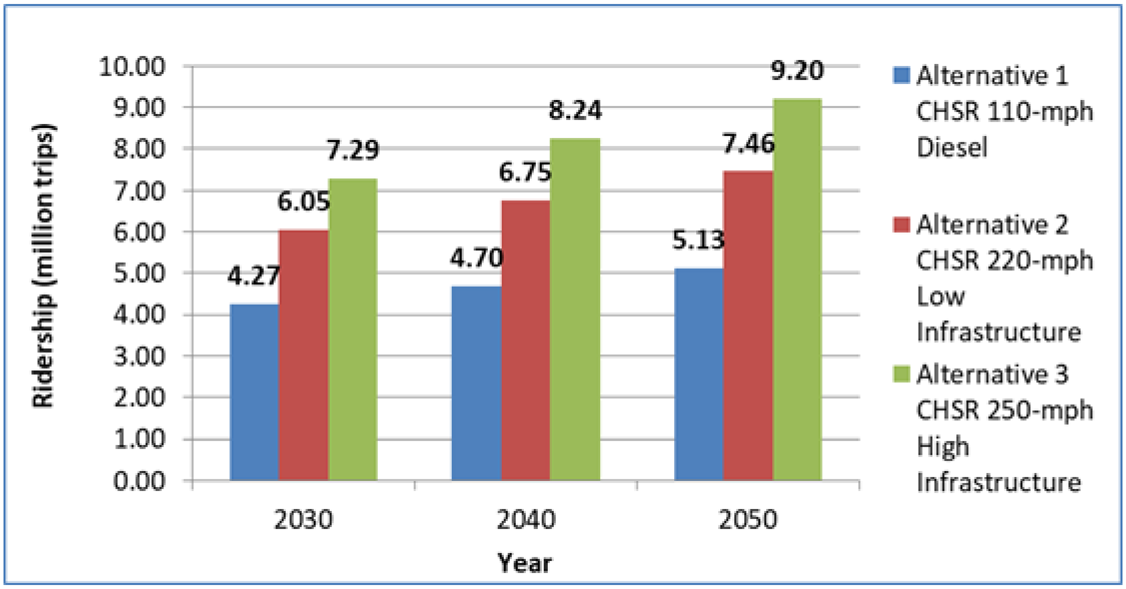
Exhibit 4-25: Fare Rates ($ per mile) by Service Scenario and Trip Purpose

	Business	Commuter	Other
Alternative 1 **CHSR 110-mph** **Improved Investment**	0.76	0.38	0.38
Alternative 2 **CHSR 220-mph** **Ultra High-Speed** **Low Infrastructure**	1.10	0.55	0.55
Alternative 3 **CHSR 250-mph** **Ultra High-Speed** **High Infrastructure**	1.20	0.60	0.60

High-Speed Rail ridership and revenue forecasts were made based on service scenarios and fare rate for each alternative, Exhibit 4-26 summarizes the forecast results of high-speed rail ridership:

- Alternative 1 is estimated to have 4.27 million trips in 2030, 4.70 million trips in 2040, and 5.13 million trips in 2050.
- Alternative 2 is estimated to have 6.05 million trips in 2030, 6.75 million trips in 2040, and 7.46 million trips in 2050.
- Alternative 3 is estimated to have 7.29 million trips in 2030, 8.24 million trips in 2040, and 9.20 million trips in 2050.

Exhibit 4-26: High-Speed Rail Ridership Forecast



The High-Speed Rail revenue forecast is shown in Exhibits 4-27.

- Alternative 1 is estimated to have $280 million revenue in 2030, $308 million revenue in 2040, and $337 million revenue in 2050.
- Alternative 2 is estimated to have $612 million revenue in 2030, $683 million revenue in 2040, and $754 million revenue in 2050.
- Alternative 3 is estimated to have $780 million revenue in 2030, $882 million revenue in 2040, and $985 million revenue in 2050.

Exhibit 4-27: High-Speed Rail Revenue Forecast

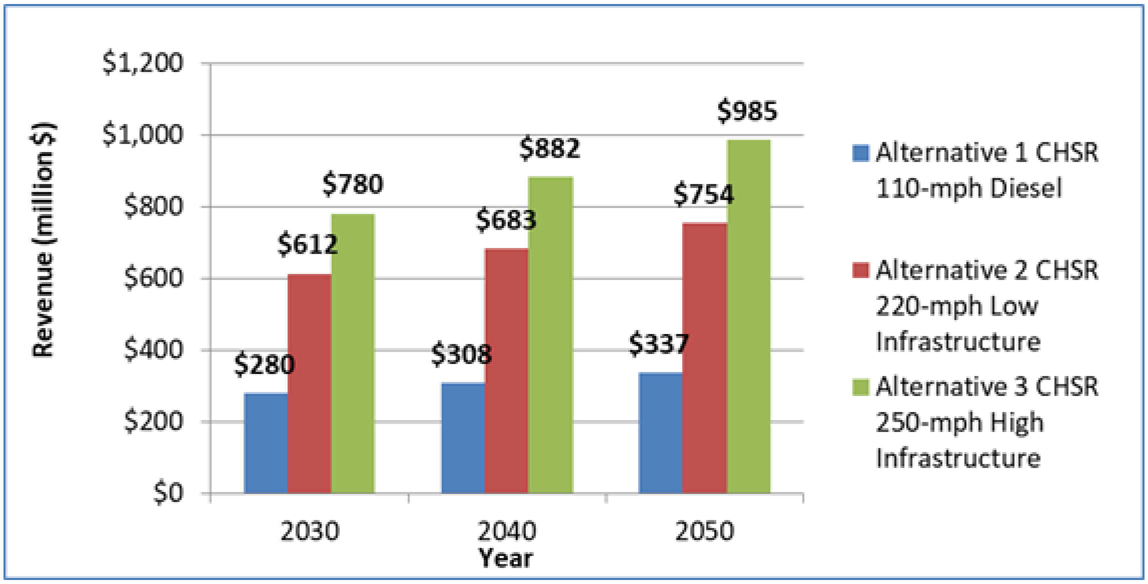
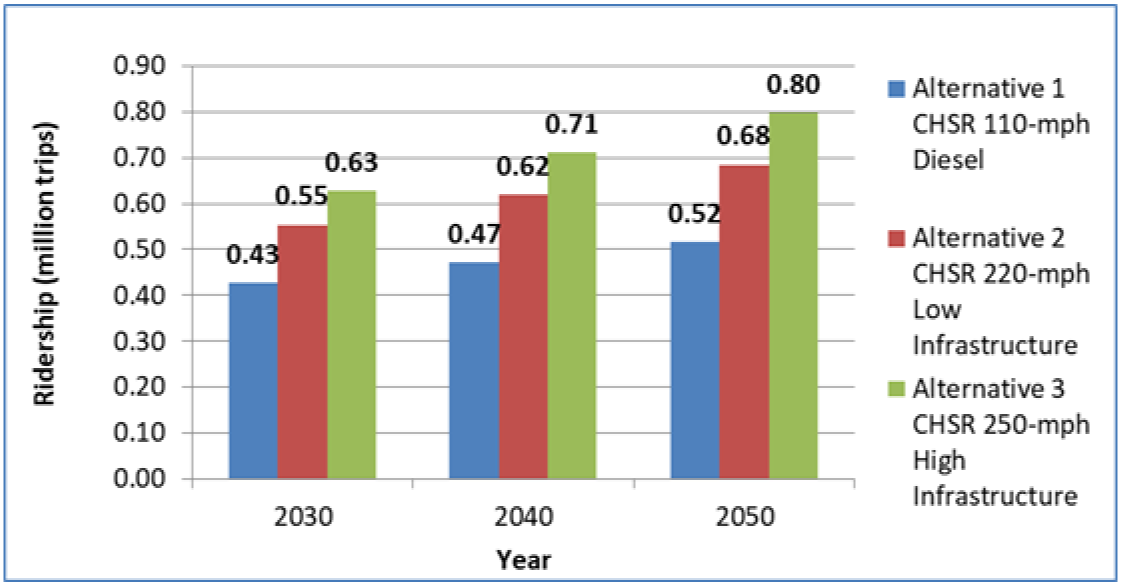


Exhibit 4-28 shows the forecasted high-speed rail ridership diverted from the air-connect trips between SEA-TAC airport and PDX airport.

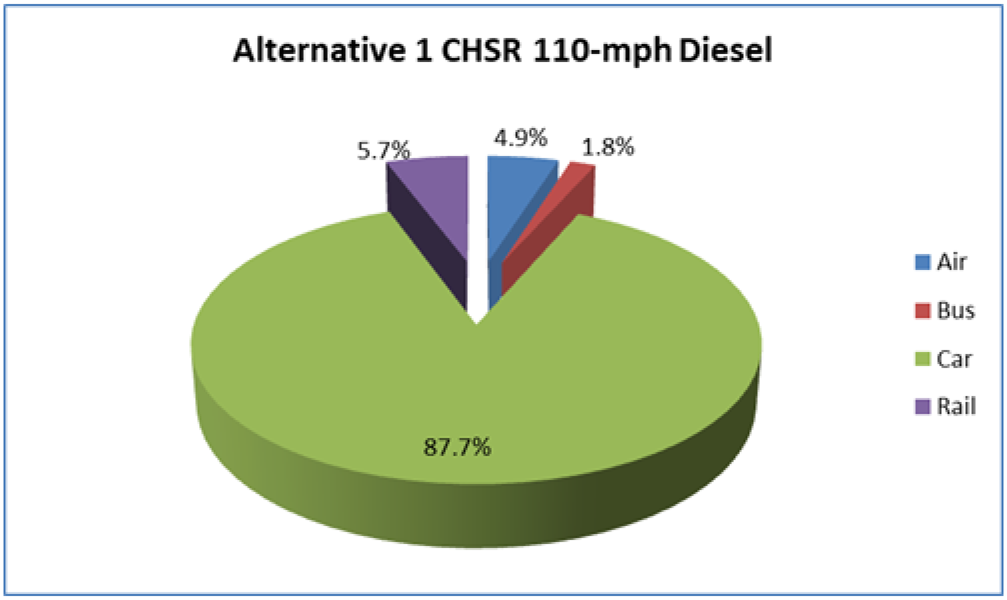
- Alternative 1 is estimated to divert 0.43 million air-connect trips in 2030, 0.47 million trips in 2040, and 0.52 million trips in 2050.
- Alternative 2 is estimated to divert 0.55 million air-connect trips in 2030, 0.62 million trips in 2040, and 0.68 million trips in 2050.
- Alternative 3 is estimated to divert 0.63 million air-connect trips in 2030, 0.71 million trips in 2040, and 0.80 million trips in 2050.

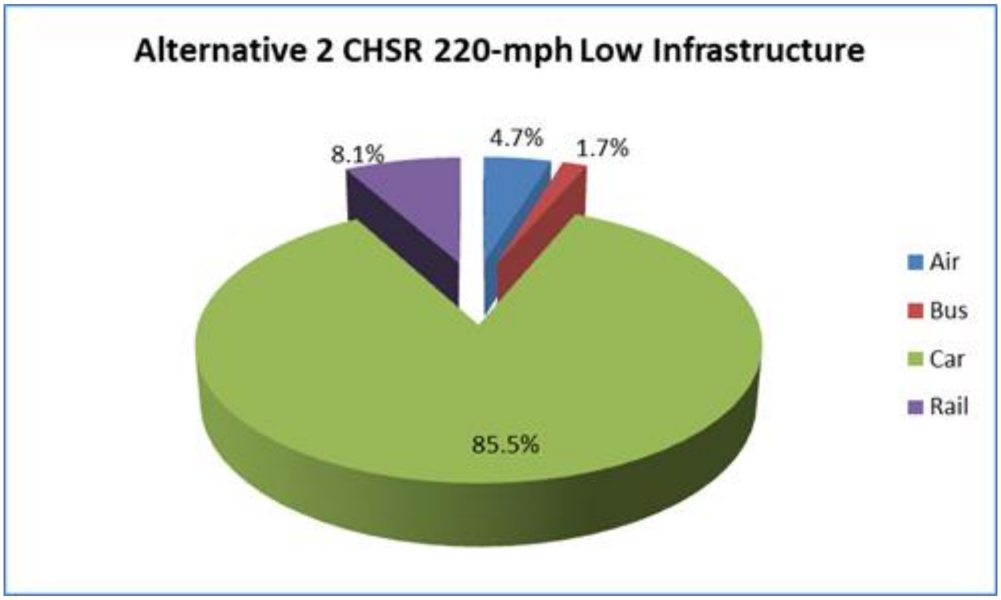
Exhibit 4-28: High-Speed Rail Air-Connect Trips between SEA-TAC and PDX Airports

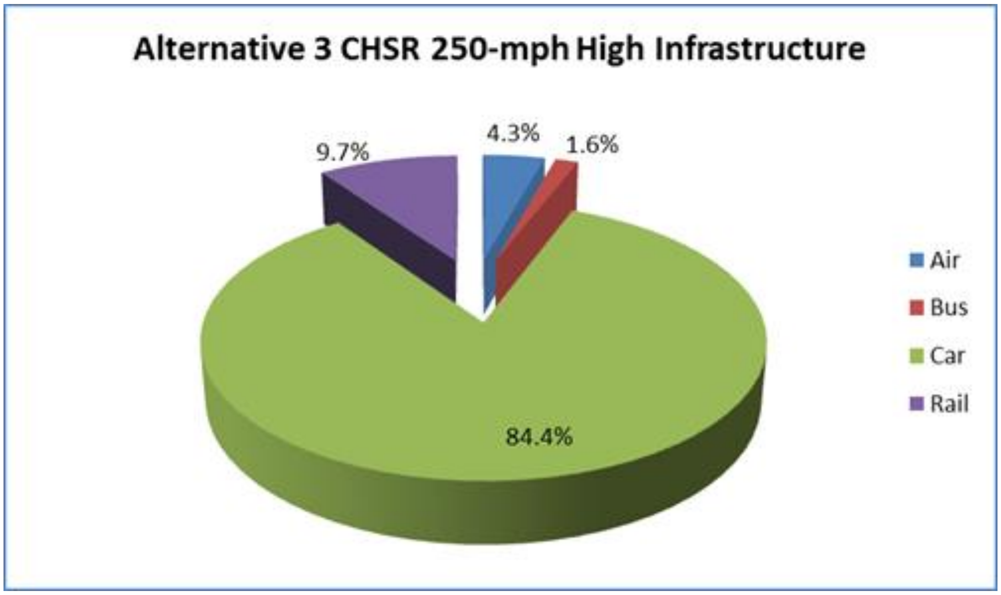


The corridor transportation mode market share forecast for each alternative in 2030 is shown in Exhibit 4-29. The auto mode continues to demonstrate its dominance in the corridor maintaining a market share above 84.4 percent to 87.7 percent in 2030. Rail market share will increase to more than five percent for Alternative 1, rail market will be eight percent for Alternative 2 and more than nine percent for Alternative 3. Air market share will be around four percent. Bus market share will remain less than two percent.

Exhibit 4-29: Portland – Seattle Corridor High-Speed Rail Market Share (2030)

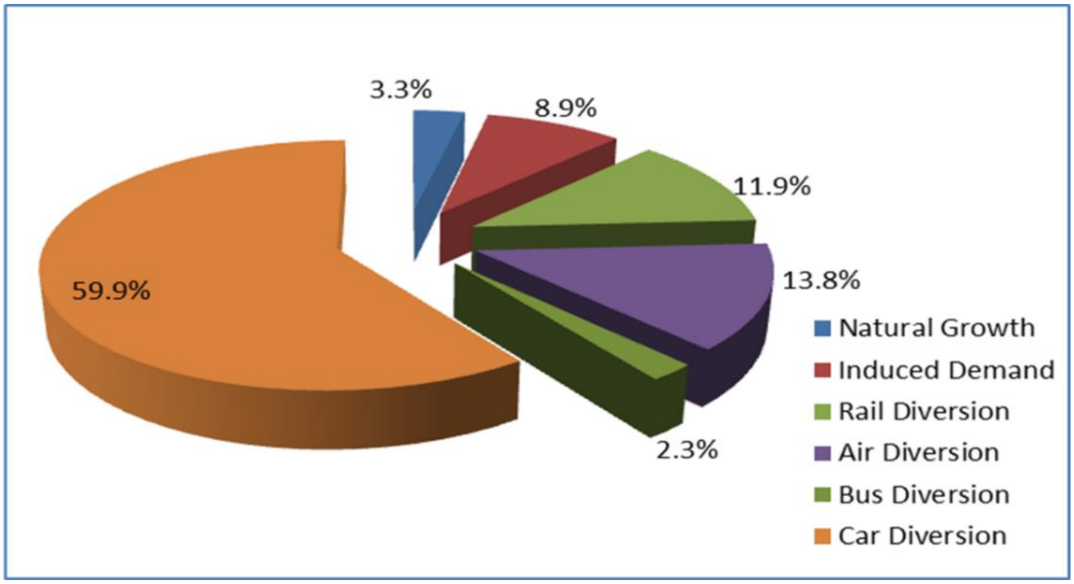






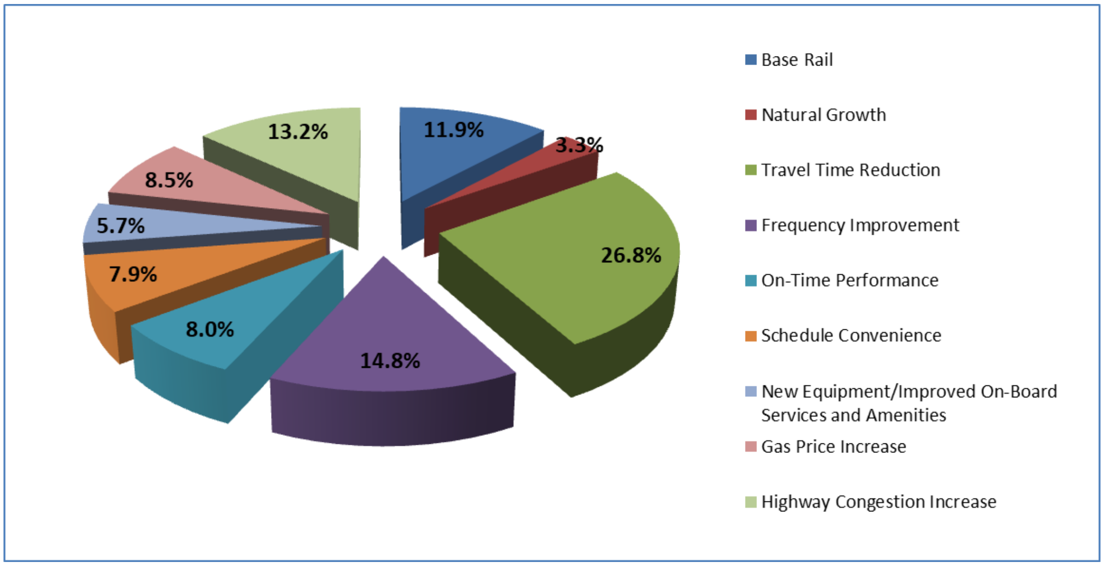
Exhibits 4-30 illustrate the sources of the rail trips. The trips diverted from other modes-primarily auto, are the most important source of rail trips, which accounts for 59.9 percent of overall rail travel market. Induced travel demand in the corridor as result of the new passenger rail service is 8.9 percent of the rail travel market. As for the diverted trips from other modes, more than 90 percent trips are from auto mode, but the auto driving still dominates future travel market.

Exhibit 4-30: Portland – Seattle Corridor High-Speed Rail Sources of Trips (2030)



Exhibits 4-31 illustrate the contributors to the rail trips. Travel time reduction is the most important contributor that accounts for 26.8 percent of rail ridership. Frequency improvement contributor is 14.8 percent. Better on-time performance and schedule convenience together account for 15.9 percent of rail ridership. Other important rail trip contributors are highway congestion increase and gas price increase, which together contribute 21.7 percent rail trips.

Exhibit 4-31: Portland – Seattle Corridor Contributors to High-Speed Rail Ridership (2030)



4.11 CORRIDOR TRAVEL MARKET FORECASTS BENCHMARKING

Benchmarking or making comparisons with other established rail systems/corridors is also an important factor for evaluating new rail projects. Rail projects that compare well with existing rail corridors are more likely to behave similarly and thus are likely to achieve similar success.

As shown in Exhibit 4-32, the Atlanta to Charlotte Passenger Rail Corridor of 130-mph technology is forecasted to have rail a trip rate of 10.30 trips per 10,000 persons per day by year 2030. The Cascadia Portland-Seattle Corridor Alternative 1 of 130-mph technology is expected to have 12.49 rail trips per 10,000 persons per day by year 2030.

Also shown in Exhibit 4-32, the NEC NYC-DC Corridor is expected to have a rail trip rate of 18.86 for the constrained Acela service and 22.19 trips for the 220-mph service per 10,000 persons per day by year 2030 and California's High-Speed Rail 220-mph Ridership is expected to be about 24.27 trips. The Cascadia Portland-Seattle Corridor Alternative 2 160-mph and Alternative 3 220-mph technologies are expected to have 17.70 and 21.33 per 10,000 persons per day by year 2030, which are comparable to similar technologies studied in the Northeast Corridor and California High-Speed Rail. This shows that the Cascadia forecasts are well in line with other high-speed corridor projects, especially when the other corridors are judged considering the comparative speed to Alternatives 1 to 3 in the Cascadia corridor.

Exhibit 4-32: Apples-to-Apples Demand Forecast Rail Trip Rate Comparison with Other Corridors

	2030 Cascadia Portland-Seattle Alternative 1 – 130 mph	2030 Cascadia Portland-Seattle Alternative 2 – 160 mph	2030 Cascadia Portland-Seattle Alternative 3 – 220~250 mph	2030 Atlanta to Charlotte Passenger Rail Corridor – 130 mph[1]	2030 NEC Master Plan NYC-DC Corridor (Constrained Acela)[2] – 150 mph	2030 NEC Next-Gen HSR NYC-DC Corridor – 220 mph[3]	2030 California High-Speed Rail Ridership Forecast – 220 mph[4]
Rail Trip Rate (trips per 10,000 person per day)	12.49	17.70	21.33	Alternative 1 Comparison 10.30	Alternative 2 Comparison 18.86	Alternative 3 Comparison 22.19	Alternative 3 Comparison 24.27

[1] Atlanta to Charlotte Passenger Rail Corridor EIS, Steer Davies Gleave, 2013

[2] The Northeast Corridor Infrastructure Master Plan, The NEC Master Plan Working Group, 2010

[3] The Amtrak Vision for the Northeast Corridor, Amtrak, 2012

[4] Bay Area/California High-Speed Rail Ridership and Revenue Forecasting Study, Cambridge Systematics, Inc., 2007

4.12 ANCILLARY REVENUES

Travel by regional passenger rail, just as by air, needs to offer its customers onboard amenities, including audio/video entertainment facilities, Wi-Fi and internet connectivity, 110-volt power, as well as a food and beverage service. The railcars used need to provide a level of comfort and safety that allows passengers to work and relax comfortably while on the train.

Onboard food service provides an important source of ancillary revenues. Onboard food service making use of trolley carts along with bistro service can cover its own cost and provide an attractive amenity for passengers. Because the trolley cart has been shown to double OBS revenues, it can result in profitable OBS operations in situations where a bistro-only service would be hard-pressed to sell enough food to recover its costs. While only a limited menu can be offered from a cart, the ready availability of food and beverages at the customer's seat is a proven strategy for increasing sales. Many customers appreciate the convenience of a trolley cart service and are willing to purchase food items that are brought directly to them. While some customers prefer stretching their legs and walking to a bistro car, other customers will not bother to make the trip. As a result of assuming a trolley cart service the OBS ancillary revenue has been estimated as 8% of the ticket revenue; this 8% is either collected in the form of direct revenue, or can be an attributed contribution to the cost, for example, of first-class tickets which often include complementary food and beverage services.

A same-day priority parcel service is an optional, ancillary business that may also be provided in conjunction with passenger rail service. Ancillary services such as express parcel can increase the profitability of the system with a very low incremental cost.

Package Express service is designed for high valued goods that can be handled manually. The service would be modeled after Eurostar's successful Esprit and British Rail's former Red Star Parcel business. It operates as an adjunct to checked baggage service which itself can be a revenue producer for the rail system. Package express service is for light parcels and is designed for same-day package delivery. It uses couriers to pick up and deliver packages from rail stations. Alternatively, customers can bring their packages to and from the stations if they want a lower cost, and do not want to employ a courier service. This type of operation was extensively studied and has been well documented as part of the Midwest Regional Rail System plan.

While the total revenue generation capability of express parcel traffic is substantial, it is assumed that 70% of its revenues would be consumed by pickup and delivery couriers; 15% would be absorbed as station operations cost so that only a residual 15% of total revenues would be left over as a contribution to train operations. Nonetheless, adding this lightweight and high value traffic does not add much to train operating cost, so the residual 15% net amount can be directly transferred to the rail system's financial statement. The value of the net contribution of express parcel has been estimated to add the equivalent of a 6% increase in the revenue earning capacity of the system.

Two major additional categories of potential revenue are ***not*** included in this SDP assessment, since they have not been traditionally included in the development of intercity rail passenger plans.

- The first is heavier parcel and air cargo freight service, such as was provided by SNCF's fleet of yellow postal trains; nonetheless, the demand for parcel service is growing rapidly, and the major parcel service providers like Amazon, FedEx and UPS are constantly looking to add capacity to their networks. A network of rail express freight services linking the airports with major centers such as sorting hubs has the ability to add additional trains, traffic, and revenue to the network. This has not been assessed as a part of the SDP although its inclusion may enhance a private operators' ability to contribute a share of the capital cost required for developing the system.
- The second is value capture and/or the ability to generate revenue from joint development at stations. This has become a significant source of revenue for some high-speed rail operators, most particularly in Japan but also in Europe and elsewhere in the world. It is not unusual for major rail projects to generate real estate development projects whose value exceeds that of the rail investment. To the extent that some of this value can be captured by the rail system, this can again enhance a private operators' ability to contribute a share of the capital cost required for developing the system.

5. OPERATIONS ANALYSIS

This chapter discusses the development of the Service and Operating Plan and describes the operating plan, station stopping patterns, frequencies, train times and train schedules for each route and technology option.

5.1 OPERATING PLAN DEVELOPMENT

5.1.1 INTERACTIVE ANALYSIS PROCESS

Given that reasonable high-speed rail routes can be developed, the key issue is the technology to be used. As shown in Exhibit 3-2 train routes and speeds; technology and service levels; fares; stations; and quality of service are all critical inputs in the operating plan process. These are used together in the interactive analysis process as shown in Exhibit 3-2 to balance all the elements of the scenario and to optimize the outcome for each scenario. For example, if train load factors are poor, then either train frequency or train size can be reduced for improving the ratio of passenger miles to seat miles. Conversely, if passenger loads exceed the capacity of the trains, then either the train size or train frequency must be increased in order to appropriately match supply to demand. TEMS' *LOCOMOTION™* train performance software is used to calculate train travel times and to determine the most appropriate train technology and operating strategies. A key requirement for the analysis is to adjust the train size and frequency levels to appropriately match demand, providing enough capacity while still producing acceptable load factors, thereby respecting the financial constraints on the operation of the system. The results of the train assessment including train size, and train miles in the interactive analysis are then used to identify the system's operating costs.

5.1.2 TRAIN TECHNOLOGY OPERATING CHARACTERISTICS

Chapter 2 provides an extensive discussion of train technology characteristics including acceleration and braking curves, and the ability of modern high-speed electric trains to handle relatively steep grades. Because of the limited power and adhesion available to freight trains, traditional lines are usually laid out with very gentle gradients, but they may have numerous curves, as they may need to twist and turn to maintain a level path. Freight lines minimize grades but may have curves.

By comparison, modern High-Speed lines should be laid out to be very straight, but they can better follow the profile of the terrain than freight lines can. High-Speed passenger line minimizes curves but may have grades.

The key tool used for development of pro-forma train schedules is the *LOCOMOTION™* Train Performance Calculator. *LOCOMOTION™* works in conjunction with a *TRACKMAN™* infrastructure database to estimate train speed given various types of track geometry, curves, gradients, and station-stopping patterns. The *TRACKMAN™* database captures all the details of grades, curves, superelevation, speed limits and station locations along the line. *LOCOMOTION™* then calculates the train running time for each route segment and sums the running times to produce a timetable. *LOCOMOTION™* assumes a train will accelerate to a maximum possible speed and will only slow down for stations or speed restrictions due to curves, crossings, tunnels, or civil speed restrictions such as grade crossings and sensitive urban areas.

The inputs for *LOCOMOTION™* consist of milepost-by-milepost data (as fine as 1/10th of a mile) defining gradient and curve conditions along the track. For this study, these data were derived from a condensed profile for existing rail alignments and the use of field inspection data along with satellite photography and GIS mapping to develop the geometry for new routes.

In addition, *LOCOMOTION™* includes a train technology database (as in Exhibit 2-17) that defines the acceleration, top speed, and braking characteristics of each train technology type. The database includes many train types with varying performance characteristics, ranging from heavy freight trains all the way up through very high-speed rail options.

Train timetables are determined from running times with the inclusion of an appropriate margin of schedule slack and used to calculate rolling stock requirements. Train frequencies and the number of cars required per train are determined via an interactive process using the demand forecast *COMPASS™* model.

The results taken from *LOCOMOTION™* will be faster than the actual times since they are based on optimized performance of trains under ideal conditions. While it is assumed that passenger trains will have dispatching priority over freight, practical schedules still need to allow 5-15 percent slack time in case of any kind of operating problem, including the possibility of freight or commuter train interference, depending on the degree of track sharing with freight. The current Amtrak service is using at least a 15 percent schedule slack margin reflecting severe levels of freight train congestion along its route. Since however the proposed high-speed route is based on dedicated passenger track, the CHSR train timetables only need a 5 percent slack margin.

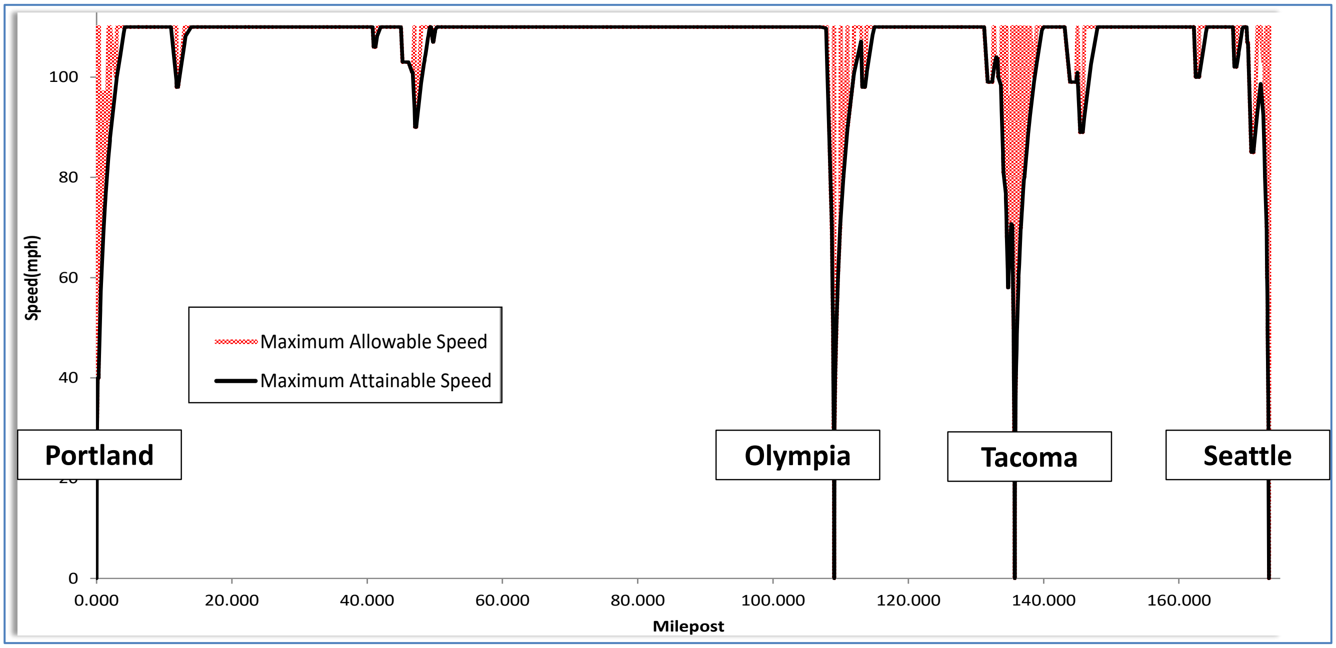
5.1.3 TRAIN RUNNING TIMES BY ALTERNATIVE

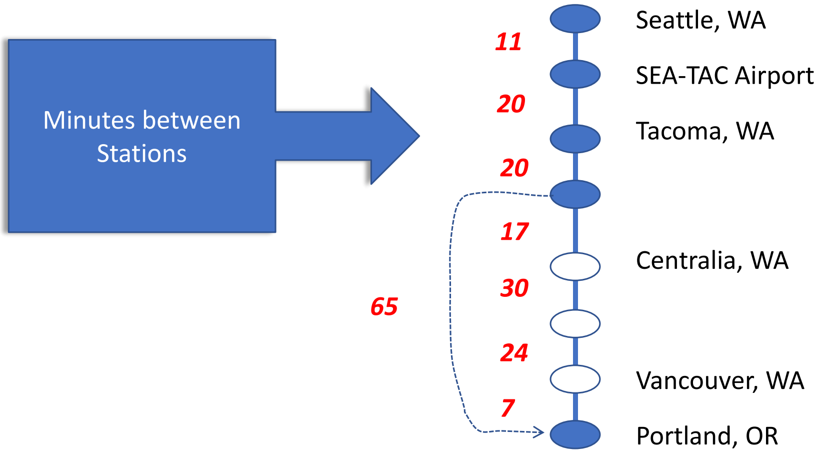
Speed profiles for the CHSR corridor were derived using *LOCOMOTION™* rail simulation software. *LOCOMOTION™* Speed Profiles for Alternatives 1, 2 and 3 are shown in Exhibits 5-1, 5-2 and 5-3. All three simulations shown are for "express" train services - this provides an "apples to apples" comparison between alternatives based on the fastest train schedules that are common to all three options. The results of the train schedule simulations are summarized in Exhibit 5-4.

However, the additional demand associated with a higher speed also allows for an increase in train frequency. However, there is only a base-line requirement to provide a minimum level of service to the smaller stations. As a result, additional frequencies beyond the minimum can be launched as express services provided there is enough end-to-end demand to fill the trains. In fact, CHSR Alternative 3 has enough demand to support the implementation of super-express (non-stopping) service from Portland to Seattle.

As a result, the faster options can also operate a greater share of express and super-express trains. This has the effect of further accelerating the schedule improvement and this further amplifies the ridership increase. As shown in Exhibit 5-4, for a local (all stopping) train Alternative 3 is 41 minutes faster than Alternative 1; however, the weighted average time reduction is 48 minutes, and Alternative 3's fastest schedule is more than an hour faster than Alternative 1. In terms of balancing supply with demand to optimize train load factors, this type of tradeoff can only be assessed iteratively as a result of the interactive analysis, which enables the optimization of the train frequency versus speed tradeoffs. In Exhibits 5-1 through 5-4, running times are expressed in hours and minutes format (HH:MM). In Exhibit 5-4 "RT" signifies then number of daily round trips operated.

Exhibit 5-1: Speed Profile for Alternative 1, Express Train from Portland to Seattle in 1:56



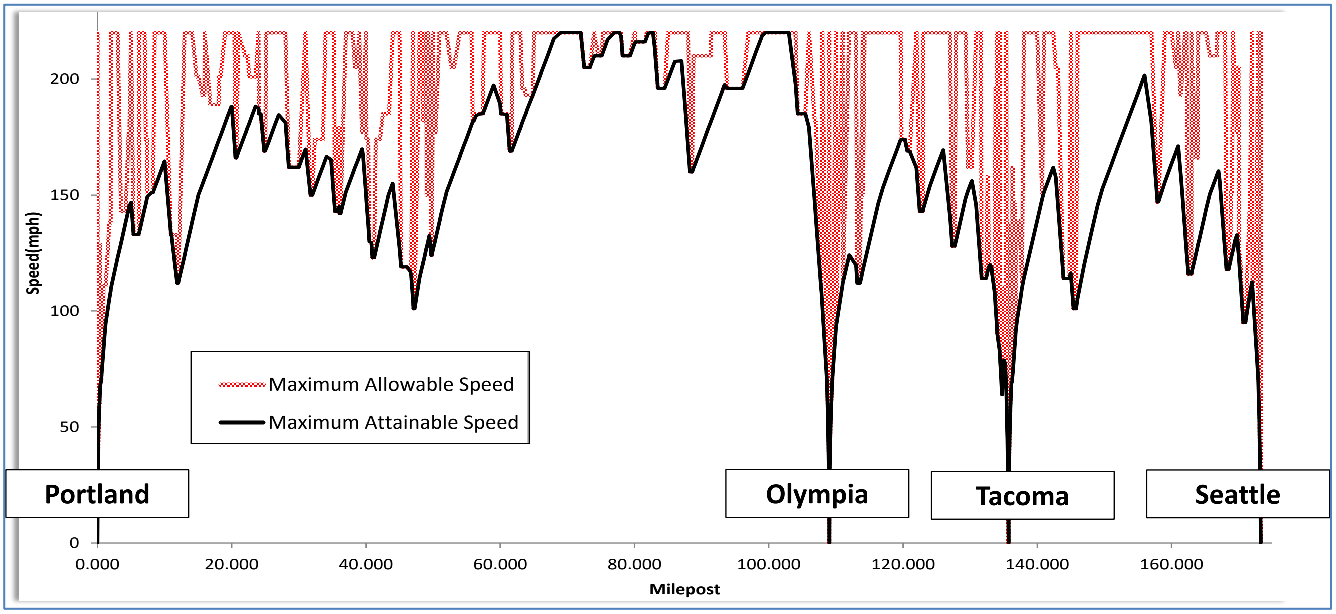


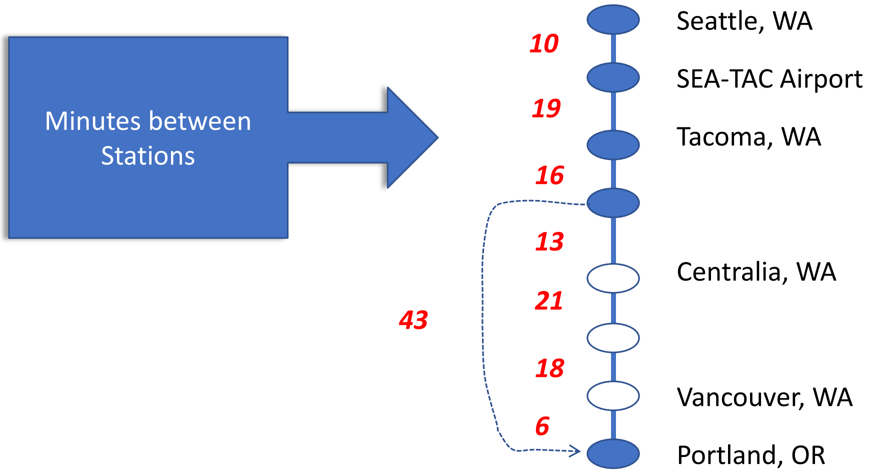
PORTLAND-SEATTLE
Higher Speed
Rail Times

- ***2:09 Local***
- ***1:56 Express***

Average Express Train Commercial Speed: 90 mph

Exhibit 5-2: Speed Profile for Alternative 2, Electric Express Train from Portland to Seattle in 1:28





SEATTLE-PORTLAND

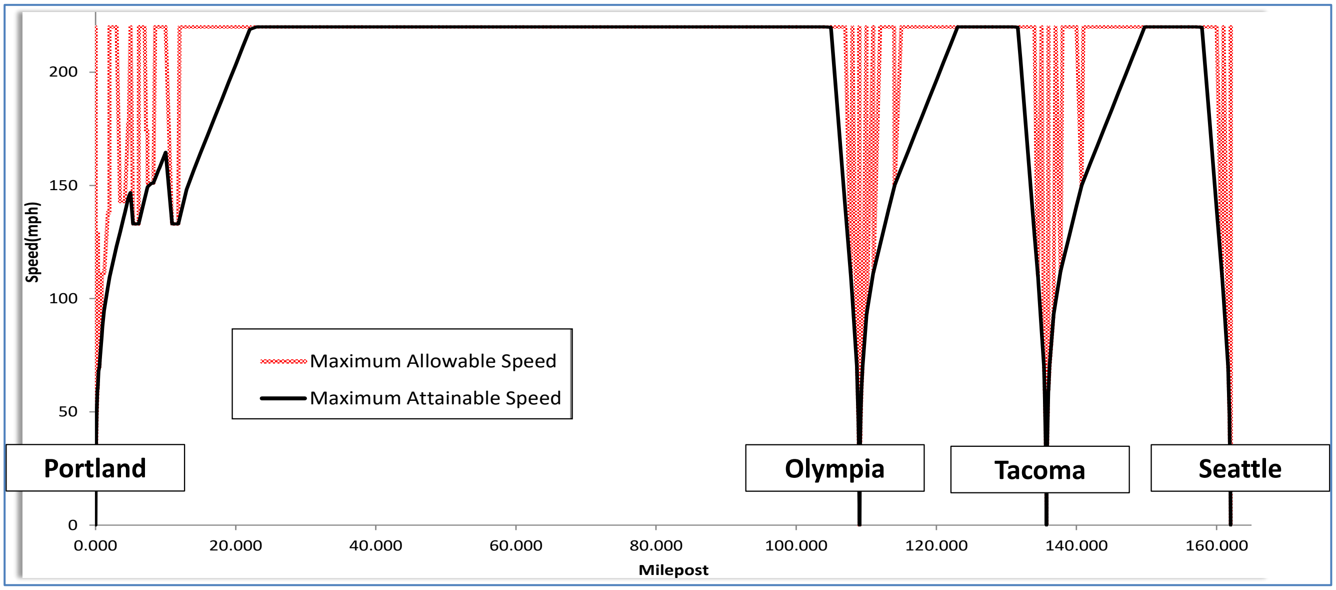
Ultra High-Speed

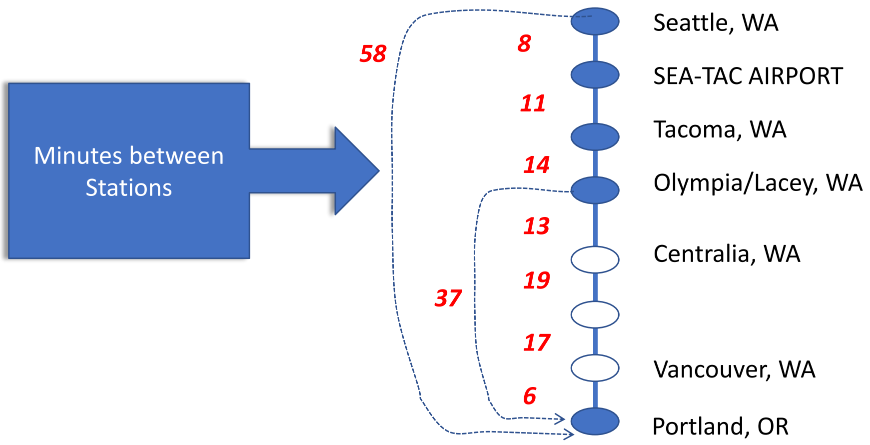
Rail Times

- ***1:43 Local***
- ***1:28 Express***

Average Express Train Commercial Speed: 118 mph

Exhibit 5-3: Speed Profile for Alternative 3, Express Train from Portland to Seattle in 1:10





SEATTLE-PORTLAND

Ultra High-Speed

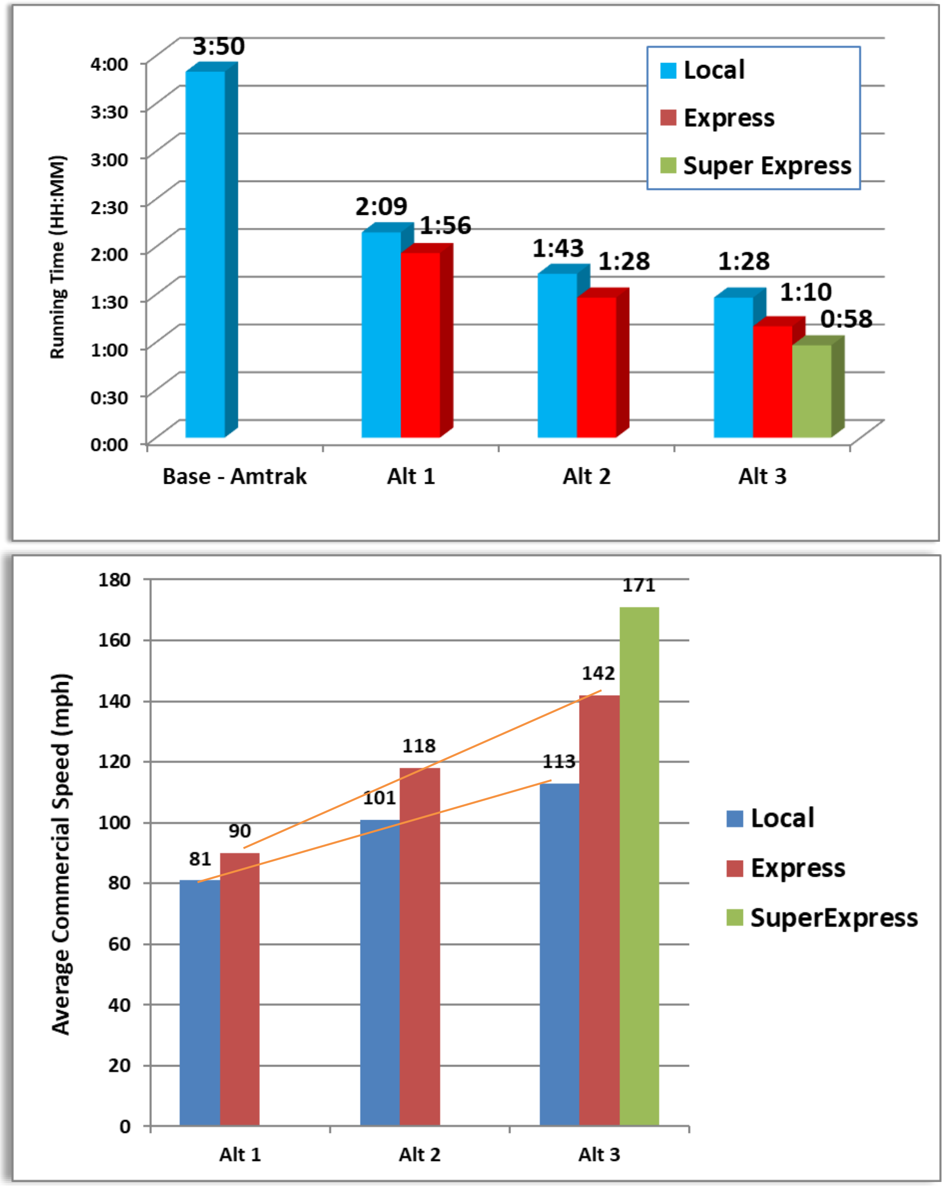
Rail Times

- ***1:28 Local***
- ***1:10 Express***
- ***0:58 Super Express***

Average Super Express Train Commercial Speed: 171 mph

The overall running time results are summarized in Exhibit 5-4. As can be seen, Alternative 3 is significantly faster than the other alternatives and also because of higher demand it permits the greatest share of express vs. local stopping trains.

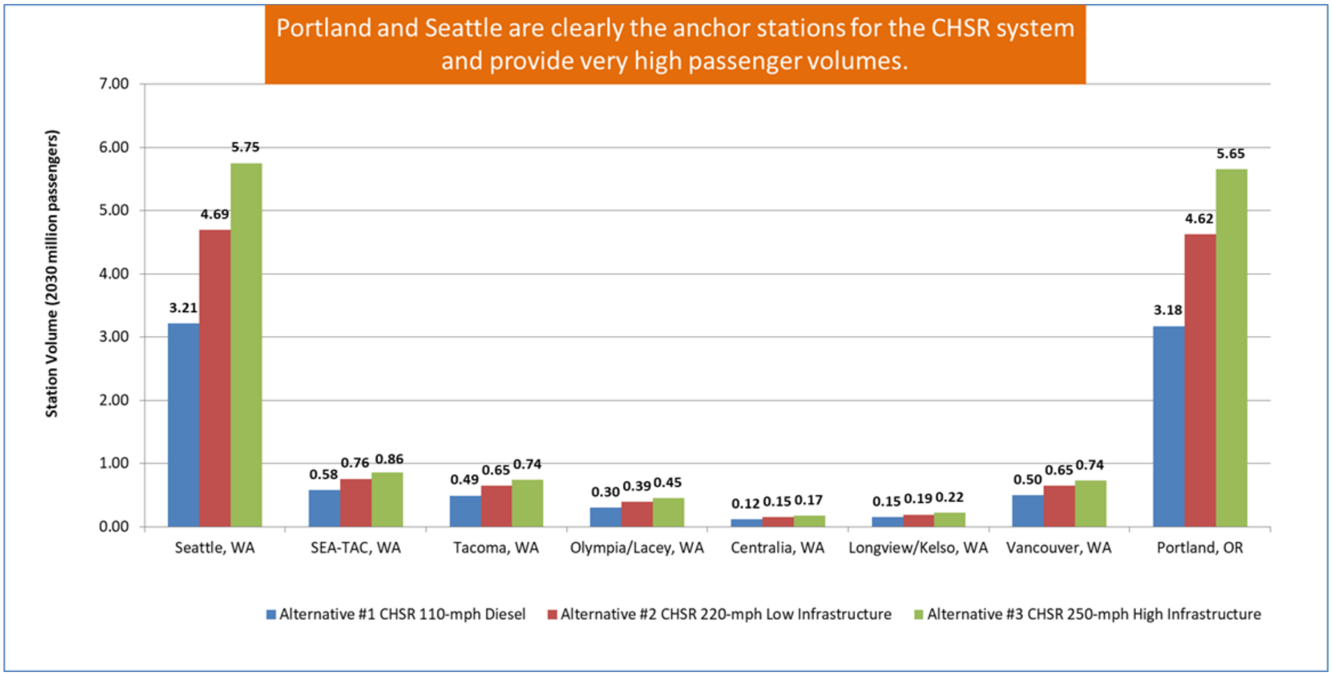
**Exhibit 5-4:
Portland to Seattle
Running Times,
Frequencies and Speeds**



	Super Express	Express Train	Regular Train	Weighted Average Time
Alternative 1 Diesel 110-mph Improved Infrastructure	-	1:56 Seattle to Portland, 6 RT	2:09 Seattle to Portland, 6 RT	2:02
Alternative 2 Electric 220 mph Low Infrastructure	-	1:28 Seattle to Portland, 10 RT	1:43 Seattle to Portland, 8 RT	1:34
Alternative 3 Electric 220 mph High Infrastructure	0:58 Seattle to Portland, 4 RT	1:10 Seattle to Portland, 10 RT	1:28 Seattle to Portland, 8 RT	1:14

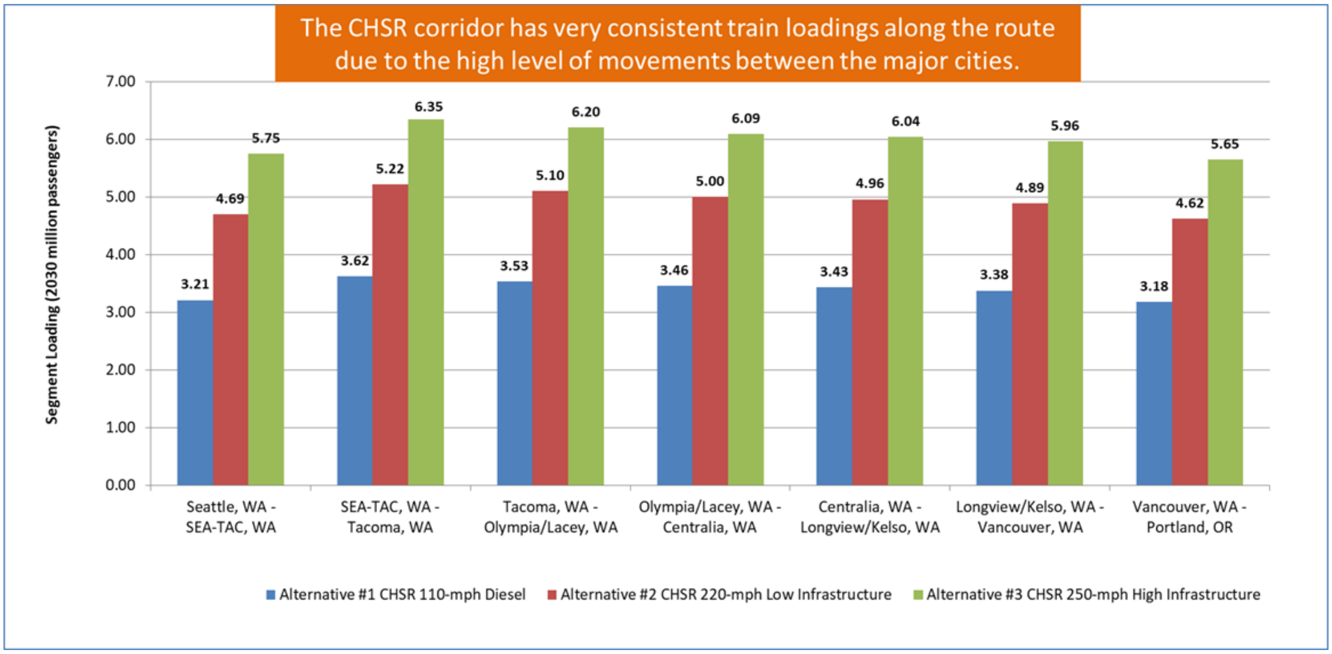
Exhibits 5-5 and 5-6 show the station volumes and resulting segment loadings for each option in 2030, in millions of riders. Exhibit 5-5 shows how the two endpoint stations provide the majority of ridership for the route, and in Exhibit 5-6 this results in an extremely consistent segment loading since most riders ride all the way through. To the extent that intermediate stations contribute ridership this would appear to be fairly balanced ons and off, which should result in the ability for a high-speed rail service to operate with excellent train loading factors exceeding 80% on average. The Paris-Lyon TGV achieves an 84 percent load factor. By comparison, many North American and Europe, commuter rail services are lucky to achieve a 40-50% load factor and if they are running empty reverse reposition trains it can be as low as 20-25%. As such the poor load factors for these services become a major contributor to the operating subsidy requirement. For CHSR, the peak load segment will be between SEA-TAC airport and Tacoma, and the loadings are 6.35 million for Alternative 3, 5.22 million for Alternative 2 and 3.62 million for Alternative 1.

Exhibit 5-5: Portland to Seattle Station Volumes



Portland and Seattle are clearly the anchor stations for the CHSR system and provide very high passenger volumes.

Exhibit 5-6: Portland to Seattle Segment Loadings


The CHSR corridor has very consistent train loadings along the route due to the high level of movements between the major cities.

Based on 312 operating days per year (weekends typically providing ½ service with most trains running Saturday morning and Sunday afternoon) and total frequencies of 12, 18 and 22 round trips per day respectively then the required train sizes in 2030 would be:

- Alternative 1: 3,620,000 / 312 / 2 / 12 / 0.80 = 604 seats
- Alternative 2: 5,220,000 / 312 / 2 / 18 / 0.80 = 581 seats
- Alternative 3: 6,350,000 / 312 / 2 / 22 / 0.80 = 462 seats

All of these train sizes are in a reasonable range; however, it makes sense to run larger trains on the lower investment options, such as Alternative 1, since frequency would have to be limited in Alternative 1 due to the presence of single track sections. Similarly, while Alternative 2 would be double tracked, it must share part of its alignment from Seattle to Tacoma with Sounder trains. By comparison, Alternative 3 has its own dedicated double track line from end to end; this alignment is not only faster, but also provides more capacity for high-speed operations. As such, Alternative 3 has plenty of capacity to operate shorter, more frequent trains. Also it is clear that by extending train lengths in the future, Alternative 3 would have a better ability to handle future growth than the other, lower cost alternatives, which would be operating at capacity from practically the day that they open.

The train frequencies, train sizes and number of train sets calculated for each Alternative are summarized in Exhibit 5-7. The number of trainsets needed is estimated as the number needed to cover daily schedules, plus one spare “protect” train for each end of the line (Portland and Seattle) in “hot” standby status, and one train that can be in the shop for repairs at any point in time. Exhibit 5-9 shows that Alternative 3 needs eight trains in rotation plus two “protect” trains and one in the shop, bringing the total fleet requirement to 11 trainsets.

Exhibit 5-7: Summary of Equipment Requirements by Alternative

Alternative	Seats per Train	Number of Daily Round Trips*	Number of Trainsets Needed
1	604	12	9
2	581	18	10
3	462	22	11

* Based on Forecasted 2030 Requirements

5.1.4 TRAIN SCHEDULE DEVELOPMENT

Based on the train running times and planned train frequencies for Alternative 3, a preliminary set of pro-forma schedules has been constructed characterizing a typical weekday schedule. These schedules, in Exhibit 5-8, show the interworking of proposed local, express, and super-express services on the line.

Since Alternative 3 CHSR corridor has a proposed double track throughout this provides the ability to schedule the service without concern for opposing train meets. A challenge, however, are the wide differentials in running time between the local, express and super express trains, which all share the same track. Given the planned level of train frequency of 22 trains however, it is possible to space out the departures enough so that the local trains will not be overtaken by the expresses or super-expresses while still enroute.

As such a double track line without any supplemental station passing sidings would be theoretically sufficient to handle the intended volume of traffic. This is especially significant for stations that might need to be built underground where building more than the minimum of two tracks may prove to be very expensive. However, station sidings might still be added as options to the above ground stations because they can provide a way for local trains to pull out of the way of express trains, which can pass the local trains while they are stopped in stations.

The planned frequency of service between Portland and Seattle of 22 round trips is very similar to the 23 daily round trips that Amtrak now operates between New York and Washington D.C. Intercity services are not as sharply peaked as commuter services, but they do have an increase in demand which has to be covered by added frequency in the morning and evening rush hours. In order to reasonably project the temporal distribution of demand throughout the day, Amtrak's current Northeast corridor schedules were used for establishing the initial arrival times of trains in Seattle and Portland. Then the departure times could be calculated based on the known train running times. Finally, schedules were shifted slightly as needed to eliminate train overtakes enroute, and to cycle the trainsets from arriving to departing trains with a minimum planned turnaround time of 25-30 minutes.

The train schedules are shown in Exhibit 5-8 and resulting equipment rotations in Exhibit 5-9.

Exhibit 5-8: Pro-Forma Alternative 3 Train Schedule

SOUTHBOUND TIMETABLE

Equipment Set	**2**	**4**	**6**	**1**	**3**	**2**	**5**	**4**	**7**	**6**	**1**	**3**	**2**	**5**	**4**	**7**	**6**	**1**	**3**	**8**	**2**	**5**
TRAIN NUMBER	LCL-1	SE-1	EX-1	EX-3	LCL-3	SE-3	EX-5	LCL-5	EX-7	LCL-7	SE-5	EX-9	LCL-9	EX-11	LCL-11	EX-13	SE-7	LCL-13	EX-15	EX-17	LCL-15	EX-19
Seattle, WA	6:17	8:01	9:25	9:49	10:08	12:00	12:15	12:33	12:56	13:39	15:05	15:20	15:53	16:50	17:06	18:03	18:32	18:47	19:24	20:01	20:27	22:09
SEA-TAC Airport, WA	6:25	-	9:33	9:57	10:16	-	12:23	12:41	13:04	13:47	-	15:28	16:01	16:58	17:14	18:11	-	18:55	19:32	20:09	20:35	22:17
Tacoma, WA	6:36	-	9:44	10:08	10:27	-	12:34	12:52	13:15	13:58	-	15:39	16:12	17:09	17:25	18:22	-	19:06	19:43	20:20	20:46	22:28
Olympia/Lacey, WA	6:50	-	9:58	10:22	10:41	-	12:48	13:06	13:29	14:12	-	15:53	16:26	17:23	17:39	18:36	-	19:20	19:57	20:34	21:00	22:42
Centralia, WA	7:03	-	-	-	10:54	-	-	13:19	-	14:25	-	-	16:39	-	17:52	-	-	19:33	-	-	21:13	-
Longview/Kelso, WA	7:22	-	-	-	11:13	-	-	13:38	-	14:44	-	-	16:58	-	18:11	-	-	19:52	-	-	21:32	-
Vancouver, WA	7:39	-	-	-	11:30	-	-	13:55	-	15:01	-	-	17:15	-	18:28	-	-	20:09	-	-	21:49	-
Portland, OR	7:45	8:59	10:35	10:59	11:36	12:58	13:25	14:01	14:06	15:07	16:03	16:30	17:21	18:00	18:34	19:13	19:30	20:15	20:34	21:11	21:55	23:19

NORTHBOUND TIMETABLE

Equipment Set	**1**	**3**	**2**	**5**	**4**	**7**	**6**	**1**	**3**	**2**	**5**	**4**	**7**	**6**	**1**	**3**	**8**	**2**	**5**	**4**	**7**	**6**
TRAIN NUMBER	SE-2	EX-2	EX-4	LCL-2	EX-6	SE-4	LCL-4	EX-8	LCL-6	EX-10	LCL-8	EX-12	LCL-10	EX-14	SE-6	LCL-12	EX-16	LCL-14	SE-8	EX-18	LCL-16	EX-20
Portland, OR	6:32	7:05	8:20	8:32	9:34	10:47	11:02	11:35	12:07	13:23	13:57	14:39	15:27	16:12	16:51	17:02	17:36	17:56	18:52	19:30	20:08	20:47
Vancouver, WA	-	-	-	8:38	-	-	11:08	-	12:13	-	14:03	-	15:33	-	-	17:08	-	18:02	-	-	20:14	-
Longview/Kelso, WA	-	-	-	8:55	-	-	11:25	-	12:30	-	14:20	-	15:50	-	-	17:25	-	18:19	-	-	20:31	-
Centralia, WA	-	-	-	9:14	-	-	11:44	-	12:49	-	14:39	-	16:09	-	-	17:44	-	18:38	-	-	20:50	-
Olympia/Lacey, WA	-	7:42	8:57	9:27	10:11	-	11:57	12:12	13:02	14:00	14:52	15:16	16:22	16:49	-	17:57	18:13	18:51	-	20:07	21:03	21:24
Tacoma, WA	-	7:56	9:11	9:41	10:25	-	12:11	12:26	13:16	14:14	15:06	15:30	16:36	17:03	-	18:11	18:27	19:05	-	20:21	21:17	21:38
SEA-TAC Airport, WA	-	8:07	9:22	9:52	10:36	-	12:22	12:37	13:27	14:25	15:17	15:41	16:47	17:14	-	18:22	18:38	19:16	-	20:32	21:28	21:49
Seattle, WA	7:30	8:15	9:30	10:00	10:44	11:45	12:30	12:45	13:35	14:33	15:25	15:49	16:55	17:22	17:49	18:30	18:46	19:24	19:50	20:40	21:36	21:57

LCL, SE-1, Ex-1, Ex-3 are train numbers.

Exhibit 5-9: Pro-Forma Alternative 3 Equipment Turns

EQUIPMENT TURNS

Trainset 1:	Depart		Arrive		Layover
SE-2	PDX	6:32	SEA	7:30	-
EX-3	SEA	9:49	PDX	10:59	2:19
EX-8	PDX	11:35	SEA	12:45	0:36
SE-5	SEA	15:05	PDX	16:03	2:20
SE-6	PDX	16:51	SEA	17:49	0:48
LCL-13	SEA	18:47	PDX	20:15	6:02

Trainset 2:	Depart		Arrive		Layover
LCL-1	SEA	6:17	PDX	7:45	-
EX-4	PDX	8:20	SEA	9:30	0:35
SE-3	SEA	12:00	PDX	12:58	2:30
EX-10	PDX	13:23	SEA	14:33	0:25
LCL-9	SEA	15:53	PDX	17:21	1:20
LCL-14	PDX	17:56	SEA	19:24	0:35
LCL-15	SEA	20:27	PDX	21:55	1:03

Trainset 3:	Depart		Arrive		Layover
EX-2	PDX	7:05	SEA	8:15	-
LCL-3	SEA	10:08	PDX	11:36	1:53
LCL-6	PDX	12:07	SEA	13:35	0:31
EX-9	SEA	15:20	PDX	16:30	1:45
LCL-12	PDX	17:02	SEA	18:30	0:32
EX-15	SEA	19:42	PDX	20:52	1:12

Trainset 4:	Depart		Arrive		Layover
SE-1	SEA	8:01	PDX	8:59	-
EX-6	PDX	9:34	SEA	10:44	0:35
LCL-5	SEA	12:33	PDX	14:01	1:49
EX-12	PDX	14:39	SEA	15:49	0:38
LCL-11	SEA	17:06	PDX	18:34	1:17
EX-18	PDX	19:30	SEA	20:40	0:56

Trainset 5:	Depart		Arrive		Layover
LCL-2	PDX	8:32	SEA	10:00	-
EX-5	SEA	12:15	PDX	13:25	2:15
LCL-8	PDX	13:57	SEA	15:25	0:32
EX-11	SEA	16:50	PDX	18:00	1:25
SE-8	PDX	18:52	SEA	19:50	0:52
EX-19	SEA	22:09	PDX	23:19	6:44

Trainset 6:	Depart		Arrive		Layover
EX-1	SEA	9:25	PDX	10:35	-
LCL-4	PDX	11:02	SEA	12:30	0:27
LCL-7	SEA	13:39	PDX	15:07	1:09
EX-14	PDX	16:12	SEA	17:22	1:05
SE-7	SEA	18:32	PDX	19:30	1:10
EX-20	PDX	20:47	SEA	21:57	1:17

Trainset 7:	Depart		Arrive		Layover
SE-4	PDX	10:47	SEA	11:45	-
EX-7	SEA	12:56	PDX	14:06	1:11
LCL-10	PDX	15:27	SEA	16:55	1:21
EX-13	SEA	18:03	PDX	19:13	1:08
LCL-16	PDX	20:08	SEA	21:36	0:55

Trainset 8:	Depart		Arrive		Layover
EX-16	PDX	17:36	SEA	18:46	-
EX-17	SEA	20:01	PDX	21:11	1:15

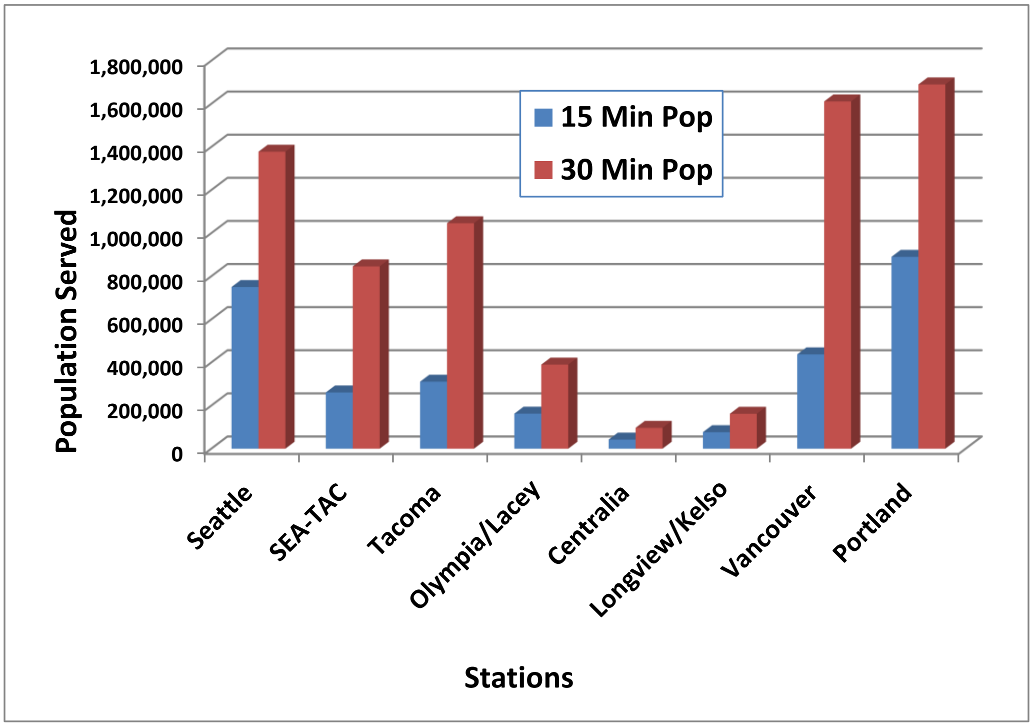
6. STATION AND ACCESS ANALYSIS

A comprehensive Station Analysis was conducted to assess the 15-min and 30-min drive time populations served by each CHSR station. Stated preference surveys have consistently shown that riders value access time approximately twice that of in-vehicle (rail travel) time; perhaps this is due to anxiety due to congestion, the stress of driving and inability to productively use their driving time while accessing the stations. In any case, the premium riders place on access time suggests that the majority of riders will likely come from within a 10–30-minute radius of each station.

Also, riders often resist accessing stations opposite their planned direction of travel. This means that someone who lives just south of the Seattle station may be more likely to drive to Tukwila (SEA-TAC) rather than drive north for going south to Portland. However, the same person might happily drive north if their destination were Vancouver, BC. *COMPASS*™ modeling of access between stations and individual zones does take these behavioral preferences into account. The drive time maps do not model directional access as precisely as the *COMPASS*™ model does. Even so, the drive time map is useful for understanding the natural market watershed areas associated with each proposed station, as well as possible overlaps between these areas.

Exhibit 6-1 summarizes the 15-min and 30-min drive time populations served by each CHSR station. It is apparent that the major stations of Seattle and Portland serve major populations bases, particularly based on the 15-minute drive time populations. However, these same populations are also well connected to the stations by transit in Seattle and Portland, and do not necessarily need to rely solely on driving. By comparison, the intermediate stations along the line are much more dependent on auto access and egress.

Exhibit 6-1: 15 min and 30 min Drive-time Populations



The 30-minute drive time populations between stations sometimes show considerable overlap, or double counting. For example, both Portland and Vancouver, WA show approximately 1.6 million populations within a 30-minute drive time of those stations. This is because the hinterland areas of both stations include substantial parts of the Portland/Vancouver SMSA. Approximately 2.4 million people live in the Portland metropolitan statistical area (MSA), making it the 25th most populous in the United States. Its combined statistical area (CSA) ranks 19th-largest with a population of around 3.2 million. About half of these people live within a 30-minute drive time of either the Vancouver, WA, or Portland stations.

Similarly, the United States Census Bureau defines the metropolitan area as the Seattle–Tacoma–Bellevue, WA metropolitan statistical area. With an estimated population of 4,018,598 as of 2020, it is the 15th largest metropolitan statistical area (MSA) in the United States and is home to over half of Washington's population. More than half of these will live within a 30-minute drive time of the Seattle, SEA-TAC or Tacoma stations.

Exhibit 6-2 plots the 15-minute drive time population against the *COMPASS™* ridership forecast for that station. While the correlation between drive time population and ridership is clear for the smaller stations, it is also apparent that the forecasts for the major endpoint stations of Seattle and Portland are much stronger. This is because the *COMPASS™* model takes into account not only trip generation, which is considered population based, but also trip attractions. As the centers of their respective urban core areas, the downtown stations of Seattle and Portland will be very strong trip attractors as well as trip generators. This attractiveness is bolstered by the strength of the urban transit connections available at the station, which are able to distribute the trips to their final destinations within each downtown. This is the reason why, as shown in Exhibit 6-2, these two major stations are able to generate and attract the vast majority of high-speed rail trips along the corridor, with the smaller intermediate stations making a relatively minor contribution to total ridership.

Exhibit 6-2: Comparison of 15-Minute Population to Forecasted Station Volumes

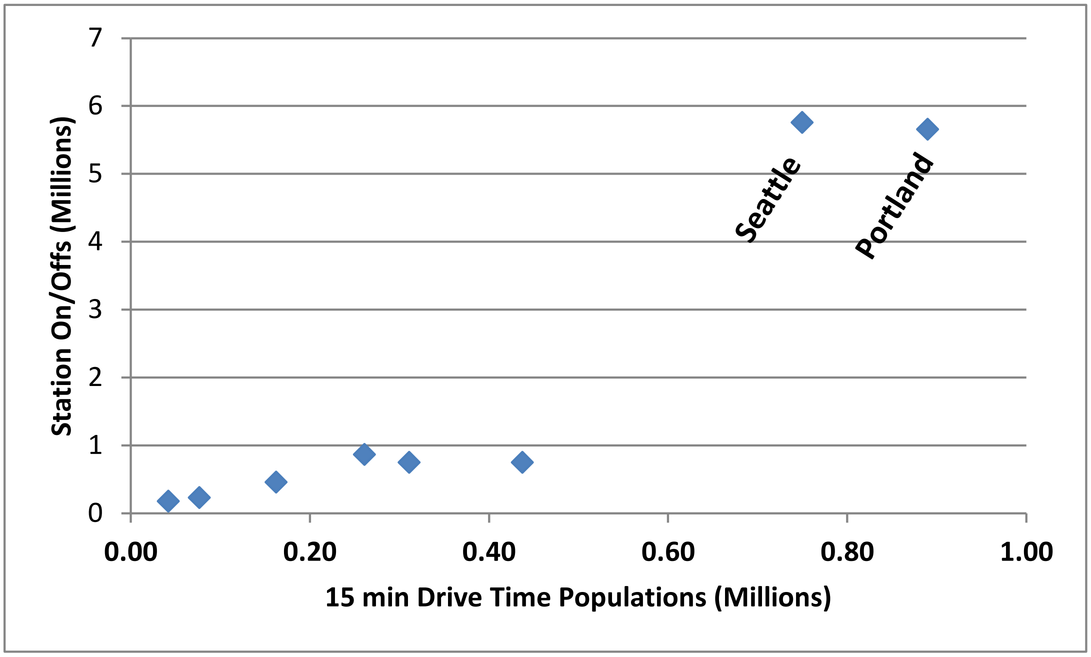
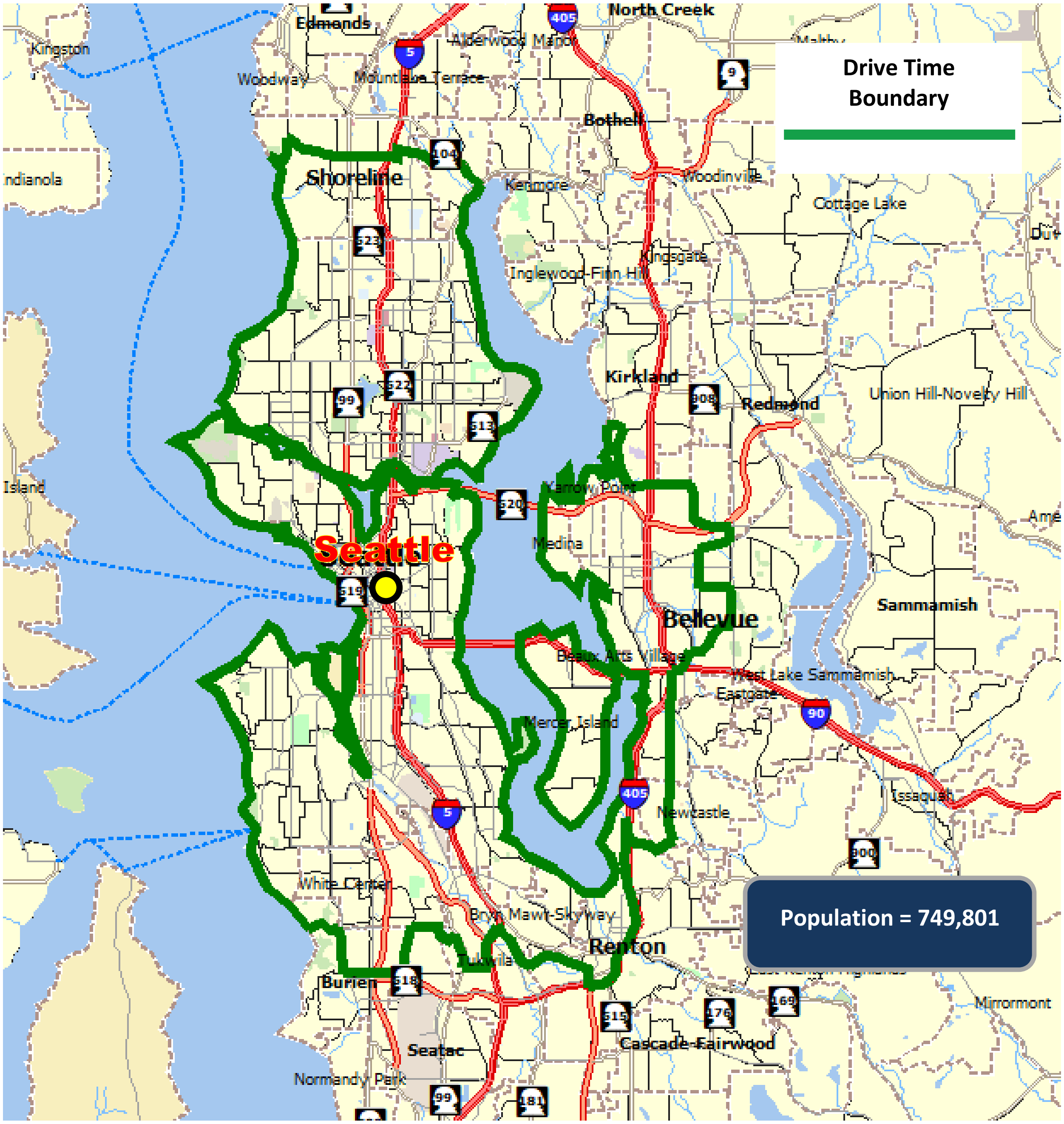


Exhibit 6-3 shows the 15-minute drive time map for Seattle, while Exhibit 6-4 shows the 30-minute drive time zone extending from the downtown Seattle station. The 2020 populations associated with these areas are 749,801 and 1,377,586, respectively. The 15-minute drive time map does not quite reach SEA-TAC airport on the south, whereas the 30-minute map does expand to include SEA-TAC airport.

Exhibit 6-3: 15-Minute Drive-Time Map for Seattle, WA



Population = 749,801

Exhibit 6-4: 30-Minute Drive-Time Map for Seattle, WA

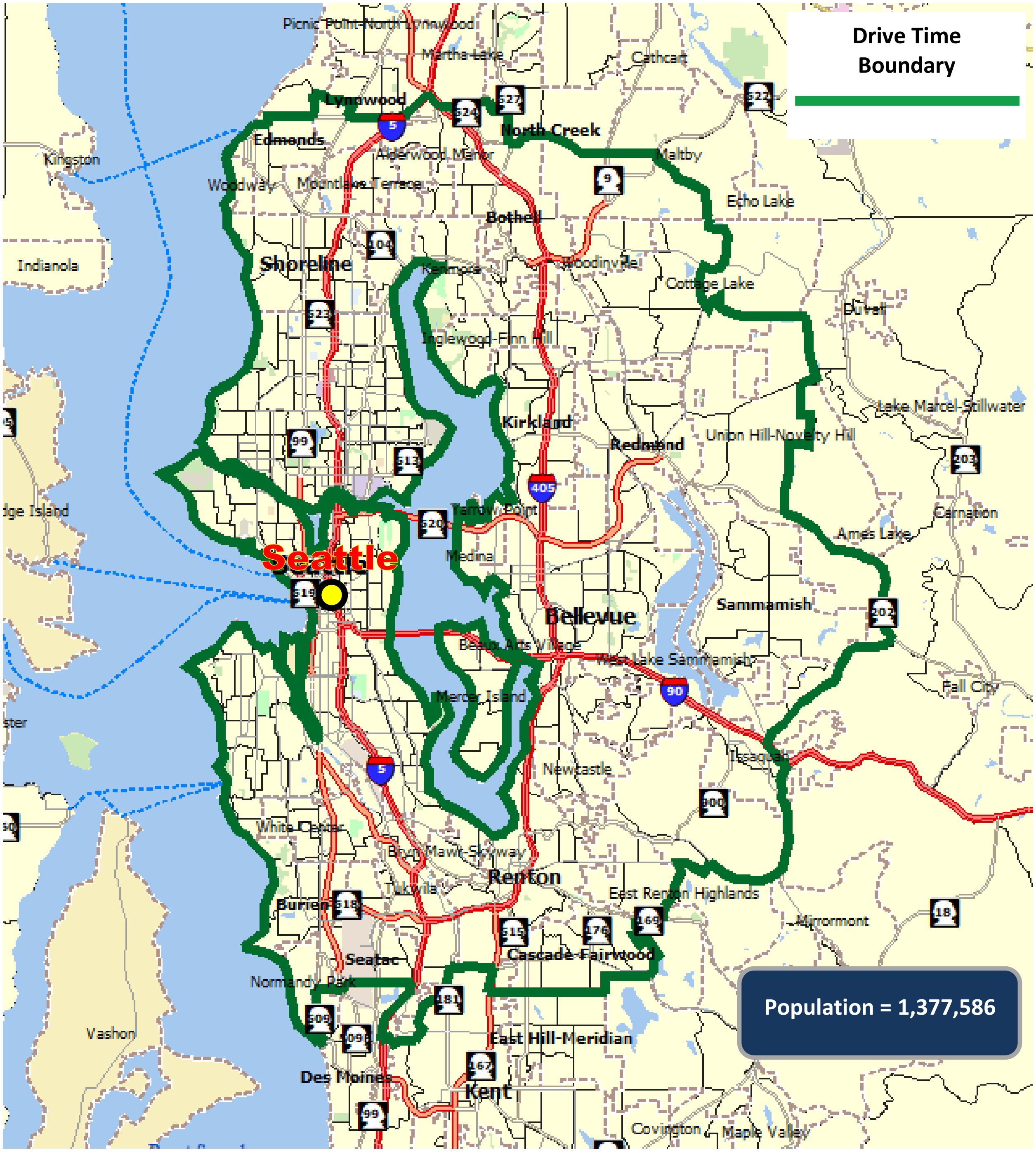


Exhibit 6-5 shows the 15-minute drive time map for SEA-TAC Airport, while Exhibit 6-6 shows the 30-minute drive time zone. The 2020 populations associated with these areas are 260,806 and 845,719, respectively. The 15-minute drive time map does not quite reach Seattle on the north or Tacoma on the south, whereas the 30-minute map for Sea-Tac does expand to include both cities.

Exhibit 6-5: 15-Minute Drive-Time Map for SEA-TAC Airport

Exhibit 6-6: 30-Minute Drive-Time Map for SEA-TAC Airport

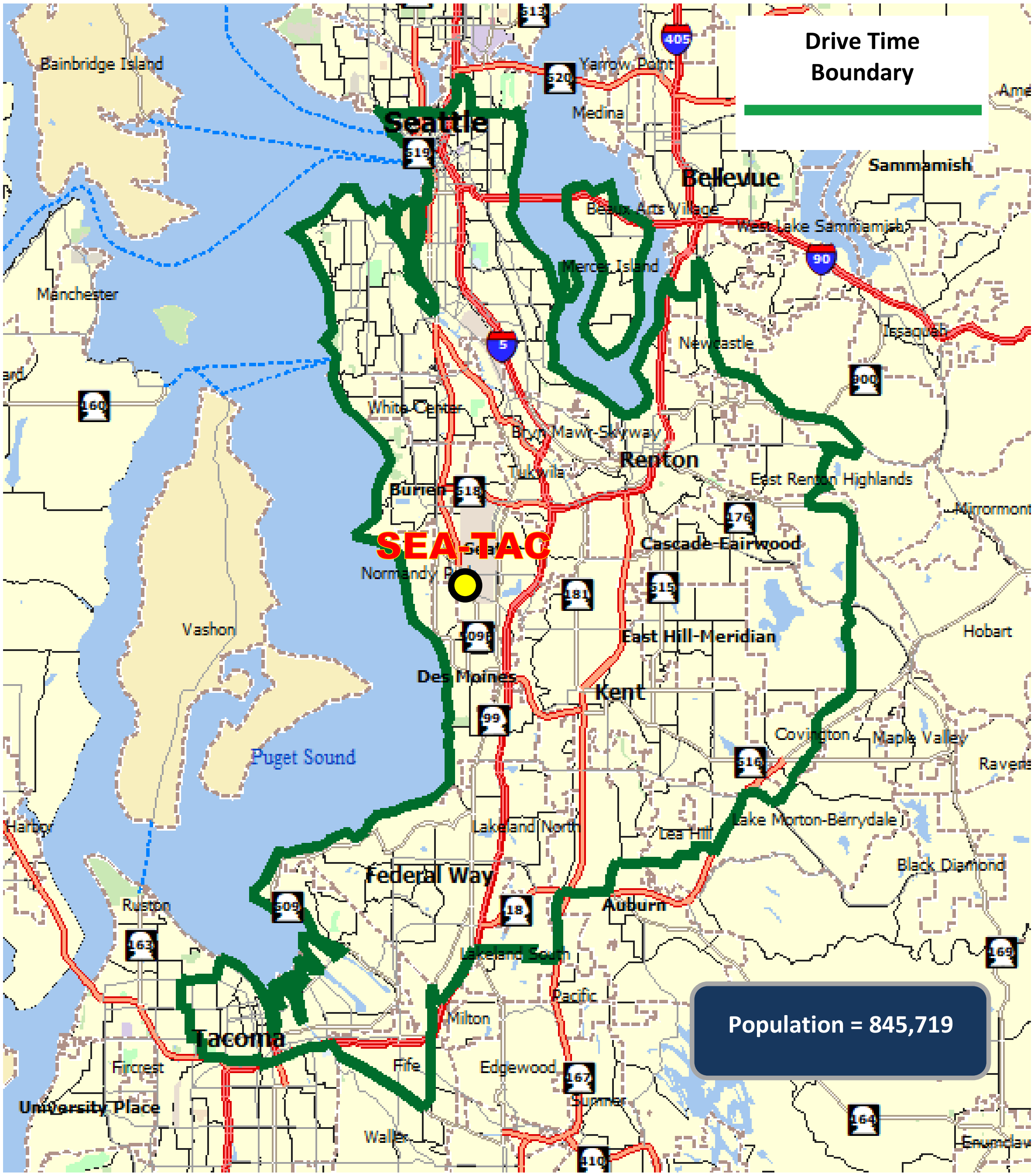


Exhibit 6-7 shows the 15-minute drive time map for Tacoma, while Exhibit 6-8 shows the 30-minute drive time map. The 2020 populations associated with these areas are 310,695 and 1,045,785 respectively. The 15-minute drive time map does not quite reach SEA-TAC on the north, whereas the 30-minute map for SEA-TAC does expand to include the airport. However, the State Capitol of Olympia is beyond both the 15-minute and 30-minute drive time range from Tacoma Dome station.

Exhibit 6-7: 15-Minute Drive-Time Map for Tacoma

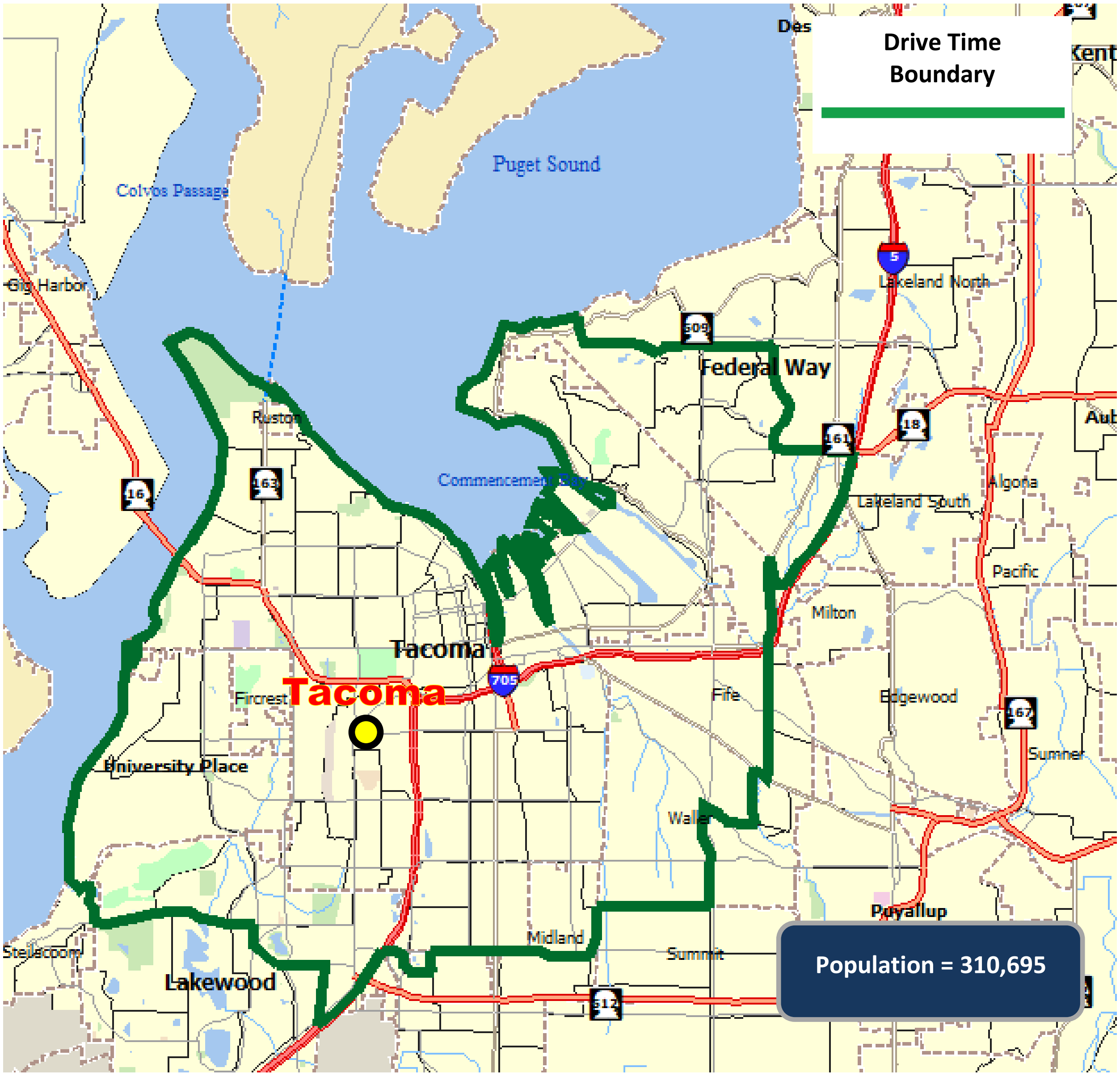


Exhibit 6-8: 30-Minute Drive-Time Map for Tacoma

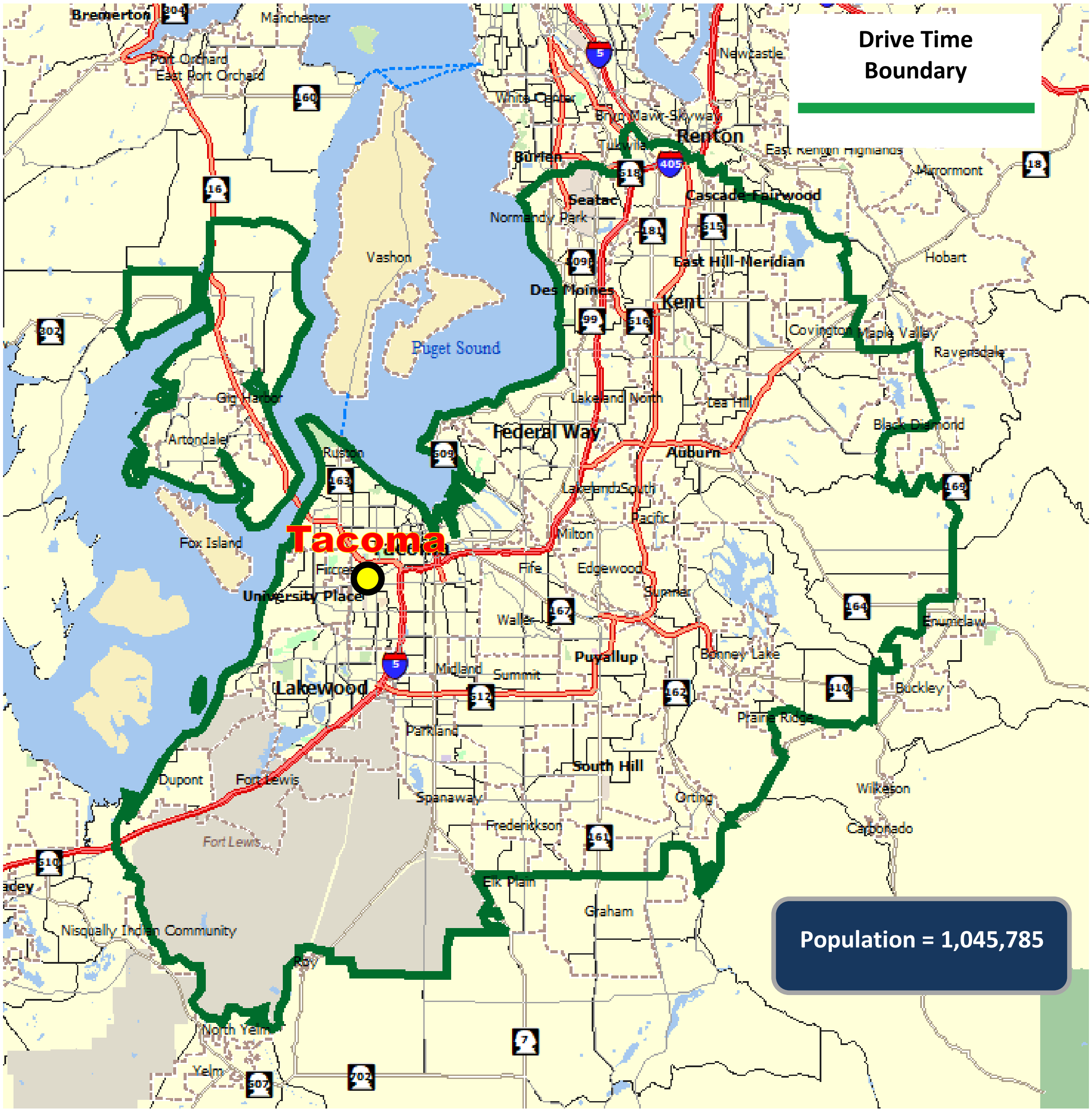


Exhibit 6-9 shows the 15-minute drive time map for Olympia, while Exhibit 6-10 shows the 30-minute drive time map. The 2020 populations associated with these areas are 162,351 and 389,936, respectively. While these populations are much less than for the larger cities of Portland or Seattle, the Olympia station will have some extra attraction since it is the State Capitol of Washington. The 15-minute drive time map has minimal overlap with any other stations' map, whereas the 30-minute map expands to include some sections of Lakewood, which is a southern suburb of Tacoma.

Exhibit 6-9: 15-Minute Drive-Time Map for Olympia

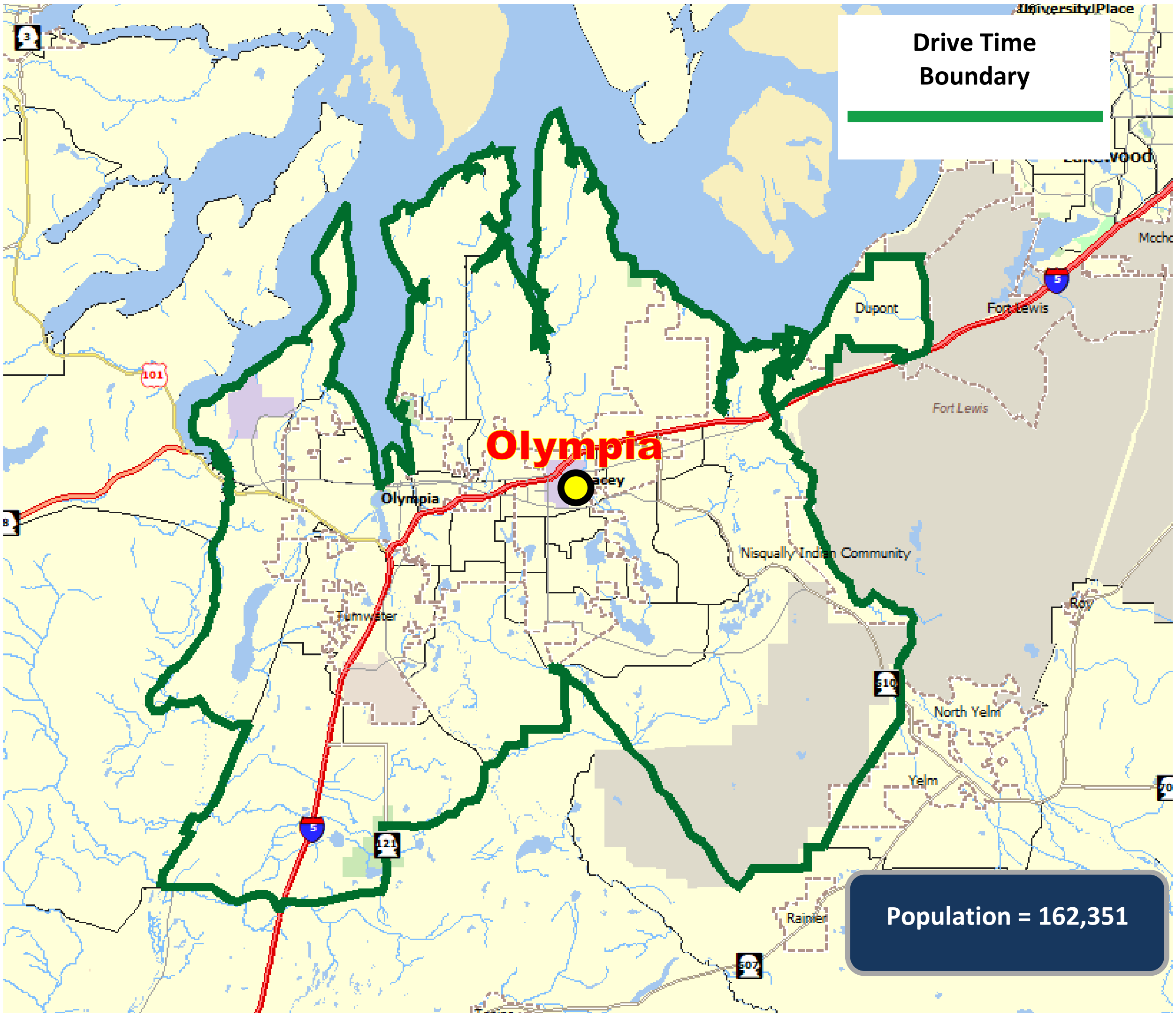


Exhibit 6-10: 30-Minute Drive-Time Map for Olympia

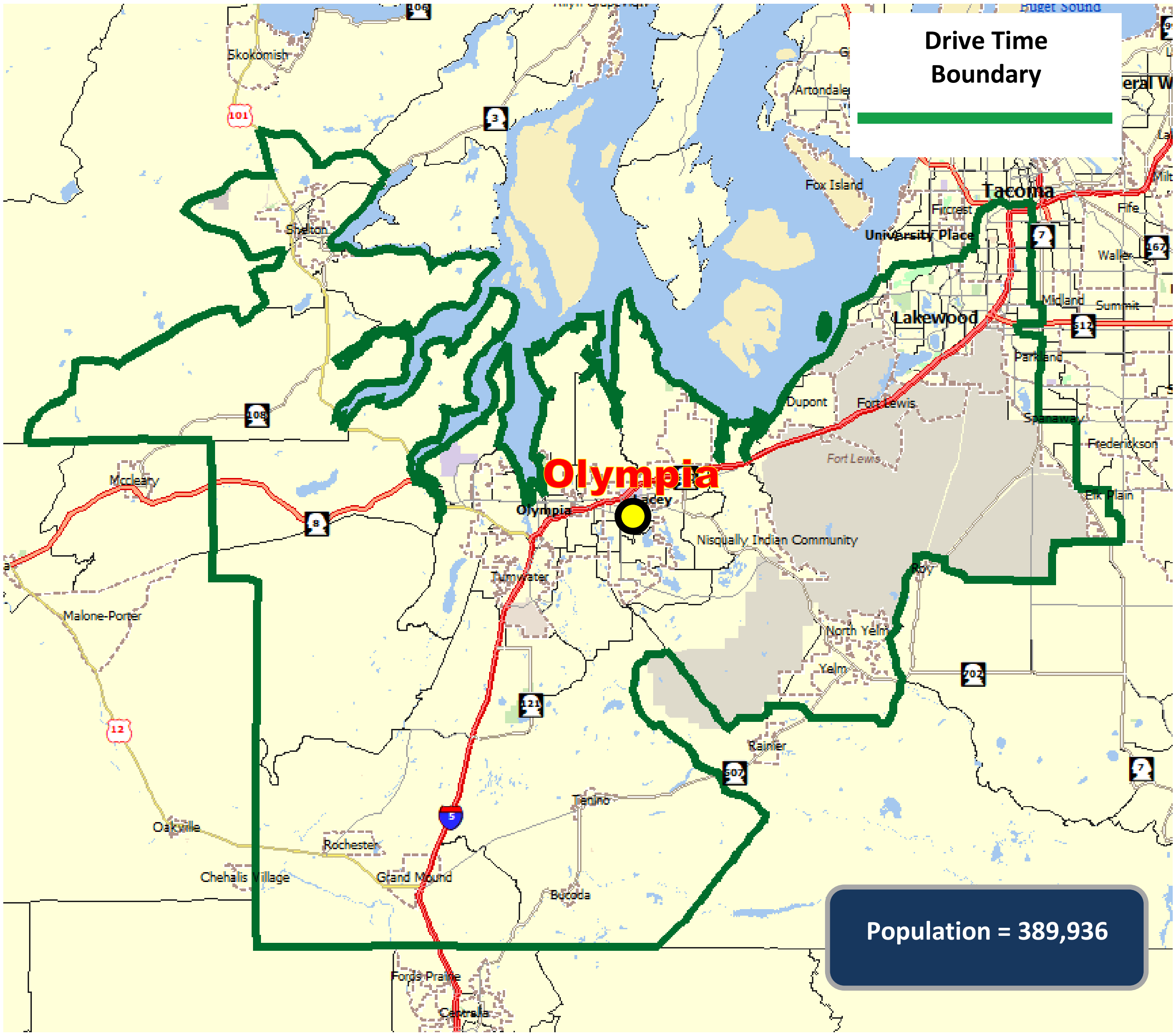


Exhibit 6-11 shows the 15-minute drive time map for Centralia, while Exhibit 6-12 shows the 30-minute drive time map. The 2020 populations associated with these areas are 42,002 and 96,599, respectively. Centralia will be the smallest station on the Portland-Seattle segment and is far enough distant as to have minimal overlap with the drive-time maps of any other station. The northern end of Centralia's 30-minute drive time map barely reaches to the outskirts of Olympia.

Exhibit 6-11: 15-Minute Drive-Time Map for Centralia

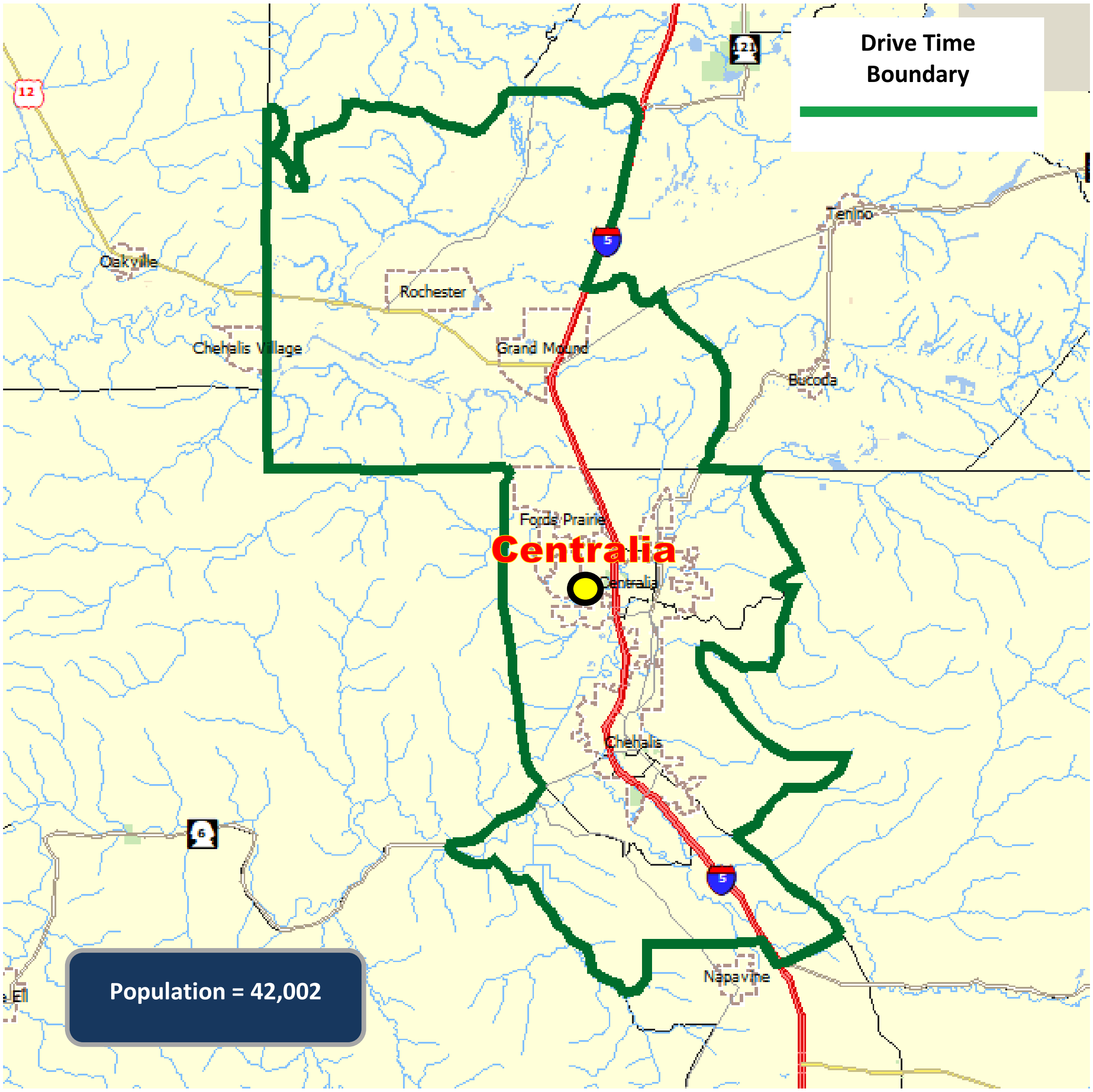


Exhibit 6-12: 30-Minute Drive-Time Map for Centralia

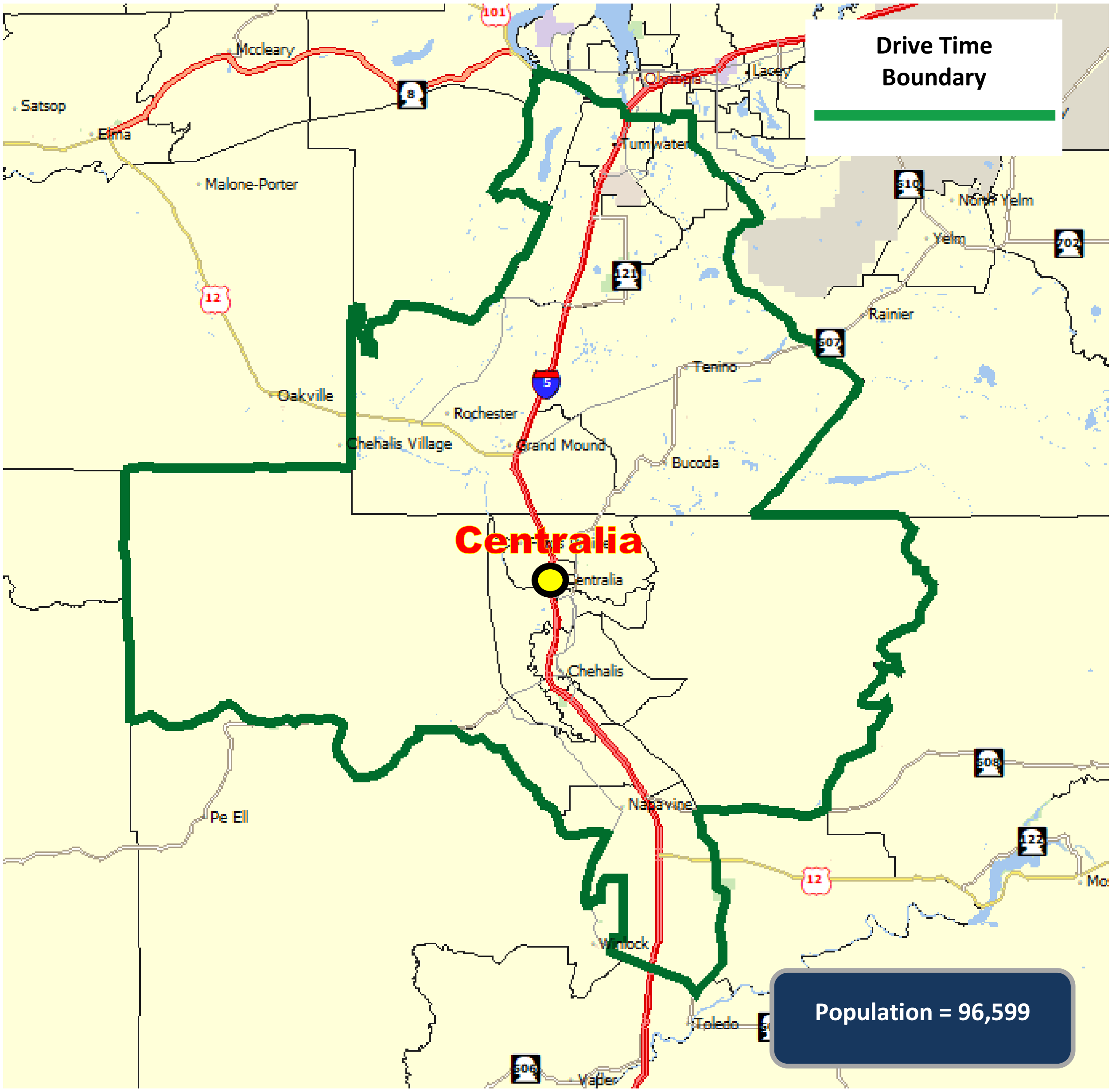


Exhibit 6-13 shows the 15-minute drive time map for Longview/Kelso, while Exhibit 6-14 shows the 30-minute drive time map. The 2020 populations associated with these areas are 76,505 and 161,856, respectively. Longview/Kelso is far enough distant as to have minimal overlap with the drive-time maps of any other station.

Exhibit 6-13: 15-Minute Drive-Time Map for Longview/Kelso

Exhibit 6-14: 30-Minute Drive-Time Map for Longview/Kelso

Exhibit 6-15 shows the 15-minute drive time map for Vancouver, WA, while Exhibit 6-16 shows the 30-minute drive time map. The 2020 populations associated with these areas are 437,462 and 1,610,781, respectively. The 15-minute drive time map for Vancouver includes some of the northern parts of Portland, OR along the south side of the Columbia River, and the 30-minute map encompasses even the Portland downtown. It is possible that some auto users from north Portland may find the Vancouver, WA station to be more convenient; however, congestion on the I-5 Interstate Columbia River Bridge and poor transit accessibility across the Columbia River both mitigate against much ridership at Vancouver, WA coming from the Oregon side of the Columbia River.

Exhibit 6-15: 15-Minute Drive-Time Map for Vancouver, WA

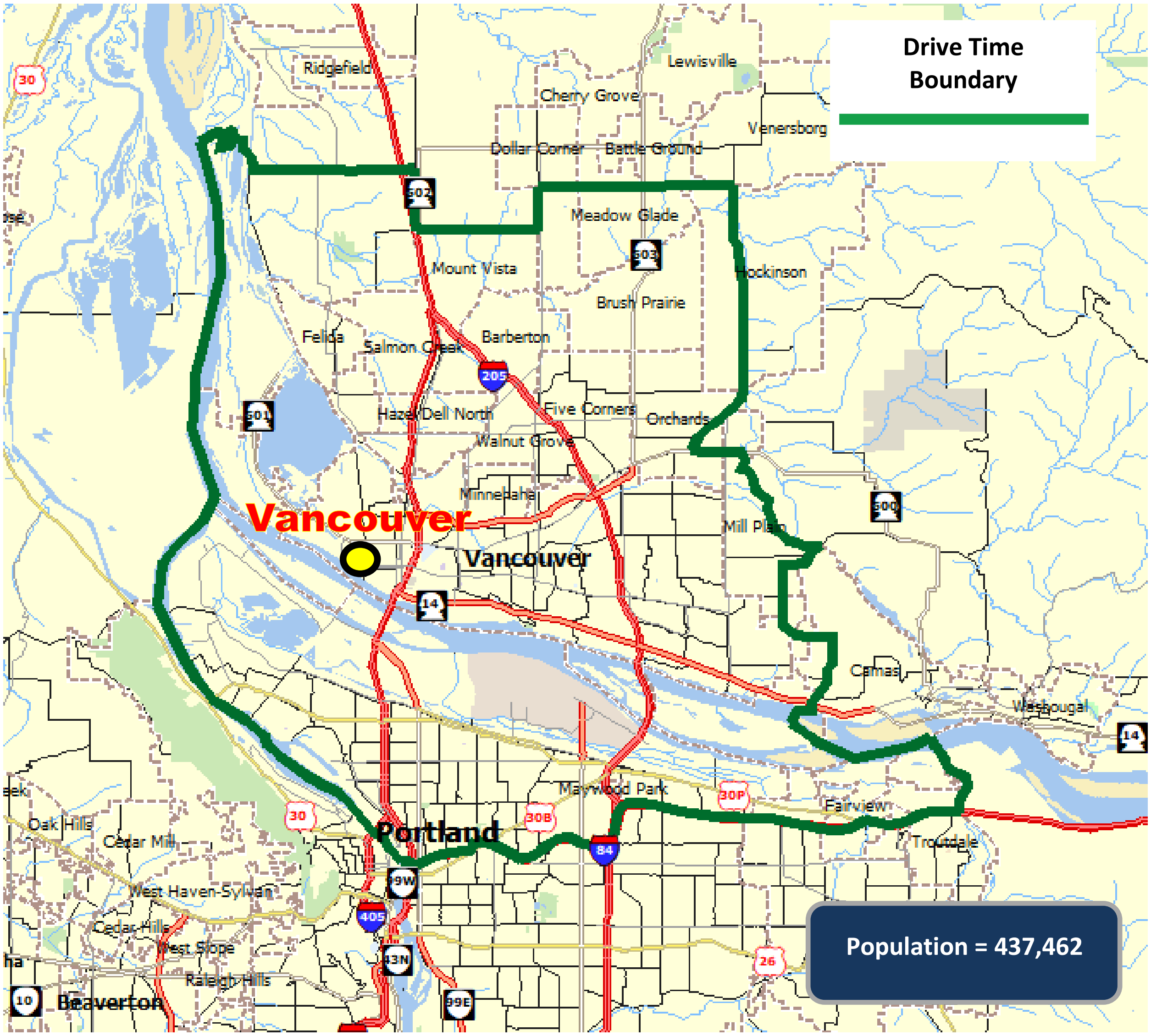


Exhibit 6-16: 30-Minute Drive-Time Map for Vancouver, WA

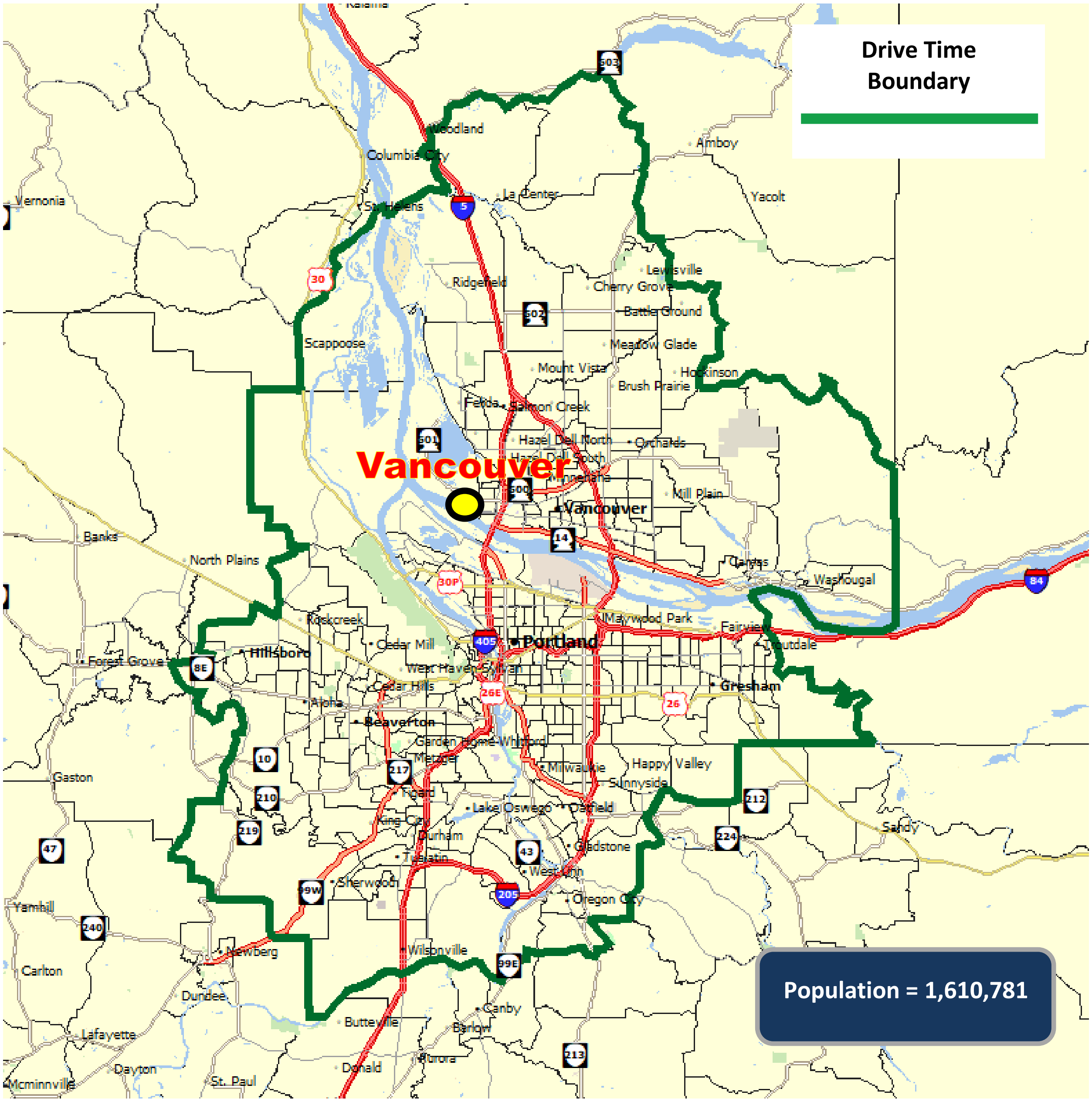


Exhibit 6-17 shows the 15-minute drive time map for Portland, OR while Exhibit 6-18 shows the 30-minute drive time map. The 2020 populations associated with these areas are 889,907 and 1,689,780, respectively. The 15-minute drive time map for Vancouver includes some of the southern parts of Vancouver, OR along the north side of the Columbia River, and the 30-minute map encompasses all of Vancouver. However, congestion on the I-5 Interstate Columbia River Bridge and poor transit accessibility across the Columbia River both mitigate against much ridership at Portland, OR coming from the Washington side of the Columbia River. As well, riders' natural bias against driving south to ride north will come into play. As such, it is much more likely that Oregon ridership will gravitate towards the Portland, OR station while Washington riders would prefer to board the train in Vancouver, WA.

Exhibit 6-17: 15-Minute Drive-Time Map for Portland, OR

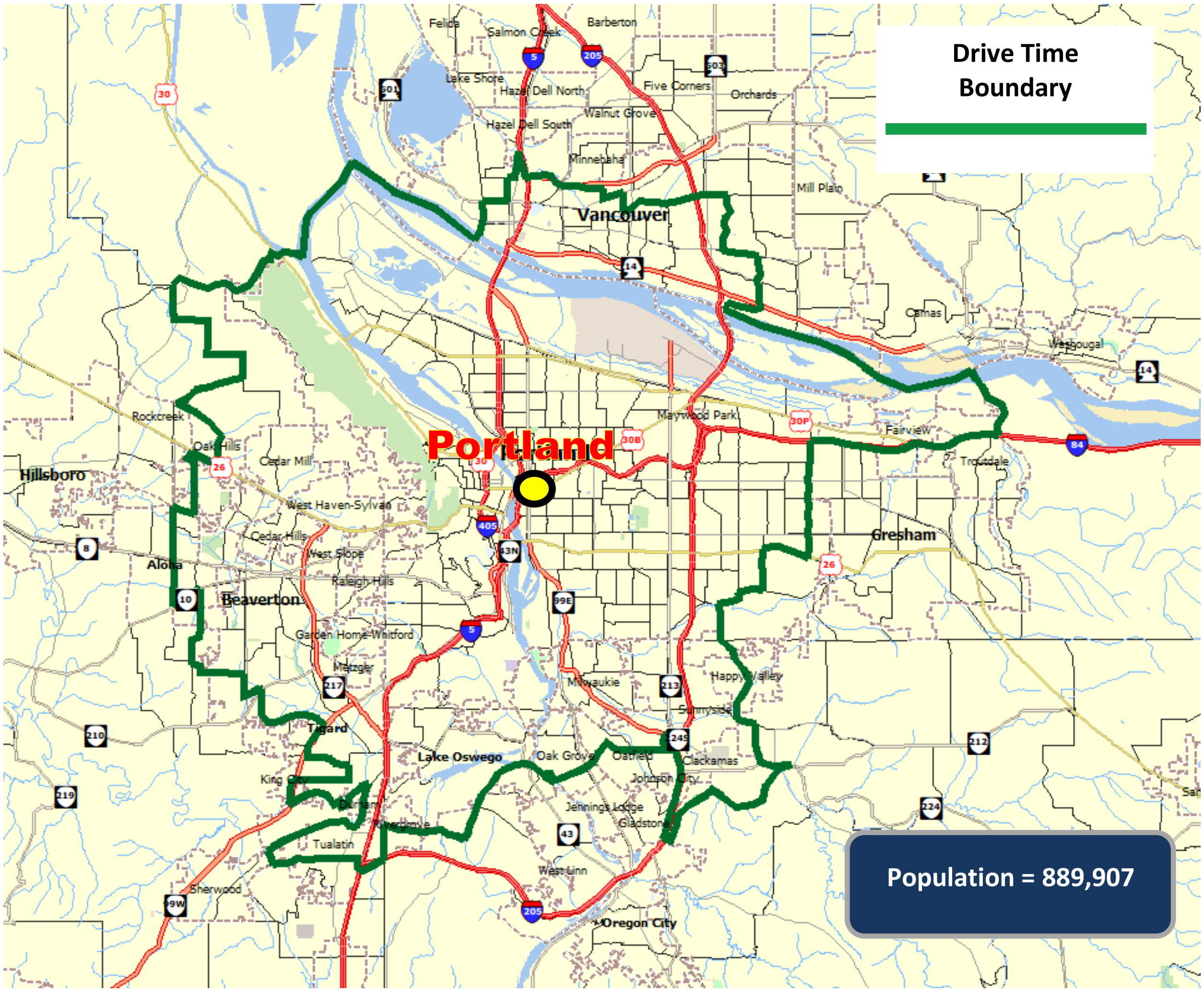
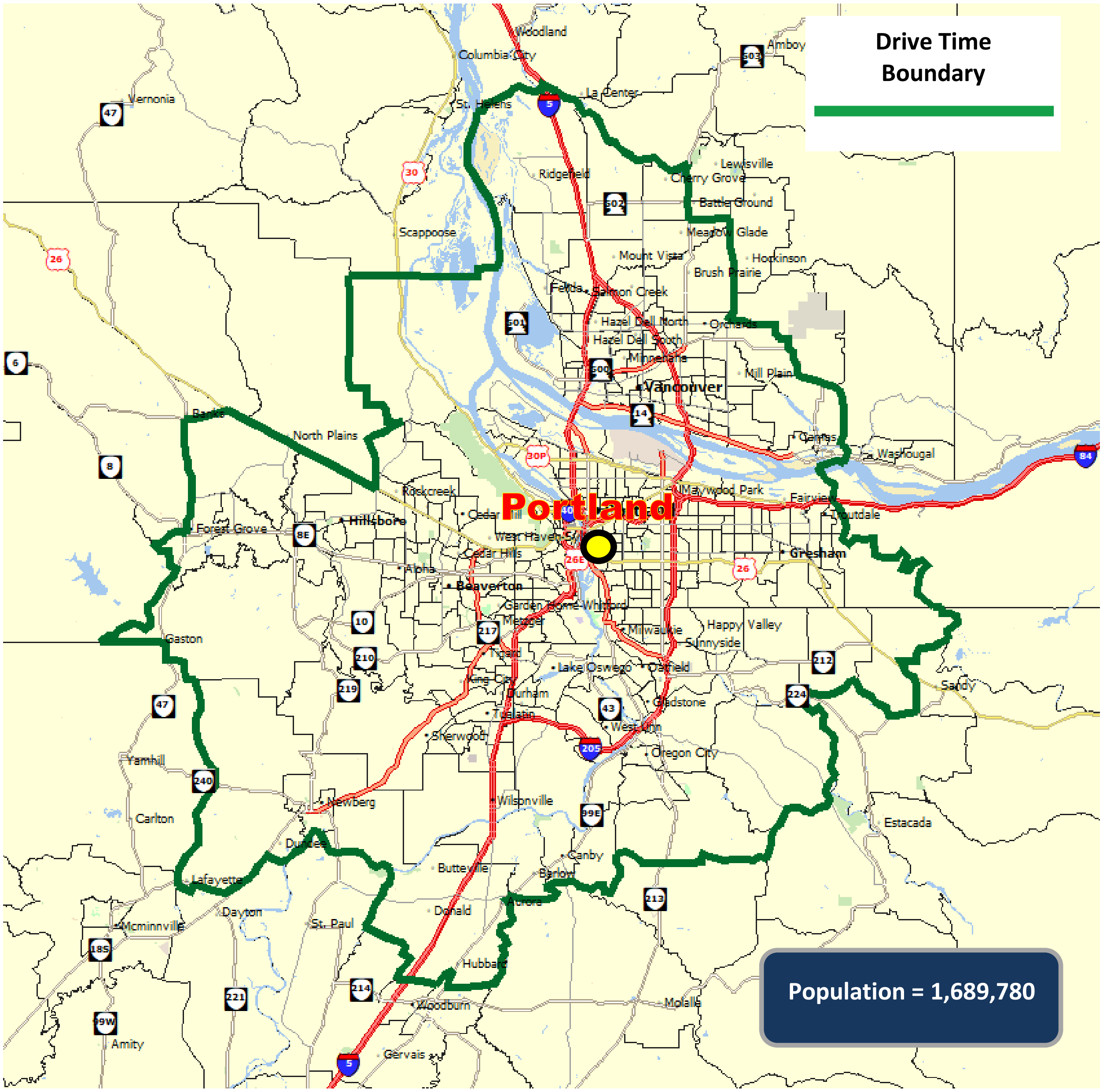


Exhibit 6-18: 30-Minute Drive-Time Map for Portland, OR



7. CONCEPTUAL ENGINEERING AND CAPITAL PROGRAMMING

This chapter discusses the capital cost methodology used and development of the capital costs for the Cascadia Corridor including breakdowns by unit costs. This chapter also presents the Capital Spending plan for the project.

7.1 CAPITAL COST METHODOLOGY

A capital costing methodology was developed to identify infrastructure, rolling stock (equipment) costs and land costs for the proposed Cascadia rail improvements. Land costs are included in the basic unit costs for each type of improvement, as a placeholder for access to railroad rights-of-way and for procurement of additional privately owned property where required to construct new passenger rail infrastructure. The Engineering Assessment was the first step in developing the capital cost estimates for the project.

7.1.1 ENGINEERING ASSESSMENT

The Engineering Assessment for this Service Development Plan has been conducted at a concept level of detail and accuracy. Exhibit 7-1 highlights the levels of accuracy associated with typical phases of project development and engineering design. A 30 percent level of accuracy is associated with the evaluation of project feasibility, while the level of accuracy of 10 percent is achieved during final design and production of construction documents. This phase of the study is only the first step in the project development process. As shown in Exhibit 7-1, the cost estimate is intended to be a mid-range projection with equal probability of the actual cost moving up or down.

Exhibit 7-1: Engineering Project Development Phases and Levels of Accuracy Development

Development Phases	Approximate Engineering Design Level	Approximate Level of Accuracy
Feasibility Study	0%	+/- 30% or worse
Project Definition/Advanced Planning	1-2%	+/- 25%
Conceptual Engineering	5-10%	+/- 25%
Preliminary Engineering	30%	+/- 20%
Pre-Final Engineering	65%	+/- 20%
Final Design/Construction Documents	100%	+/- 10% or better

The first step in the Engineering Assessment is to divide each corridor into segments. Route segments for existing railroad rights-of-way generally begin and end at major railroad control points or rail stations. For greenfield alignments, segments begin and end at stations or junction points. Seven segments of the Cascadia corridor are discussed and defined in Chapter 3. A systematic engineering planning process has been used to conduct the Engineering Assessment using the five basic costing elements:

- Guideway and Track Elements
- Structures – Approaches, Flyovers, Bridges and Tunnels
- Systems
- Crossings
- Stations and Maintenance Facilities

Three auxiliary costing elements have been defined in the chapter as follows:

- Right-of-Way and Land
- Vehicles
- Professional Services & Contingencies

The Engineering Assessment includes these eight costing elements. In addition to the field inspections and extensive work with GIS and railroad track charts, the assessment included a thorough review of the alignment studies and estimate the costs.

7.1.2 Infrastructure Capital Costs Development

A concept capital costing methodology was used appropriate to the current early level of development of the route alignment and environmental analysis. For a double track, electrified alignment, costs as shown in Exhibit 7-2 were used. These are mid-range costs that were sourced directly from the engineering review and USDOT FRA benchmark costs. The unit costs were almost identical to those used in Washington State's Ultra High-Speed Rail study.[15] However, these tunneling, elevated and at-grade costs were reduced to $149, $78 and $13 million per mile respectively for the development of a single-tracked, non-electrified alignment in Alternative 1.

Exhibit 7-2: ”All in” Unit Capital Costs based on theType of Alignment

Tunnel - $230M/mile

Elevated Guideway - $123M/mile

Cut and Fill - $25M/mile

For applying this costing framework, the three-unit costs above are assumed to already include the costs for: Right-of-Way and Land, Professional Services (28%), Contingencies (30%), Guideway and Track Elements, Structures – Approaches, Flyovers, Bridges and Tunnels and Systems including electrification and signaling. There are no highway or rail crossings on the proposed alignment which will be fully grade-separated, so this category or costs is irrelevant. Station costs are assumed to be funded by the private developers and be implemented as part of Transit Oriented Development (TOD) projects in each city. Finally, the costs for Equipment and the necessary Maintenance Facilities have been rolled together since often the trainsets and equipment needed for maintaining them are obtained as part of a single procurement.

Although tunneling is clearly the most expensive alternative, and cut and fill the cheapest, given the character of the terrain and natural beauty of the landscape, it was decided to limit the maximum cut depth to 75 feet. Any deeper than this a tunnel can be used. It is recognized that in developing I-5 and other highway systems, much deeper cuts have been made, even to a depth of 300 feet or more, but to protect the environment in development of the rail system, limiting the cut depth would produce much less impact on the landscape. This issue is further discussed in the Tier 1 Service NEPA report as well as in the Value Engineering section below.

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[15] See Table 5-10 on page 5-13 of the *Ultra-High-Speed Ground Transportation Study*, Prepared for Washington State Department of Transportation by CH2MHill in February 2018. Weblink: https://wsdot.wa.gov/sites/default/files/2018/07/26/ultra-high-speed-ground-transportation-study.pdf

7.1.3 VALUE ENGINEERING

All tunneled sections were reviewed to ensure that the tunnels were really needed, if they could be bypassed and still maintain acceptable geometry, or if the length of tunneling could be reduced by changing the elevation of the tunnels or by open cutting.

For example, the main difference between Alternative 3 and the lower investment in Alternative 1 and 2 is the use of tunnels for shortening the alignment through the built-up areas of Lakewood, Tacoma, Lakeland and Seattle. To eliminate these tunnels in Alternatives 1 and 2, the alignment utilized the existing BNSF rail corridor through the built-up urban area. By comparison, Alternative 3 uses extensive tunneling throughout this northern stretch of the alignment.

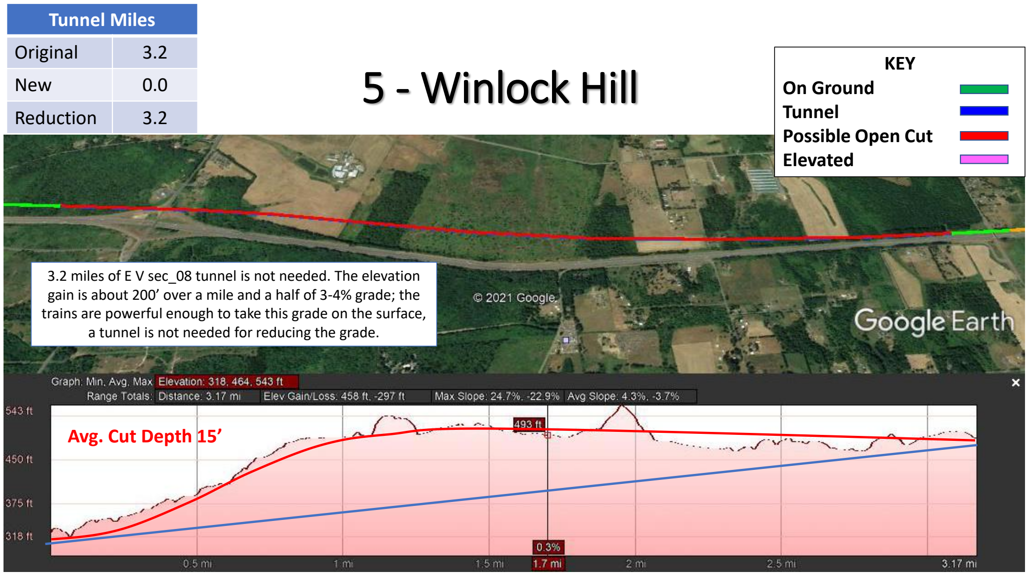
South of Olympia to Vancouver, WA where the countryside is more rural there exist instances where the areas above the tunnels are undeveloped. In such areas, tunnels might be replaced with open cuts down to a depth of 300’ or more as used for I-5 highway. However, such deep cuts would leave unsightly scars in the terrain, which today may not be acceptable from either an aesthetic or environmental point of view. Deeper cuts were, however, included in the 2016 CHSR proposal along with the surface alignment through Lakewood, Tacoma, and Lakeland in an effort to limit the cost. Since this resulted in an inconsistency between the costing of the three Alternatives, cuts were limited to 75 feet in each case to ensure a proper comparison.

For the purpose of this analysis, it was decided to limit the maximum cut depth to about 75 feet; but also, to allow for steeper rail track grades, while of course maintaining limits on vertical as well as horizontal curvature. This maintains the high-speed capability of the alignment while taking advantage of the grade-climbing capability of modern high-speed trains. The agreed upon standards were:

- **Maximum Gradient:** 4% as used in the European UIC standards, and recently used on Cologne-Frankfort HSR line in Germany. The Rocky Mountain High-Speed Rail study had developed rail options with gradients as steep as 7%. To achieve this, it was required that all axles be powered and additional electrical capability in the trains and wayside to handle the high-power requirements of such operations. By comparison, just about any off-the-shelf high-speed trainset can handle 4% grades.
- **Maximum Vertical Curve**: 0.075 percent per 100 feet or less for high-speed (220-mph) sections, consistent with European standards
- **Maximum Cut Depth:** 75 feet from Top of Rail, which is close to the minimum overburden needed for launching a TBM anyway, subject of course to Engineering judgement and discretion

The tunnel segments on all three Alternatives 1, 2 and 3 were then reassessed by applying this consistent set of standards to all the Alternatives. Some open cut sections that had been included in Alternatives 1 and 2 were disallowed and replaced with tunnel, so this resulted in an increase in cost. However, some of the proposed tunnel sections in the new Alternative 3 were found to be shallower than 75 feet depth or could be reprofiled to achieve this, with no structures on top that would prevent open cutting. This results in a decrease of tunneling costs for Alternative 3, The Winlock Hill example in Exhibit 7-3 shows how this was done for one particular case. By utilizing an allowable gradient of 4%, the rail line can follow the terrain with a gradual incline, resulting in the elimination of 3.2-mile tunnel.

Exhibit 7-3: Example Tunnel Reduction Opportunity



Tunnel Miles	
Original	3.2
New	0.0
Reduction	3.2

5 - Winlock Hill

3.2 miles of E V sec_08 tunnel is not needed. The elevation gain is about 200’ over a mile and a half of 3-4% grade; the trains are powerful enough to take this grade on the surface, a tunnel is not needed for reducing the grade.

7.1.4 CAPITAL COST SUMMARY

Based on the application of a consistent set of standards for gradients, cut depth and tunneling, the capital costs for developing the three Alternatives between Portland, OR and Seattle, WA have been estimated as shown in Exhibit 7-4.

Exhibit 7-4: Capital Costs for the Three Alternatives

Infrastructure Type	Alternative #1			Alternative #2			Alternative #3		
	Miles	Unit Cost	Total	Miles	Unit Cost	Total	Miles	Unit Cost	Total
Cut and Fill	16.40	$13	$213	16.40	$25	$410	31.16	$25	$779
At Grade	103.80	$13	$1,370	103.80	$25	$2,595	30.11	$25	$753
Flyover	34.70	$78	$2,702	34.70	$123	$4,268	60.94	$123	$7,496
Tunnel	18.40	$149	$2,742	18.40	$230	$4,232	43.49	$230	$10,003
Equipment + Stations			$1,000			$1,000			$1,200
Placeholder						$550			$550
TOTAL	**173.30**		**$8,027**	**173.30**		**$13,055**	**165.70**		**$20,780**
Cost per Mile ($Mill)	**$46.32**			**$75.33**			**$120.71**		
Plus Airport Loops			**$990**			**$1,500**			**$1,500**
TOTAL w/AIRPORTS			**$9,017**			**$14,555**			**$22,280**

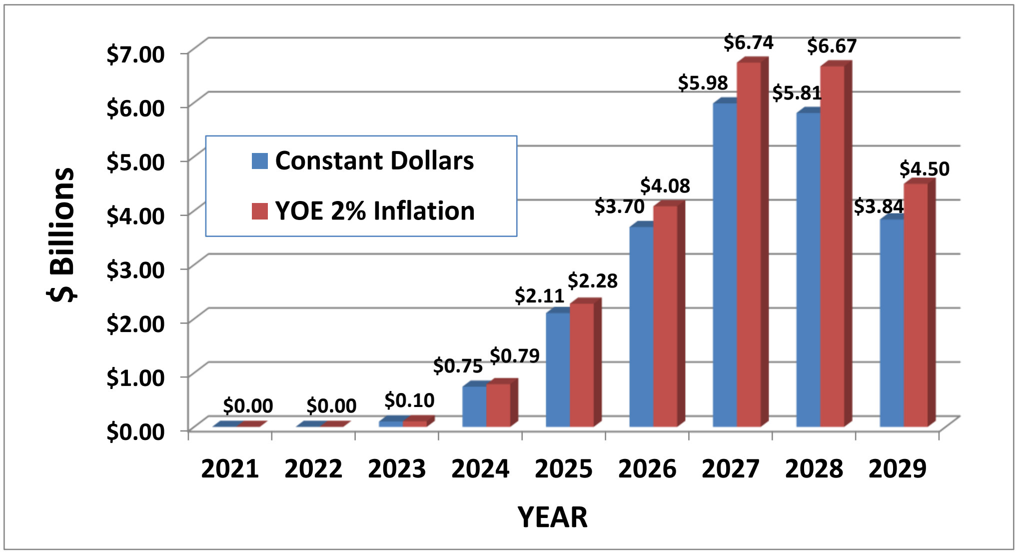
In their UHSGT report for Washington DOT[16], WSP projected a cost of $24-42 billion on 310 miles, or $77.1 to $135.5 million per mile. The cost of Alternative 2 approximates the low end of WSP's range, while Alternative 3's cost is near the top end of the range. These capital costs are consistent with WSDOT's earlier estimates but reflect the characteristics of actual alignments. These costs will be subject to further refinement in future detailed work.

7.2 IMPLEMENTATION, FUNDING NEEDS AND YEAR-OF-EXPENDITURE ANALYSIS

Year of Expenditure (YOE) dollars are dollars that are adjusted for inflation from the present time to the expected year of construction. Planning regulations require that revenue and cost estimates in the MTP, STIP, and TIP[17] prepared by Metropolitan Planning Organizations, must use inflation or growth rate(s) to reflect "year of expenditure dollars," based on reasonable financial principles and information, developed cooperatively by the State, MPOs, and public transportation operators. [23 CFR § 450.216(l), § 450.322 (f)(10)(iv), and § 450.324(h)] Year of expenditure cost estimates should also be used in NEPA documentation.[18]

Accordingly, the Capital Cost of $22.3 billion in 2021 dollars has been expressed in YOE dollars based on a 2030 implementation date. This calculation is based on a 2% annual inflation rate assumption between now and 2030 and results in a total project cost of $25.2 billion in YOE dollars as compared to $22.3 billion in current dollars (Exhibit 7-5). This is useful for projecting the actual funding requirement that would be needed to finance construction of the system in the future. However, Benefit Cost ratios are always calculated in Constant Dollar terms, where the constant dollar value of distribution of capital costs is used in the discounting (Net Present Value) calculations associated with estimation of the Benefit Cost ratios in Chapter 9.

Exhibit 7-5: Capital Spending Plan and Year-of-Expenditure Cost



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[16] WSP, *Ultra-High-Speed Ground Transportation Business Case Analysis, Final Report, July 2019*. Weblink: https://wsdot.wa.gov/sites/default/files/2019/07/12/Ultra-High-Speed-Ground-Transportation-Study-Business-Case-Analysis-Full-Report-with-Appendices-2019.pdf

[17] Metropolitan Transportation Plan (MTP); Transportation Improvement Program (TIP); Statewide Transportation Improvement Program (STIP): see http://www.planning.dot.gov/documents/briefingbook/bbook.htm

[18] See: http://www.fhwa.dot.gov/ipd/project_delivery/resources/financial_plans/guidance.aspx
and http://www.fhwa.dot.gov/planning/tpr_and_nepa/tprandnepasupplement.pdf

8. OPERATING AND MAINTENANCE COSTS AND CAPITAL PROGRAMMING

8.1 OPERATING AND MAINTENANCE COSTS METHODOLOGY

This section describes the build-up of the unit operating costs that have been used in conjunction with the operating plans, to project the total operating cost of each corridor option for the three Cascadia options. A costing framework originally developed for the Midwest Regional Rail System (MWRRS) was adapted for use in this study. Following the MWRRS methodology[19], nine specific cost areas have been identified. As shown in Exhibit 8-1, variable train-mile driven costs include equipment maintenance, energy and fuel, and train and onboard (OBS) service crews. Passenger miles drive insurance liability, while ridership influences marketing, and sales. Fixed costs include administrative costs, station costs, and track and right-of-way maintenance costs. Signals, communications, and power supply are included in the track and right-of-way costs.

This framework enables the direct development of costs based on directly controllable and route-specific factors and allows sensitivity analyses to be performed on the impact of specific cost drivers. It also enables direct and explicit treatment of overhead cost allocations, to ensure that costs which do not belong to a corridor are not inappropriately allocated to the corridor, as would be inherent in a simple average cost-per-train mile approach. It also allows benchmarking and direct comparability of the CHSR costs with those developed by other high-speed rail studies across the nation.

Exhibit 8-1: Operating Cost Categories and Primary Cost Drivers

Drivers		Cost Categories
Train Miles	→	**Equipment Maintenance** **Energy and Fuel** **Train and Engine Crews** **Onboard Service Crews**
Passenger Miles	→	**Insurance Liability**
Ridership and Revenue	→	**Sales and Marketing**
Fixed Cost	→	**Service Administration** **Track and ROW Maintenance** **Station Costs**

For development of costs, since there are a number of different corridor and technology options, it is essential to maintain consistency of the costing basis across all options. For developing a fair comparison:

- Unit Costs that depend on the propulsion/speed should reflect legitimate differences between technologies and routes; and
- Unit Costs that do not depend on propulsion/speed should remain the same across all technologies and routes.

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[19] Follow the links under “Midwest Regional Rail Initiative (MWRRI)” at http://www.dot.state.mn.us/planning/railplan/studies.html

- Operating costs can be categorized as variable or fixed. As described below, fixed costs include both Route and System overhead costs. Route costs can be clearly identified to specific train services but do not change much if fewer or additional trains were operated.
- Variable costs change with the volume of activity and are directly dependent on ridership, passenger miles or train miles. For each variable cost, a principal cost driver is identified and used to determine the total cost of that operating variable. An increase or decrease in any of these will directly drive operating costs higher or lower.
- Fixed costs are generally predetermined, but may be influenced by external factors, such as the volume of freight tonnage, or may include a relatively small component of activity-driven costs. As a rule, costs identified as fixed should remain stable across a broad range of service intensities. Within fixed costs are two sub-categories:
    - Route costs such as track maintenance, train control and station expense that, although fixed, can still be clearly identified at the route level.
    - Overhead or System costs such as headquarters management, call center, accounting, legal, and other corporate fixed costs that are shared across routes or even nationally. A portion of overhead cost (such as direct line supervision) may be directly identifiable but most of the cost is fixed. Accordingly, assignment of such costs becomes an allocation issue that raises equity concerns. These kinds of fixed costs are handled separately.

Operating costs have been developed based on the following premises:

- Based on results of recent studies, a variety of sources including suppliers, current operators' histories, testing programs and prior internal analysis from other passenger corridors were used to develop the cost data. However, as the rail service is implemented, actual costs will be subject to negotiation between the passenger rail authority and the contract rail operator(s).
- Freight railroads will maintain track and right-of-way that they own, but ultimately, the actual cost of track maintenance will be resolved through negotiations with the railroads. For this study, a track maintenance cost model will be used that reflects actual freight and passenger railroad cost data.
- Maintenance of train equipment will be contracted out to the equipment supplier.
- Train operating practices will follow existing work rules for crew staffing and hours of service. Average operating expenses per train-mile for train operations, crews, management, and supervision were estimated through a bottoms-up staffing approach based on typical passenger rail organizational needs.

The MWRRS costing framework was developed in conjunction with nine states that comprised the MWRRS steering committee and with Amtrak. In addition, freight railroads, equipment manufacturers and others provided input to the development of the costs. However, the costing framework has been validated with recent operating experience based on publicly available data from other sources, particularly the Midwest 403B Service trains Northern New England Passenger Rail Authority's (NNEPRA) Downeaster costs and data on Illinois operations that was provided by Amtrak. It has been brought to a 2021 costing basis and additional cost categories not included in the original MWRRS study, such as for electrification, have been added into the framework.

The original concept for the MWRRS was for development of a new service based on operating methods directly modeled after state-of-the-art European rail operating practice. Along with anticipated economies of scale, modern train technology could reduce operating costs when compared to existing Amtrak practice. In the original 2000 MWRRS Plan, European equipment costs were measured at 40 percent of Amtrak's costs. However, in the final MWRRS plan that was released in 2004, train-operating costs were significantly increased to a level that is more consistent with Amtrak's current cost structure. However, adopting an Amtrak cost structure for financial planning does not suggest that Amtrak would actually be selected for the corridor operation. Rather, this selection increases the flexibility for choosing an operator without excluding Amtrak, because multiple operators and vendors will be able to meet the broader performance parameters provided by this conservative approach.

8.2 VARIABLE COSTS

These costs include those that directly depend on the number of train-miles operated or passenger-miles carried. They include train equipment maintenance, train crew cost, fuel and energy, onboard service, and insurance costs.

8.2.1 TRAIN EQUIPMENT MAINTENANCE

Equipment maintenance costs include all costs for spare parts, labor and materials needed to keep equipment safe and reliable. The costs include periodical overhauls in addition to running maintenance. It also assumes that facilities for servicing and maintaining equipment are designed specifically to accommodate the selected train technology. This arrangement supports more efficient and cost-effective maintenance practices. Acquiring a large fleet of trains with identical features and components, allows for substantial savings in parts inventory and other economies of scale. In particular, commonality of rolling stock and other equipment will standardize maintenance training, enhance efficiencies, and foster broad expertise in train and system repair.

The MWRRS study developed a cost of $8.23 per train mile for a 250-seat diesel train in $2002. This cost was increased to $14.42 per train mile in $2021. Available evidence suggests that the maintenance cost for a conventional electric train should be about 9 percent cheaper per equivalent seat-mile than that of a diesel train; however, high-speed electric trains have a more than proportional increase in power: a typical 130-mph diesel train has about 18 kw/Seat; the 220-mph Alstom AGV has 24 kw/Seat[20] while the 160-mph Acela is rated at 30kw/Seat. However, the Acela needs this much power due to the high weight of the steel coaches and low seating capacity of the train. As a result, the maintenance cost per mile for the 220-mph electric train benchmarked only slightly lower than that for the 130-mph diesel of equivalent capacity; a cost of $14.08 per mile was assumed for the 220-mph electric train. The 79-mph conventional Amtrak train benchmarked at a higher cost of $15.43 due primarily to a lack of economies of scale associated with typical lighter density Amtrak corridors.

For this study:

- The intermediate $14.42 cost will be assumed for the 130-mph diesel options.
- A $14.08 cost per train mile will be used for a 250-seat, 220-mph electric train operating on a Greenfield.
- For trains of larger seating capacity than 250 riders, these costs are scaled in direct proportion to the train size.

These costs are summarized in Exhibit 8-4.

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[20] See: http://en.wikipedia.org/wiki/Automotrice_%C3%A0_grande_vitesse

8.2.2 TRAIN AND ENGINE CREW COSTS

The train operating crew incurs crew costs. Following Amtrak staffing policies, the operating crew would consist of an engineer, a conductor and an assistant conductor and is subject to federal Hours of Service regulations. Costs for the crew include salary, fringe benefits, training, overtime and additional pay for split shifts and high mileage runs. An overtime allowance is included as well as scheduled time-off, unscheduled absences and time required for operating, safety, and passenger handling training. Fringe benefits include health and welfare, FICA, and pensions. The cost of employee injury claims under FELA is also treated as a fringe benefit for this analysis. The overall fringe benefit rate was calculated as 55 percent. In addition, an allowance was built in for spare/reserve crews on the extra board.

Crew costs depend upon the level of train crew utilization, which is largely influenced by the structure of crew bases and any prior agreements on staffing locations. Train frequency strongly influences the amount of held-away-from-home-terminal time, which occurs if train crews have to stay overnight in a hotel away from their home base. Since a broad range of service frequencies and speeds have been evaluated here, a parametric approach was needed to develop a system average per train mile rate for crew costs. Such an average rate necessarily involves some approximation, but to avoid having to reconfigure a detailed crew-staffing plan whenever the train schedules change, an average rate is appropriate for the current feasibility level study. For this study:

- A value of $4.60 per train mile was used for all high-speed options since all of them are fairly fast and high frequency options that can afford a same-day round trip for most operating crews.
- 79-mph service would cost $6.59 per train-mile because of poor crew utilization in these low-frequency, slower scenarios. With trains operating less frequently there is less opportunity to return crews to their home base on the same day, leading to more split shifts and overnight layovers. However, these trains were not part of any options assessed in this study.
- For trains of larger seating capacity than 250 riders, these costs are scaled in direct proportion to the train size.

8.2.3 FUEL AND ENERGY

An average consumption rate of 1.94 gallons/mile was estimated for a 110-mph 250-seat train, based upon nominal usage rates of all three technologies considered in Phase 3 of the MWRRS Study. Assuming $3.91 a gallon for diesel fuel, this translates into a cost of $7.60 per train mile, more than quadrupling (407%) the cost of diesel fuel that was prevalent at the time of the earlier MWRRS study. During the same time period however, electricity costs did not rise nearly so much. For example, Virginia electric power costs rose only by 46%.

However, electric traction has an advantage over diesel since it can be powered from any energy source, not just petroleum-based fuel. Even taking typical peaking demands into account, electricity is typically cheaper than diesel fuel. As a result, the rapid rise of petroleum costs over the past twenty years has tipped the cost advantage towards electrification.

However, there is a large regional variation in electricity and peak usage rate structures. For example, electric power has in the past been more expensive than diesel traction in the northeastern United States. But the southeast enjoys lower average electricity rates than do northeastern states:[21] in 2010, for example, Virginia electric power for transportation averaged only 7.7¢ per kWH as compared to 11.9¢ per kWH in New Jersey.

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[21] See http://www.eia.gov/electricity/state/

More to the point, petroleum-based energy prices in the Pacific Northwest have been consistently ***higher*** than the US national average, while electricity costs have been consistently ***lower***.[22]

- At $3.448 a gallon, Seattle area consumers paid 13.4 percent more than the $3.041 national average in May 2011. A year earlier, consumers in the Seattle area paid 22.0 percent more than the national average for a gallon of gasoline. The local price of a gallon of gasoline has been within 22.0 percent of the national average in the month of May during the past five years.
- The 11.6 cents per kWh Seattle households paid for electricity in May 2021 was 17.1 percent ***less*** than the nationwide average of 14.0 cents per kWh. Last May, electricity costs were 14.9 percent ***lower*** in Seattle compared to the nation. In each of the past five years during the month of May, prices paid by Seattle area consumers for electricity were ***less*** than the U.S. average by at least 14.9 percent.

The actual price paid is also driven by the peak hour surcharges that can more than double a railroad's electric energy bill. However, by employing power smoothing techniques such as onboard and wayside energy storage, as well as by regenerating electric power while braking, the rail operator might reduce the level of fluctuation in its energy usage, so it pays closer to the base average kilowatt-hour power generation charge. Given the high cost associated with electric power purchases, the issue of demand smoothing is an issue that should receive careful attention in the train equipment procurement, as well as in the design of the electric traction system. The structure of peak usage charges should be negotiated with the electric utilities to ensure that the operator can purchase the power it needs at the lowest possible cost. However, it should be clear that relative energy costs in the Pacific Northwest strongly favor the use of electrification rather than petroleum-based power for rail operations.

As shown in Exhibit 8-4 and including the Peak Usage charge, the comparable electric cost for an Acela 150-mph locomotive-hauled electric train is just $2.62 per train mile as compared to $7.60 for the diesel 130-mph train. Also, the 220-mph electric train on a greenfield needs to accelerate and brake less than a train operating over an existing curvy rail or highway alignments would. This results in a more uniform electric load which should lead to a more favorable utility rate negotiation.

On the other hand, the 220-mph electric train does go faster. This speed increases its energy consumption. As a result, all diesel options assume a 2021 fuel cost of $7.60 per train mile, and all electric options assume an electric cost of $2.63 per train mile for a 250-seat train, all scaled proportionately to train size. These energy costs are then adjusted each year in line with the relevant Energy Information Administration forecasts.

8.2.4 ONBOARD SERVICES

Onboard service (OBS) costs are those expenses for providing food service onboard the trains. OBS adds costs in three different areas: equipment, labor and cost of goods sold. Equipment capital and operating cost is built into the cost of the trains and is not attributed to food catering specifically. Small 200-seat trains cannot afford a dedicated dining or bistro car. Instead, an OBS employee or food service vendor would move through the train with a trolley cart, offering food and beverages for sale to the passengers.

The goal of OBS franchising should be to ensure a reasonable profit for the provider of onboard services, while maintaining a reasonable and affordable price structure for passengers. In previous studies, it has been found that the key to attaining OBS profitability is selling enough products to recover the train mile related labor costs. For example, if small 200-seat trains were used, given the assumed OBS cost structure, even with a trolley cart service the OBS operator will be challenged to attain profitability. However, the expanded

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[22] See https://www.bls.gov/regions/west/news-release/averageenergyprices_seattle.htm retrieved on July 12, 2021.

customer base on larger 300-seat trains can provide a slight positive operating margin for OBS service. 400-seat or larger electric trains should usually provide a comfortable positive profit margin for the OBS operator.

The cost of goods sold is estimated as 50 percent of OBS revenue, based on Amtrak's route profitability reports. Labor costs, including costs for commissary support and OBS supervision, have been estimated at:

- Existing rail 79-mph scenarios would cost $3.66 per train-mile because of poor crew utilization in these very low-frequency scenarios. With trains operating less frequently there is less opportunity to return crews to their home base on the same day, leading to more split shifts and overnight layovers. However, these trains were not part of any options assessed in this study.
- All the Alternatives 1-3 use $2.41 per train mile for OBS labor, reflecting operating efficiencies related both to higher speeds and more frequent trains, since all three of the proposed options are fast enough to largely reduce the need for away-from-home layovers.
- These costs are generally consistent with Amtrak's level of wages and staffing approach for conventional bistro car services. However, this Business Plan recommends that an experienced food service vendor provide food services and use a trolley cart approach. A key technical requirement for providing trolley service is to ensure the doors and vestibules between cars are designed to allow a cart to easily pass through. Since trolley service is a standard feature on most European railways, most European rolling stock is designed to accommodate the carts. Although convenient passageways often have not been provided on U.S. equipment, the ability to support trolley carts is an important equipment design requirement for the planned service.

8.2.5 INSURANCE COSTS

Liability costs were estimated at 1.4¢ per passenger-mile, the same rate that was assumed in the earlier MWRRS study brought to 2021. Federal Employees Liability Act (FELA) costs are not included in this category but are applied as an overhead to labor costs.

The Amtrak Reform and Accountability Act of 1997 (§161) originally provided for a limit of $200 million on passenger liability claims. Amtrak carries that level of excess liability insurance, which allows Amtrak to fully indemnify the freight railroads in the event of a rail accident. This insurance protection has been a key element in Amtrak's ability to secure freight railroad cooperation. In addition, freight railroads perceive that the full faith and credit of the United States Government is behind Amtrak, while this may not be true of other potential passenger operators. However, a General Accounting Office (GAO) review[23] has concluded that this liability cap applies to commuter railroads as well as to Amtrak. This was actually tested in 2008 following Metrolink's Chatsworth accident, when the $200 million cap was applied. As a result, this liability cap would also likely apply to potential CHSR franchisees, although in 2015 following the Frankford Junction incident, the FAST act raised this ceiling to $295 million. Since this limitation would seem to be available to potential franchisees, it would be much easier for any operator to obtain insurance that could fully indemnify a freight railroad at a reasonable cost.

8.3 FIXED ROUTE COSTS

This cost category includes those costs that, while largely independent of the number of train-miles operated, can still be directly associated to the operation of specific routes. It includes such costs as track maintenance, which varies by train technology, and station operations.

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[23] See: http://www.gao.gov/highlights/d04240high.pdf

8.3.1 TRACK AND RIGHT-OF-WAY COSTS

Currently, it is industry practice for passenger train operators providing service on freight-owned rights-of-way to pay for track access, dispatching and track maintenance. The following cost components are included within the Track and Right-of-Way category:

- **Track Maintenance Costs**. Costs for track maintenance were estimated based on Zeta-Tech's January 2004 draft technical monograph Estimating Maintenance Costs for Mixed High-Speed Passenger and Freight Rail Corridors.[24] Zeta-Tech costs have been adjusted for inflation to $2021.
- **Dispatching Costs and Out-of-Pocket Reimbursement.** Passenger service must also either reimburse a freight railroad's added costs for dispatching its line, providing employee efficiency tests and for performing other services on behalf of the passenger operator, or provide these services itself. As a result, costs for train dispatching and control are incurred on both dedicated as well as shared tracks and are now shown under a separate "Operations and Dispatch" cost category.
- **Costs for Access to Track and Right-of-Way**. Access fees, particularly train mile fees incurred as an operating expense, are specifically excluded from this calculation. It is assumed that freight railroads will be compensated up-front, on a one-time basis for access to any necessary right-of-way, so that ongoing operations would not be burdened by this expense.

Exhibit 8-2 shows the conceptual relationship between track maintenance cost and total tonnage that was calibrated from the 2004 Zeta-Tech study. It shows a strong relationship between tonnage, FRA track class (4 through 6, corresponding to a 79-mph to 110-mph track speed) and maintenance cost. At low tonnage, the cost differential for maintaining a higher track class is not very large, but as tonnage grows, so too does the added cost. For shared track, if freight needs only Class 4 track, the passenger service would have to pay the difference, called the "maintenance increment", which for a 25 MGT line would come to about $22,000 per mile per year (in $2002), including capital costs[25]. The required payment to reimburse a freight railroad for its added cost would be less for lower freight tonnage, more for higher freight tonnage.

Exhibit 8-2 also breaks out the operating versus total track maintenance cost, showing that capital (the difference between total and operating cost) is a significant share of the total cost. For track maintenance:

- ***Operating costs*** cover expenses needed to keep existing assets in service and include both surfacing and a regimen of facility inspections.
- ***Capital costs*** are those related to the physical replacement of the assets that wear out. They include expenditures such as for replacement of rail and ties, but these costs are not incurred until many years after construction. In addition, the regular maintenance of a smooth surface by reducing dynamic loads actually helps extend the life of the underlying rail and tie assets.

Exhibit 8-2 shows that the cost of shared track depends strongly on the level of freight tonnage, since passenger trains are relatively lightweight and do not contribute much to the total tonnage. As a result, the same cost functions shown in Exhibit 8-2 can also be used for costing dedicated passenger track. With dedicated track, the passenger system is assumed to cover the entire operating cost for maintaining its own

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[24] Zeta-Tech, a subsidiary of Harsco (a supplier of track maintenance machinery) is a rail consulting firm who specializes in development of track maintenance strategies, costs, and related engineering economics. See a summary of this report at http://onlinepubs.trb.org/onlinepubs/trnews/trnews255rpo.pdf. The full report is available upon request from the FRA.

[25] Calculated as $38,446 - $31,887 + ($2.440 – $1.810) * 25 = $22,309 per year. Note that the yellow highlighted cells in the table correspond to the three lines shown on the graph.

track. Because passenger train tonnage is very low however, it can be seen that the cost differential between Class 4, 5 and 6 track is very small.

On top of the basic track maintenance costs, an allowance of 39.5¢ per train-mile (in $2002) was added by Zeta-Tech for freight railroad dispatching and out-of-pocket costs. Inflated to $2021 this dispatching and out-of-pocket cost now comes to 50.8¢ per train mile, which is applied both to dedicated and shared tracks. Keep in mind that this cost, like other train-mile driven costs is scaled to train size in the costing spreadsheet. This cost is now separated from track maintenance under the “Operations and Dispatch” category.

Adjusting Zeta-Tech’s $2002 costs shown in Exhibit 8-2 up to $2021:

- The assumed Operating maintenance cost per track mile. The cost for maintaining dedicated Class 4 track is about $27,924 per year; the cost for catenary maintenance adds $26,859 in operating cost per track mile to the cost of the electrified options, bringing the total to $54,783.
- In addition, the Capital cost per track-mile for dedicated Class 6 track is $30,514. There is no separate capital cost replacement for catenary, since the $26,859 per track-mile estimate accounts for both operating and normalized capital power system maintenance.

Reducing axle loads is a common design practice for 220-250-mph high-speed equipment. This helps keep guideway maintenance costs low and in line with the above assumed costs. French experience[26] showed that the maintenance cost of a dedicated high-speed track was actually lower (just 55%) of the cost of a conventional track with equivalent traffic. According to the French railways, the justification for such a difference was due basically to three causes: the uniformity of TGV rolling stock, the reduced axle loading (17 metric tons) and the strict quality conditions imposed during the construction of the line. Table 6 of this same report showed that the mixture of traffic operated over a line influences track maintenance cost much more than does the top speed. This finding is consistent with United States experience. As a result, considering the maintenance of a 220-250-mph dedicated track costs as equivalent to that of a Class 6 line shared with freight trains is, if anything, conservative.

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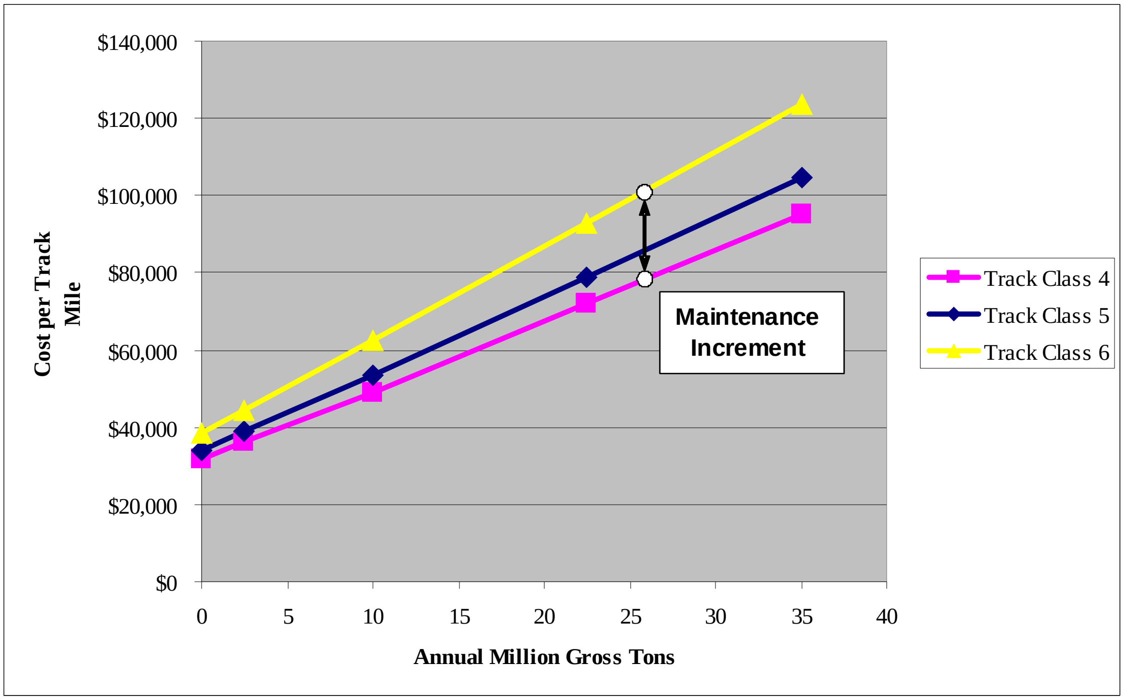
[26] See Maintenance Costs of High-Speed Lines in Europe: State of the Art, Transportation Research Record, Railways 2008: http://trb.metapress.com/content/gg76453p458327qr/?genre=article&id=doi%3a10.3141%2f2043-02

Exhibit 8-2: Zeta-Tech 2004 Calibrated Track Class vs. Tonnage Total Cost Function (“Middle Line” Case, in $2002)



TOTAL	LOW		MIDDLE		HIGH	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
Class 3[1]	$17,880	$0.917	$21,683	$1.231	$25,487	$1.548
Class 4	$26,294	$1.348	$31,887	$1.810	$37,481	$2.277
Class 5	$28,072	$1.509	$33,937	$2.020	$39,801	$2.530
Class 6	$31,714	$1.837	$38,446	$2.440	$45,178	$3.035

OPER	LOW		MIDDLE		HIGH	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
Class 3	$6,558	$0.579	$8,216	$0.726	$9,873	$0.872
Class 4	$9,644	$0.852	$12,082	$1.067	$14,519	$1.283
Class 5	$11,283	$0.997	$14,135	$1.249	$16,987	$1.501
Class 6	$14,640	$1.293	$18,371	$1.623	$22,101	$1.953

While operating costs are needed every year, capital maintenance costs for dedicated tracks are gradually introduced using a table of ramp-up factors provided by Zeta-Tech, see Exhibit 8-3. A fully normalized capital maintenance level is not reached until 20 years after completion of the rail construction program. This is used for calculating “Cyclic Maintenance” in the Benefit Cost Analysis. But because Cyclic Maintenance is not an Operating Cost under Generally Accepted Accounting Principles (GAAP), it is not normally included in the Operating Ratio calculation.

Exhibit 8-3: Capital Cost Ramp-Up Following Upgrade of a Rail Line

Year	% of Capital Maintenance	Year	% of Capital Maintenance
0	0%	11	50%
1	0%	12	50%
2	0%	13	50%
3	0%	14	50%
4	20%	15	75%
5	20%	16	75%
6	20%	17	75%
7	35%	18	75%
8	35%	19	75%
9	35%	20	100%
10	50%		

8.3.2 STATION OPERATIONS

A simplified fare structure, heavy reliance upon electronic ticketing and avoidance of a reservation system will minimize station personnel requirements. Station costs include personnel, ticket machines and station operating expenses. Station Operations assume the following:

- Staffed stations will be assumed at all stations. All stations will be assumed open for two shifts. The cost for the staffed stations includes eight positions at each new location, costing $644,640 per year, as well as the cost of utilities, ticket machines, cleaning, and basic facility maintenance.
- The major stations at Portland and Seattle are assumed to have double the operating cost of the smaller intermediate stations. This brings the overall total cost for stations to $6,446,400 per year

8.3.3 SYSTEM OVERHEAD COSTS

The category of System Overhead largely consists of Service Administration or management overheads, covering such needs as the corporate procurement, human resources, accounting, finance, and information technology functions as well as call center administration. A stand-alone administrative organization appropriate for the operation of a corridor system was developed for the MWRRS and later refined for the Ohio Hub studies. This organizational structure, which was developed with Amtrak's input and had a fixed cost of $8.9 million plus $1.43 per train-mile (in $2002) for added staff requirements as the system grew. Inflated to $2021, this became $11.45 million plus $1.84 per train mile. However, the Sales and Marketing category also has a substantial fixed cost component for advertising and call center expense, adding another $2.9 million per year fixed cost, plus variable call center expenses of 70.9¢ per rider.[27] Finally, credit card (1.8% of revenue) and travel agency commissions (1%) are all variable.

Therefore, the overall financial model for a Stand-alone organization therefore has $14.35 million ($11.45 + $2.9 million) annually in fixed cost for administrative, sales and marketing expenses. In addition, the system operator was allowed a 10 percent markup on certain direct costs as an allowance for operator profit.

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[27] In the MWRRS cost model, call center costs were built up directly from ridership, assuming 40 percent of all riders call for information, and that the average information call will take 5 minutes for each round trip. Call center costs, therefore, are variable by rider and not by train-mile. Assuming some flexibility for assigning personnel to accommodate peaks in volume and a 20 percent staffing contingency, variable costs came to 57¢ per rider. These were inflated to 70.9¢ per rider in $2020.

8.4 RESULTS/TABLES

Exhibit 8-4 summarizes the Unit Cost factors used for developing Operating costs for the Cascadia corridor. Following the original MWRRS methodology, those costs marked with an asterisk (*) are subject to the 10% Operator Profit markup. Train-miles driven costs are for a 250-seat train scaled to the required train size.

Exhibit 8-4: Cascadia Unit Costs by Alternative

Unit Cost	Driver	Alternative 1 110-mph Diesel	Alternative 2 Electric Low Investment	Alternative 3 Electric High Investment
Equipment Maintenance	Train-Miles	$14.42	$14.08	$14.08
Train Crew *	Train-Miles	$4.60	$4.60	$4.60
Fuel or Energy *	Train-Miles	$7.60	$2.62	$2.62
On Board Services (Labor) *	Train-Miles	$2.41	$2.41	$2.41
On Board Services (Goods Sold) *	% of OBS Revenue	50%	50%	50%
Insurance	Passenger-Mile	1.4¢	1.4¢	1.4¢
Track (Dedicated, no Electrification)	Dedicated Track Miles	$27,924 plus Cyclic Capital	N/A	N/A
Track and Electrification (Dedicated)	Dedicated Track Miles	N/A	$54,783 plus Cyclic Capital	$54,783 plus Cyclic Capital
Operations and Dispatch *	Train-Miles	50.8¢	50.8¢	50.8¢
Stations * - Staffed	Fixed	$6,446,400	$6,446,400	$6,446,400
Administration and Management (Fixed) *	Fixed	$14.35 mill	$14.35 mill	$14.35 mill
Administration and Management (Variable Train-Mile) *	Train-Miles	$1.84	$1.84	$1.84
Administration and Management (Call Center: Variable Riders) *	Riders	70.9¢	70.9¢	70.9¢
Credit Card and Travel Agency Commissions *	Percent of Revenue	2.8%	2.8%	2.8%
Operator Profit Markup	Selected (*) Costs	10%	10%	10%

Exhibit 8-5 summarizes the Unit Cost breakdown for the Diesel Alternative 1 in 2030. Equipment maintenance, followed by the costs of Fuel and Management overhead are the three largest cost drivers collectively comprising 55% of the total operating cost. Fuel costs reflect the relatively high costs associated with diesel propulsion, and the high management overheads show that the scale of operation is not large enough to spread administrative costs over a large base. After this, On Board Services and Train Crews are the next largest costs. 8% of the cost is for Infrastructure maintenance. Fuel is 14% of total operating cost and is second largest item.

Exhibit 8-5: Cascadia Alternative 1 2030 Cost Breakdown

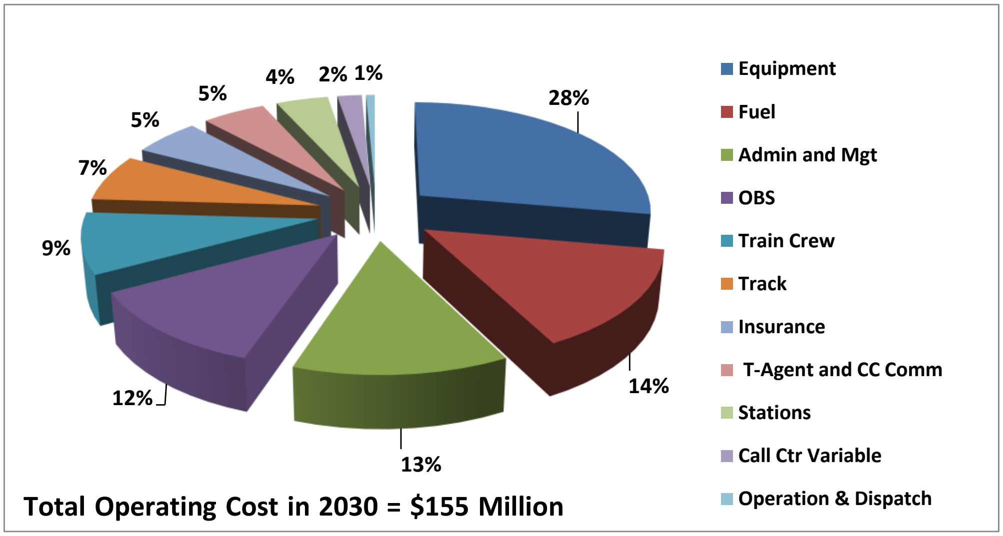


Exhibit 8-6 summarizes the Unit Cost breakdown for the Low Investment Alternative 2. It shows that Equipment maintenance, followed by the cost of Onboard Services and Train Crews are the three largest cost drivers collectively comprising 57% of the total operating cost. 9% of the cost is for Infrastructure maintenance. Electricity is 5% of total operating cost and is 8th largest item.

Exhibit 8-6: Cascadia Alternative 2 2030 Cost Breakdown

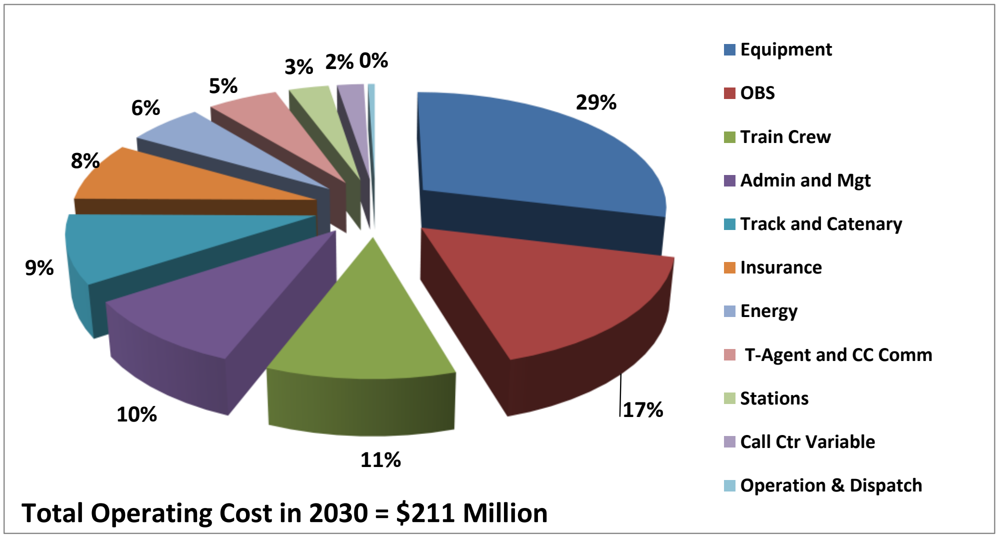


Exhibit 8-7 summarizes the Unit Cost breakdown for the ultra high-speed Alternative 3. It shows that Equipment maintenance, followed by the cost of Onboard Services and Train Crews are the three largest cost drivers collectively comprising 57% of the total operating cost. 9% of the cost is for Infrastructure maintenance. Electricity is 5% of total operating cost and is 8th largest item.

Exhibit 8-7: Cascadia Alternative 3 2030 Cost Breakdown

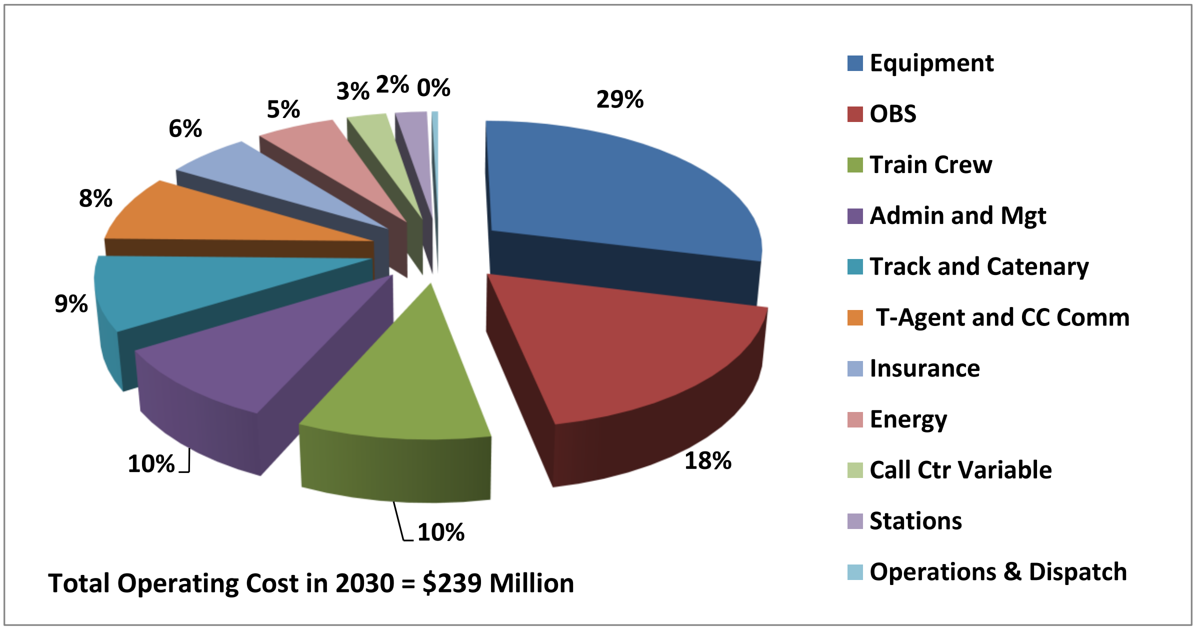


Exhibit 8-8 shows the economies of scale relationship that is associated with the operation of more frequent high-speed trains, and also the efficiencies gained by the use of electric rather than diesel power for operating the trains. This shows that the average operating cost per train mile declines from $110 per train mile for the diesel option to just $92 per train mile in ultra high-speed Alternative 3.

Exhibit 8-8: CHSR 2030 Average Cost per Train Mile

Alternative	Total Annual Operating Cost	Daily Round Trips	Average Cost per Train Mile
Alternative 1	$155 million/year	12 RT	$110 per train mile
Alternative 2	$211 million/year	18 RT	$100 per train mile
Alternative 3	$239 million/year	22 RT	$92 per train miles

9. PUBLIC BENEFITS ANALYSIS

This chapter focuses discussion on the Financial and Economic Analysis used to assess the viability of the CHSR Alternatives according to USDOT FRA criteria. It defines the criteria and describes the process used to assess the financial and economic benefits of the system. This chapter also provides both the financial and economic results for each option.

9.1 ASSESSMENT CRITERIA AND PRINCIPLES

This analysis uses the same criteria (updated to include INFRA Grant criteria) and structure as the 1997 FRA Commercial Feasibility Study. This study set out criteria for establishing a public/private partnership between the Federal government, State and local communities, and the private sector for intercity rail projects. The study described two conditions that were considered essential for receiving Federal funding support for proposed intercity passenger rail projects:

- An operating cost ratio of at least 1.0, defined as a pre-condition for an effective public/private partnership, so that once the system has been constructed, a private operator could operate the system on a day-to-day basis without requiring an operating subsidy, and
- A benefit/cost ratio greater than 1.0, to ensure that the project makes an overall positive contribution to the economy, at both the regional and national levels.

The Commercial Feasibility Study makes it clear that “federal consideration of specific High-Speed Ground Transportation project proposals could apply additional criteria that could differ from, and be much more stringent than, this report’s threshold indicators for partnership potential.”

Operating ratios are usually expressed on a year-by-year basis, but they can also be expressed as a Present Value of Revenue / Present Value of Operating Cost over the lifetime of a project.

Benefit Cost ratios are usually expressed as a Present Value of Total Benefit / Present Value of Total Cost over the lifetime of a project.

At a feasibility level of study, analysis is based on a number of assumptions that are needed to carry out the analysis. These assumptions include such factors as: rate of socioeconomic growth, rate of demographic growth, rate of energy price increase and the capital cash flows in accordance with a multi-year, implementation plan. Once more detailed assessments are made and more specific information on the rate of ridership and revenue growth and a system implementation plan detailing the capital cash flows become available, then that information can be included to further refine the initial estimates of the Financial Return and Benefit Cost ratio.

This chapter describes the process by which the alternatives were evaluated and how this analysis led to the identification of a number of feasible options based on the economic and financial criteria adopted.

9.2 FINANCIAL AND ECONOMIC OBJECTIVES

For each alternative being evaluated, measures of financial and economic efficiency were calculated. These measures were determined from assessments integrating the forecasted capital, operating and maintenance costs with the forecasted revenue projections over the lifetime of the project. Specifically, the analysis was based on the following components:

- Operating and implementation plans for the alternative passenger rail service options
- Cost estimates for operations, infrastructure, and acquisition of rolling stock

- Ridership and revenue estimates based on projected travel demand. These forecasts include assumptions regarding fare levels and oil prices, highway congestion and the responsiveness of the air industry to the introduction of the Diesel 110-mph and Electric 220-mph Alternatives.
- Cash flow analysis that includes statements of revenues and expenses for each alternative.

Two measures, net present value (NPV) and Benefit Cost ratio were used to evaluate the economic returns of the system. Similar measures, net present value (NPV) and Operating ratio, were used to evaluate the financial returns and the potential for franchising the operations.

Both measures require the development of a project's year-by-year financial and economic returns, which are then discounted to the base year to estimate present values (PV) over the lifetime of the project. For this analysis, a 30-year project life from 2030 to 2060 was assumed, with a seven-year implementation period from 2023-2029. Revenues and cost cash flows were discounted using two discount rates: 3 percent and 7 percent. The 3 percent discount rate reflects the real cost of money in the market as reflected by the long-term bond markets, and the 7 percent discount rate reflects the Federal government's desire to establish a benchmark comparison by discounting long term benefits at a greater rate than the market for public securities.

The operating ratios reported here in this chapter, follow a commercial criteria definition; but are different from the commercial operating ratio calculations that are typically presented by freight railroads and intercity bus companies. For the current analysis, the selected feasibility criteria were as follows:

- The Operating Ratio as calculated here includes direct operating costs only. The operating ratio calculations presented here do not include capital costs, depreciation, or interest. The costs used are incremental costs.
- The Operating Ratio presented here is defined as Revenues/Costs. It should be noted that freight railroads and intercity bus companies typically define it as the reciprocal Costs/Revenues.

As defined by this analysis, a positive operating ratio does not imply that a passenger service can attain full financial profitability by covering its capital costs, but it does allow the operation to be franchised and operated by the private sector. The definition puts passenger rail on the same basis as other passenger transportation modes, such as intercity bus and air, where the private sector operates the system but does not build or own the infrastructure it uses. It does, however, pay access fees to the freight railroads where they own the track. In the case of passenger rail, these would include track access costs. All calculations are performed using the standard financial formula, as follows:

Financial Measure:

$$\text{Operating Ratio} = \frac{\text{Financial Revenues}}{\text{Operating Costs}}$$

Economic Measures:

$$\text{Net Present Value} = \text{Present Value of Benefit} - \text{Present Values of Costs}$$

$$\text{Benefit Cost Ratio} = \frac{\text{Present Value of Revenues}}{\text{Present Value of Costs}}$$

Present Value is defined as:

$$PV = \sum_t \frac{C_t}{(1+r)^t}$$

Where:

PV = Present value of all future cash flows

C_t = Cash flow for period t

r = Discount rate reflecting the opportunity cost of money

t = Time

In terms of Economic Benefits, a positive NPV and Benefit Cost Ratio imply that the project makes a positive contribution to the economy. The 3 percent discount rate reflects the real cost of money in the market as reflected by the long-term bond markets, and the 7 percent discount rate reflects the Federal government's desire to establish a benchmark comparison by discounting long term benefits at a greater rate than the market for public securities. Consistent with standard practice, Benefit Cost ratios are calculated from the perspective of the overall society without regard to who owns particular assets, receives specific benefits, or incurs particular costs.

9.2.1 KEY ASSUMPTIONS

The analysis projects travel demand, operating revenues and operating and maintenance costs for all years from 2030 through 2060. The financial analysis has been conducted in real terms using constant 2021 dollars. Accordingly, no inflation factor has been included and a real discounting rate of 3 to 7 percent was used. Revenues and operating costs have also been projected in constant dollars over the time frame of the financial analysis. A summary of the key efficiency measure inputs are presented below.

9.2.1.1 RIDERSHIP AND REVENUE FORECASTS

Ridership and revenue forecasts were originally prepared for 2030, 2040 and 2050. Revenues in intervening years were projected based on interpolations, reflecting projected annual growth in ridership. Revenues included not only passenger fares, but also onboard service revenues. Because of this, the revenues are slightly higher than those that were forecasted in Chapter 4.

9.2.1.2 CAPITAL COSTS

Capital costs include rolling stock, track, freight railroad right-of-way purchase or easement fees, bridges, fencing, signaling, grade crossings, maintenance facilities and station improvements. The capital cost projections are based on year-by-year projections of each cost element and include all of the capital costs, plus some selected elements of additional costs as needed to support year-by-year capacity expansion of the system. A year-by-year implementation plan was developed (as shown in Exhibit 7-5) which detailed the Capital cash flows and funding requirements. Using this information, the Benefit Cost calculations were able to be assessed.

9.2.1.3 OPERATING EXPENSES

Major operating and maintenance expenses include equipment maintenance, track and right-of-way maintenance, administration, fuel and energy, train crew and other relevant expenses. Operating expenses were estimated in 2021 constant dollars so that they would remain comparable to revenues. However, these costs do reflect the year-by-year increase in expense that is needed to handle the forecasted ridership growth, in terms of not only directly variable expenses such as credit card commissions, but also the need to add train capacity and operate either larger trains, or more train-miles every year in order to accommodate anticipated ridership growth.

Operating costs are included as a cost, whereas system revenues are included as a benefit in the discounting calculation over the life of the system. In this way they directly offset one another in the Net Present Value calculation and are also reflected in the Benefit Cost calculation. It can be seen that a system that requires an operating subsidy, e.g., where costs exceed revenues, will tend also to reflect this in the Benefit Cost ratio. This is why slow speed options such as conventional Amtrak services often fail on both the Operating Ratio and Benefit Cost ratio criteria.

9.2.2 ASSESSMENT AND ESTIMATE OF ECONOMIC BENEFITS

A key requirement is the need for public capital investment to be supported by the economic benefit that will be generated by the rail system. Calculation of the economic benefit includes both consumer surplus and revenues generated by the system and environmental and external mode benefits, while costs include both capital and operating costs. Similar to the way most highway projects are justified, the primary justification for intercity rail projects relies on time savings multiplied by the user’s value of time. The consumer surplus term equates to the passenger user’s value of time savings as being the benefit an individual receives over and above the fare charged for using the system.

Calculation of benefit cost ratios requires a detailed, year-by-year forecast to support the calculation of Net Present Values for all the costs and benefits associated with the project. Specifically, a year-by-year estimate of system revenues, consumer surplus, operating costs, capital costs, and external benefits is needed to develop the Benefit Cost Analysis.

In line with Federal, State and Municipal projections, the rate of population growth, the increasing price of oil, and the increasing congestion on highways (e.g., I-5), means that there is a gradual increase in rail users over the life of the project. This has several consequences for the correct calculation of Benefit/Cost ratios for the project:

- It would be inappropriate to increase the ridership and revenue of the system in future years, without also reflecting the added operating and capital costs that will be needed to accommodate this growth in traffic.
- The result is a steady improvement in the system financial performance that reflects improved economies of scale over the 30-year life of the system. While the Benefit Cost ratios calculated do take this forecast growth into account, they also add the additional capital cost for providing the capacity needed to handle it. The economic benefits to be used in the analysis include two main categories:
    - User Benefits (Consumer Surplus)
    - Other Mode and Resource Benefits

9.2.2.1 USER BENEFITS

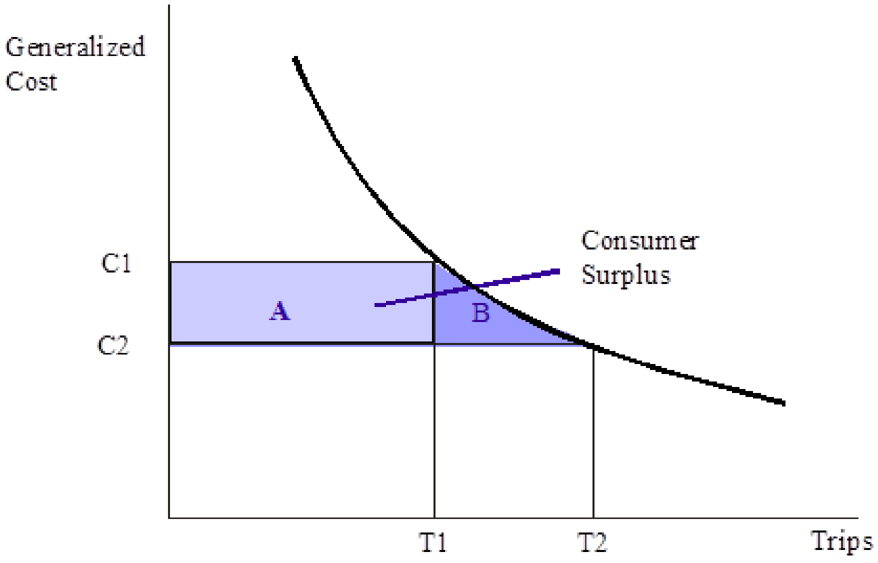
The analysis of user benefits for this study is based on the measurement of Generalized Cost of Travel, which includes both time and money. Time is converted into money by the use of Values of Time. The Values of Time (VOT) used in this study were derived from stated preference surveys conducted in previous study phases of work and used in the *COMPASS™* Multimodal Demand Model for the ridership and revenue forecasts. These

VOTs are consistent with previous academic and empirical research and other transportation studies conducted by TEMS.

Benefits to users of the rail system are measured by the sum of system revenues and consumer surplus. Consumer surplus is used to measure the demand side impact of a transportation improvement on users of the service. It is defined as the additional benefit consumers (users of the service) receive from the purchase of a commodity or service (travel), above the price actually paid for that commodity or service. Consumer surpluses exist because there are always consumers who are willing to pay a higher price than that actually charged for the commodity or service, i.e., these consumers receive more benefit than is reflected by the system revenues alone. Revenues are included in the measure of consumer surplus as a proxy measure for the consumer surplus forgone because the price of rail service is not zero. This is an equity decision made by the USDOT to compensate for the fact that highway users pay zero for use of the road system (the only exception being the use of toll roads). The benefits apply to existing rail travelers as well as new travelers who are induced (those who previously did not make a trip) or diverted (those who previously used a different mode) to the new passenger rail system.

The *RENTS™* financial and economic analysis estimates passenger travel benefits (consumer surplus) by calculating the increase in regional mobility, traffic diverted to rail, and the reduction in travel cost measured in terms of generalized cost for existing rail users. The term generalized cost refers to the combination of time and fares paid by users to make a trip. A reduction in generalized cost generates an increase in the passenger rail user benefits. A transportation improvement that leads to improved mobility reduces the generalized cost of travel, which in turn leads to an increase in consumer surplus. Exhibit 9-1 presents a typical demand curve in which Area A represents the increase in consumer surplus resulting from cost savings for existing rail users and Area B represents the consumer surplus resulting from induced traffic and trips diverted to rail.

Exhibit 9-1: Consumer Surplus Concept



The formula for consumer surplus is as follows –

Consumer Surplus = $(C_1 - C_2)*T1 + ((C_1 - C_2)*(T_2 - T_1))/2$

Where:

C_1 = Generalized Cost users incur before the implementation of the system

C_2 = Generalized Cost users incur after the implementation of the system

T_1 = Number of trips before operation of the system

T_2 = Number of trips during operation of the system

The passenger rail fares used in this analysis are the average optimal fares derived from the revenue-maximization analysis that was performed for each alternative. User benefits incorporate the measured consumer surplus, as well as the system revenues, since these are benefits are merely transferred from the rail user to the rail operator.

9.2.2.2 OTHER MODE BENEFITS

OTHER MODE AND RESOURCE BENEFITS: In addition to rail-user benefits, travelers using auto or air will also benefit from the rail investment, since the system will contribute to highway congestion relief and reduce travel times for users of these other modes. For purposes of this analysis, these benefits were measured by identifying the estimated number of auto passenger trips diverted to rail and multiplying each by the updated monetary values derived from previous stated preference studies updated to 2021.

HIGHWAY CONGESTION: The highway congestion delay savings is the time savings to the remaining highway users that results from diversion of auto users to the rail mode. To estimate travel time increase within the corridor, historical highway traffic volumes were obtained from the State DOTs and local planning agencies. The average annual travel time growth in the corridor was estimated with the historical highway traffic volume data and the Bureau of Public Roads (BPR) function that can be used to calculate travel time growth with increased traffic volumes.

THE AIRPORT CONGESTION DELAY SAVINGS: The Airport Congestion Delay Savings were based 1997 FRA Commercial Feasibility Study and updated to 2021 value. The Airport Congestion Delay Savings includes the airport operation delay saving and air passenger delay saving.

AUTO OPERATING COST (NON-BUSINESS): Vehicle operating cost savings for non-business travelers have been included in the current analysis as an additional resource benefit. This reflects the fact that social/leisure travelers do not accurately value the full cost of driving when making trips. As a result, the consumer surplus calculation for commuters, social, leisure and tourist travelers has not fully reflected the real cost of operations of an automobile, but only the cost of gas. The difference between the cost of gas and the full cost of driving reflects a real savings that should be included in a Benefit Cost analysis.

EMISSIONS: The diversion of travelers to rail from the auto mode generates emissions savings. The calculated emissions savings are based on changes in energy use with and without the proposed rail service. This methodology takes into account the region of the country, air quality regulation compliance of the counties served by the proposed rail service, the projection year, and the modes of travel used for access/egress as well as the line-haul portion of the trip. Highway Reduced Emissions were estimated from the vehicle miles traveled (VMT) and flight reductions derived from the ridership model. The assumption is that a reduction in VMT or flights is directly proportional to the reduction in emissions. The pollutant values were taken from the latest TIGER III Grant Benefit-Cost Analysis (BCA) Resource Guide.[28]

PUBLIC SAFETY BENEFITS: Public Safety is calculated from the diverted Vehicle-Miles times the NHTSA[29] fatality and injury rate per Vehicle mile and then times the values of fatality and injury from the latest TIGER III Grant

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[28] http://www.dot.gov/sites/dot.dev/files/docs/TIGER_BCA_RESOURCE_GUIDE.pdf

[29] http://www.nhtsa.gov/

Benefit-Cost Analysis (BCA) Resource Guide.[28] This was calculated for 2030, 2040 and 2050 then interpolated or extrapolated for all other years.

9.3 FINANCIAL RESULTS

A financial evaluation was completed for the three CHSR alternatives. The Financial Analysis methodology followed typical financial cash flow analysis and USDOT-INFRA Grant guidelines, as well as OMB discount procedures for the economic analysis. There are two key operating financial performance factors for the system, which are the key drivers of the financial evaluation:

- **System Revenues:** These include the fare box revenues and revenues from onboard sales. Revenues were derived from the Ridership and Revenue Analysis.
- **Operating Costs:** These are the operating and maintenance costs associated with running the train schedules and include onboard service costs. The operating costs for the system were developed using the methodology.

The **Operating Surplus**, which is defined as Revenues minus Operating Cost, is a critical factor in the overall business case as it determines the ability to franchise the operation.

- **If the operating surplus is positive**, the system will not require any operating subsidy, and it will even be able to make a contribution towards its own Capital cost, as the Northeast Corridor does today. In addition, because the system is generating a positive cash flow, a Public/Private Partnership or other innovative financing methods can be used to construct and operate the system. This absolves the local entity of any need for providing an operating subsidy but more than this, it is not uncommon for the operating cash flow to be sufficient to cover the local match requirement as well.
- **If the operating surplus is negative**, the system will not only require a grant of capital to build the system, but in addition it will also require an ongoing operating subsidy. An operating subsidy not only prevents the project from being a Public/Private Partnership, but casts doubt on the efficiency of the system and the reason for the project. In addition, a subsidy will reduce the economic performance of the system as it will actually offset part of the economic benefits of the system (e.g., Consumer Surplus, Environmental Benefits). This will depress the Benefit Cost ratio. If the subsidy is not too great and the capital cost is not too high, in some cases it may still be possible to maintain a positive Benefit Cost ratio. But the larger the subsidy and the higher the capital cost, the harder it is to show a positive Benefit Cost ratio. It is not uncommon for passenger rail systems that operate slower than 100-mph to fail both FRA's Operating Ratio and Benefit Cost criteria.

9.3.1 OPERATING RATIOS

Exhibit 9-2 shows the 2040 revenue, operating cost, and operating ratio for all three of the CHSR alternatives. All three Alternatives have a positive operating ratio, with the operating ratio and available free cash flow from operations rising as speeds go up.

The results of the Financial Analysis show that any of the three alternatives could be franchisable with a positive cash flow that is much greater than the system operating costs.

Exhibit 9-2: Year 2040 Revenues and Operating Costs for Cascadia Alternatives 1-3

Year 2040	Alternative 1 110-mph Diesel	Alternative 2 Electric Low Infrastructure	Alternative 3 Electric High Infrastructure
REVENUES (Millions of 2021 Dollars)			
System Passenger Revenues	$308.25	$682.85	$882.05
OBS	$24.66	$54.63	$70.56
EXP Parcel NET	$25.35	$55.41	$70.62
TOTAL REVENUES	$358.26	$792.88	$1,023.23
COSTS (Millions of 2020 Dollars)			
Train Crew	$15.10	$22.14	$25.50
OBS	$20.24	$38.91	$48.64
Equipment Maintenance	$47.35	$67.78	$78.06
Fuel and Energy	$25.71	$13.00	$14.97
Track Maintenance	$10.52	$20.63	$19.72
Insurance	$9.19	$13.48	$15.52
Call Ctr Variable	$3.33	$4.79	$5.85
T-Agent and CC Comm	$8.63	$19.12	$24.70
Stations	$6.45	$6.45	$6.45
Admin and Mgt	$20.39	$23.21	$24.55
Operation & Dispactch	$1.07	$1.07	$1.03
TOTAL COSTS	$167.98	$230.58	$264.99
OPERATING SURPLUS	$190.27	$562.31	$758.24
OPERATING RATIO	2.13	3.44	3.86

The most effective alternative in terms of operating cost ratio and financial net present values is Alternative 3. The results for which are shown in Exhibit 9-3. It can be seen that the operating ratio for the project is substantial, and that there is a very significant operating profit associated with either the 3 percent or 7 percent discount rate. Since the 3 percent discount rate is more in line with the current cost of money, the overall operating profit is likely to be 11.3 billion dollars. This shows the potential for a private sector contribution to the CHSR project capital costs.

Exhibit 9-3: Revenues and Operating Costs Net Present Values for Alternative 3

Alt 3 Electric High Infra ($2021)		3%	7%
Project Revenues			
	System Passenger Revenues	$14,799.04	$6,879.69
	On Board Revenues	$1,183.92	$550.37
Total Revenues		**$15,982.96**	**$7,430.06**
Operating Costs			
	O&M Costs	$4,439.12	$2,071.11
Total Operating Costs		**$4,439.12**	**$2,071.11**
Revenues Less Costs		**$11,543.84**	**$5,358.95**
Operating Ratio		**3.60**	**3.59**

9.4 ECONOMIC RESULTS

The Demand side Economic Analysis was completed using data derived from the Ridership and Revenue Analysis, the Infrastructure Analysis, and the Operating Analysis.

In addition, the economic benefits of the system to be assessed for the analysis include:

- **Consumer Surplus** – benefit to system users
- **Highway Congestion Savings** – benefits to road users of less congestion
- **Airport Delay Savings** – benefits to air travelers
- **Safety Benefits** – benefit of less accidents
- **Reduced Emissions** – benefit of lower emissions levels
- **Highway Resource Savings –** benefit of lower vehicle and energy use

9.4.1 BENEFIT COST RATIO AND NET PRESENT VALUE

The evaluation of the proposed Cascadia High-Speed Rail System also included an economic analysis of the route. The following Exhibits 9-4 and 9-5 shows the benefit cost ratio for all three of the CHSR Alternatives at the 3% and 7% discount rates recommended by the GAO. As can be seen, all three alternatives have a positive benefit/cost ratio at both the 3% and 7% discount rates (B/C > 1.00), thus showing that any of these approaches could provide an economically viable approach to improving the Portland to Seattle rail service.

Given the fact that the 7% discount rate is actually a capital rationing rate, the ability to project positive Cost Benefit ratios at such a high interest rate shows the strength of the CHSR Corridor and the need for investing in the development of the corridor. However, the CHSR Ultra High Speed Alternative 3 performs the best since it has the highest NPV of public benefits at 7%, producing nearly $5.3 billion in net Public Benefits which is higher than Alternative 2's $4.5 billion result. This shows that Ultra High-Speed Rail is an outstanding project that it would bring a strong benefit to the Cascadia Mega-Region, and to the US economy as a whole.

Exhibit 9-4: Benefit Cost Ratios at 3% Discount Rate (Millions of 2021$) for the Cascadia HSR Corridor

Present Value at 3%		**Alt #1 Diesel Low Inves**	**Alt #2 Electric Low Infra**	**Alt #3 Electric High Infra**
Benefits to Users				
	Users Consumer Surplus	$11,500.73	$22,952.32	$30,978.07
	Express Parcel NET	$491.77	$1,074.86	$1,369.92
	Total User Benefits	**$11,992.49**	**$24,027.18**	**$32,347.99**
Benefits to Public at Large				
	Highway Congestion Saving	$3,242.11	$7,604.17	$10,373.66
	Highway Emission Saving	$203.98	$478.92	$652.99
	Highway Safety Savings	$820.80	$1,824.42	$2,417.46
	Airport Operational Delay Saving	$644.07	$1,699.71	$2,539.27
	Airport Passenger Delay Saving	$375.24	$990.26	$1,479.40
	Total Public at Large Benefits	**$5,286.20**	**$12,597.49**	**$17,462.77**
Total Benefits		**$17,278.70**	**$36,624.67**	**$49,810.76**
Costs				
	Capital Cost	$7,754.21	$12,516.64	$19,159.78
	O&M Costs	$2,811.79	$3,848.95	$4,439.12
	Cyclic Mtn	$96.61	$96.61	$92.35
Total Costs		**$10,662.61**	**$16,462.19**	**$23,691.25**
Benefits Less Costs		**$6,616.09**	**$20,162.48**	**$26,119.51**
Project Benefit/Cost Ratio		**1.62**	**2.22**	**2.10**

Exhibit 9-5: Benefit Cost Ratios at 7% Discount Rate (Millions of 2021$) for the Cascadia HSR Corridor

Present Value at 7%		Alt #1 Diesel Low Inves	Alt #2 Electric Low Infra	Alt #3 Electric High Infra
Millions of 2021 dollars				
Benefits to Users				
	Users Consumer Surplus	$5,213.86	$10,370.80	$13,948.14
	Express Parcel NET	$209.41	$457.72	$583.37
	Total User Benefits	**$5,423.27**	**$10,828.52**	**$14,531.51**
Benefits to Public at Large				
	Highway Congestion Saving	$1,517.21	$3,546.67	$4,822.38
	Highway Emission Saving	$95.44	$223.41	$303.55
	Highway Safety Savings	$384.07	$850.96	$1,123.80
	Airport Operational Delay Saving	$301.40	$792.78	$1,180.41
	Airport Passenger Delay Saving	$175.60	$461.88	$687.72
	Total Public at Large Benefits	**$2,473.73**	**$5,875.70**	**$8,117.85**
Total Benefits		**$7,897.00**	**$16,704.21**	**$22,649.36**
Costs				
	Capital Cost	$6,399.36	$10,329.67	$15,812.10
	O&M Costs	$1,317.30	$1,802.20	$2,071.11
	Cyclic Mtn	$36.26	$36.26	$34.66
Total Costs		**$7,752.92**	**$12,168.14**	**$17,917.87**
Benefits Less Costs		**$144.08**	**$4,536.08**	**$4,731.48**
Project Benefit/Cost Ratio		**1.02**	**1.37**	**1.26**

9.5 COMMUNITY BENEFITS

In order to estimate the economic impact of the CHSR Corridor project, it is important to understand the character of the different economic benefits that can be quantified.

Benefits will arise from the development and the presence of the passenger rail system. The impact of these benefits will be significant both at a firm and household level (see Exhibit 9-6). However, it is important to understand that the sets of benefits quantified in this report, assume equilibrium in the economy. In order for the economy to be in equilibrium, the Supply side Benefits must equal Demand side Benefits. Supply side and Demand side benefits should not be added together in the assessment of the full benefits of the project, as they are merely two different measurements of the same benefits.[30]

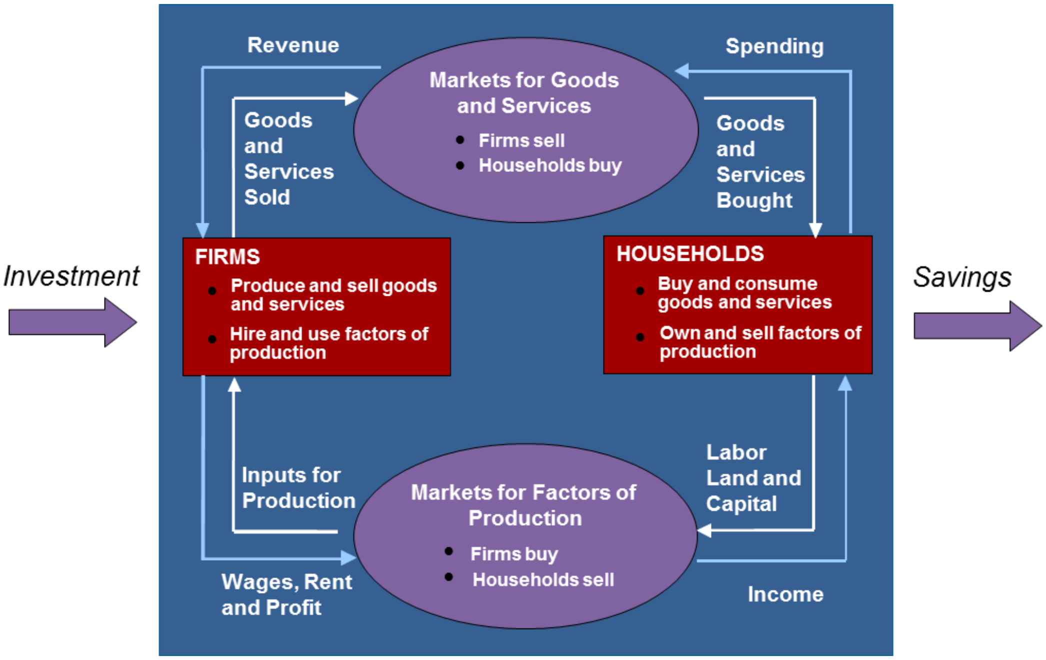
9.5.1 THE CHARACTER OF THE OVERALL ECONOMY

The model of the economy[31] shows that an economy is circular in character, with two equal sides (Exhibit 9-6).

On one side of the economy is the consumer side – the market for goods and services – in which consumers buy goods and services by spending the income earned by working for a commercial enterprise. If a transportation investment improves travel times and costs for individuals, it increases consumer surplus. An analysis of the impact of a transportation investment on the market for goods and services quantifies the level of Consumer Surplus generated by a project, by showing how much time, money and resources individuals save. This was measured in the Demand side Cost Benefit Analysis.

The notion that a transportation project will be worthwhile if travel is made more cost effective is based on the idea that not only the cost, but also the travel time of a trip has value. Academic and empirical research has also shown that this concept holds true for commuters and recreational travelers. Considerable research has been carried out to both identify the theoretical justification for value of travel time and to quantify its value.

Exhibit 9-6: Simple Model of the Economy



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[30] See: Mishan, E. 'Cost Benefit Analysis,' New York, NY: Praeger Publishers, 1976.

[31] See Samuelson, P. & Nordhaus, W. Economics. 14th Edition. New York: McGraw-Hill, 1992.

On the other side of the economy is the market for factors of production. Most importantly, it is the market for land, labor and capital, which individuals provide to firms in exchange for wages, rent and profit. From the perspective of policy makers and the local community, this side of the economy is very interesting as it shows how investment in a new transportation infrastructure changes the productivity of the economy by creating new business opportunities; and therefore, increases jobs, income, property values and wealth.

One of the most important aspects of the circular economy model is that it shows that any project has two impacts, one in the consumer market – the benefits to travelers; the second, in the factor markets or Supply side of the economy[32] – which identifies benefit to the community in terms of improved welfare due to increases in jobs, income and wealth. The supply side benefits can be quantified as the increase in Economic Rent. This is shown in Exhibit 9-7.

For the economy to reach equilibrium, both sets of benefits must be realized. As such, the benefits of a project are realized twice, once on the Demand side and once on the Supply side. As a result, there are two ways to measure the productivity benefits of a transportation project; and theoretically, both measurements must equal each other. This is a very useful property since in any specific analysis one measure can be used to check the other, at least at the aggregate level. This is very helpful and provides a check on the reasonableness of the estimates of project benefits.

However, in assessing the benefits of a transportation project, it is important not to double-count the benefits by adding Supply side and Demand side benefits together. It must be recognized that these two sets of benefits are simply two different ways of viewing the same benefit. The two markets are both reflections of each other and measure the same thing. For example, if both sets of benefits equal $50 million, then the total benefit is only $50 million as expressed in two different ways: travelers get $50 million of travel benefits and the community gets $50 million in jobs, income, and increased profits. As a ripple effect (or transfer payment), the economy also gets an expanded tax base and temporary construction jobs.

Therefore, if a given transportation project is implemented, equivalent productivity benefits will be seen in both the consumer market for goods and services (as the economy benefits from lower travel times and costs), as well as in the Supply side factor markets. In the Supply side market, improved travel efficiency is reflected in more jobs, income and profit. Therefore, for a given transportation investment, the same benefit occurs on both sides of the economy. In the consumer markets, users enjoy lower travel costs and faster travel times. On the Supply side of the economy, the factor markets take advantage of the greater efficiency in transportation. As a result, both sides of the economy move to a new level of productivity in which both sides of the economy are balanced in equilibrium.

Improved efficiency will generate Supply side spending and productivity benefits that have a very real impact on the performance of the local economy. The method that develops estimates of productivity jobs and wealth creation is an Economic Analysis. It measures how the performance of a new transportation investment raises the efficiency of the economy. This efficiency improvement creates jobs and income and raises local property values to reflect the improved desirability of living or working in the area.

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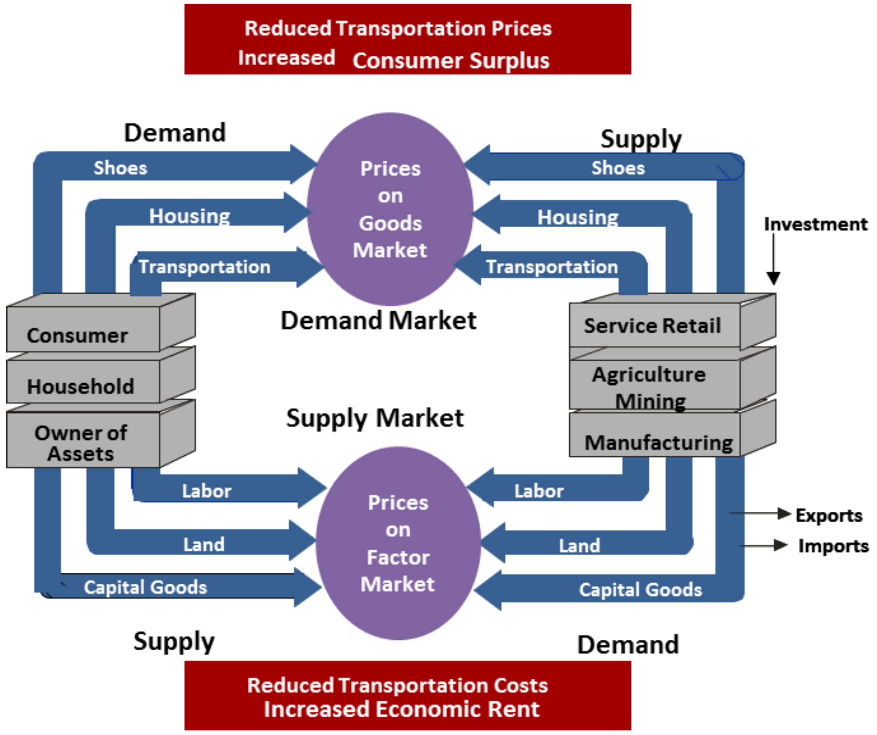
[32] See: Mishan, E. 'Cost Benefit Analysis,' New York, NY: Praeger Publishers, 1976.

Exhibit 9-7: Relation between Consumer Surplus and Economic Rent in the Economy



9.5.2 ASSESSING SUPPLY SIDE BENEFITS

The Economic Rent theory builds from the findings of Urban Economics and The Economics of Location that support Central Place Theory.[33] Central Place Theory argues that in normal circumstances, places that are closer to the "center" have a higher value or economic rent. This can be expressed in economic terms, particularly jobs, income and property value. There is a relationship between economic rent factors (as represented by employment, income, and property value) and impedance to travel to market centers (as measured by generalized cost). As a result, lower generalized costs associated with a transport system investment led to greater transportation efficiencies and increased accessibility. This, in turn, results in lower business costs/higher productivity and, consequently, in an increase in economic rent. This is represented by moving from point V_1 to point V_2 in Exhibit 9-8, as a result of the improved accessibility as measured by moving from GC_1 to GC_2.

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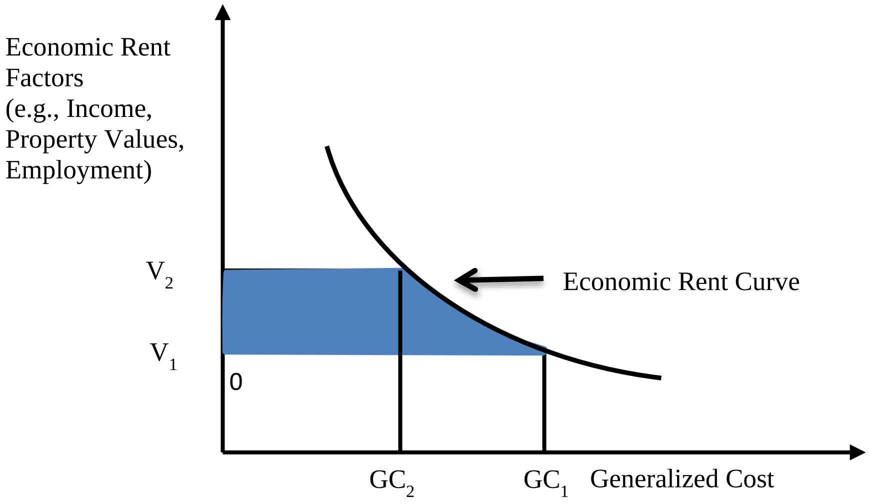
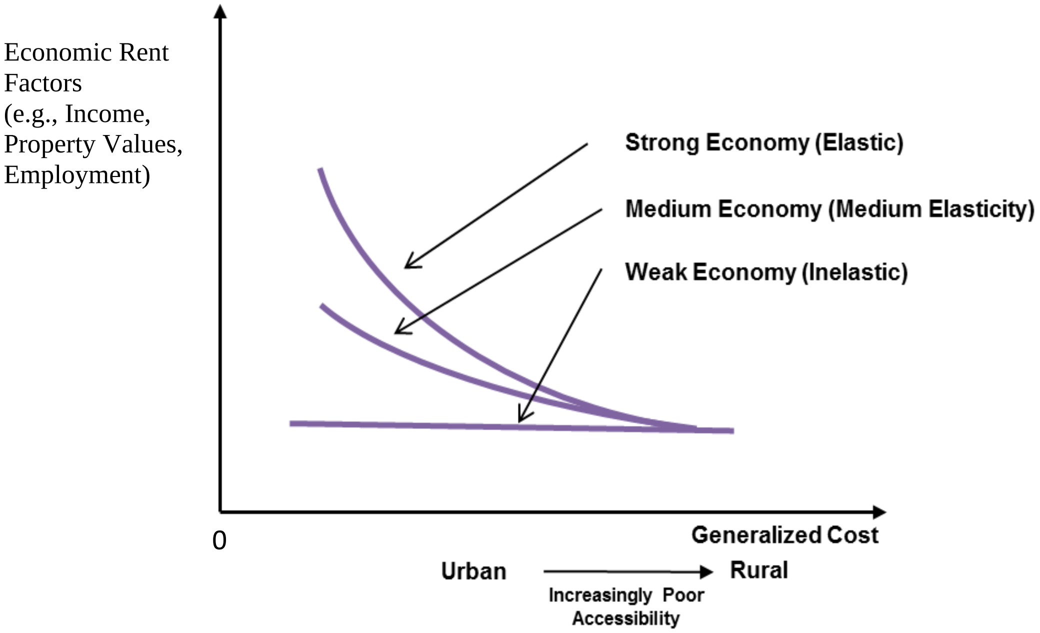
[33] Metcalf, A.E. 'Economic Rent: A New Dimension in the Economic Evaluation Process', Transportation Research Board, 71st Annual Meeting, January 12-16, Washington, DC, 1992.

Exhibit 9-8: Economic Rent Illustration



It should be noted that the shape of the economic rent curve reflects the responsiveness (elasticity) of the economy to an improvement in accessibility. Large cities typically have very large economic rent activity (represented by a steep Economic Rent Curve), which indicates that a project improving transportation accessibility will have a significant economic impact; smaller communities have less economic rent activity (less steep curves), and rural areas have very flat curves that indicate lower economic responsiveness. Similarly, depressed areas will experience flatter curves than better off areas. This is due to factors not directly related to transportation, such as level of education, population structure and industrial structure. A significantly improved transportation provision may bring a useful contribution to alleviating the problems faced by disadvantaged areas but will not by itself solve the economic issues and problems that these areas face. See Exhibit 9-9.

Exhibit 9-9: Representation of Different Economic Rent Curves by Strength of Economy



Finally, the strength of the relationship between generalized cost and economic factors is established by calculating the relationship between economic rent factors and generalized cost weighted by the amount of trips completed for the particular region of study. This ensures that when calculating the Supply side effect of a transportation improvement, real gains in accessibility that benefit a large number of users, produce greater Supply side benefits than projects that provide real accessibility gains for a small number of individuals.

The mathematical expression of the Economic Rent Curve is therefore:

$SE_i = ß_0\, GC_i$

Where:

SE_i - Economic rent factors – i.e., socioeconomic measures, such as: employment, income, property value of zone i;

GC_i - Weighted generalized cost of auto travel for all purposes from (to) zone i to (from) other zones in the study area;

$ß_o$ - Calibration parameters.

9.5.3 DATA SOURCES AND STUDY DATABASE

For the economic impact study, zones developed in the Cascadia Corridor were adopted as shown in Exhibit 9-10.

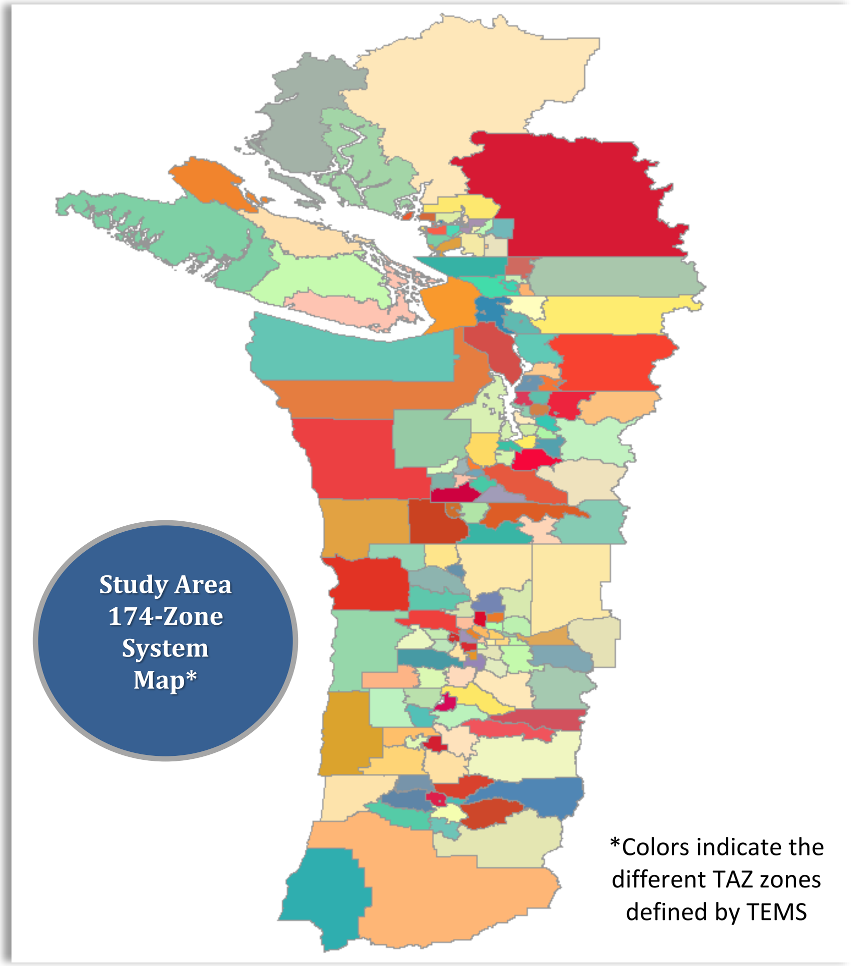


Exhibit 9-10: Cascadia HSR Corridor Zone System Map

*Colors indicate the different TAZ zones defined by TEMS

In order to estimate the economic impact, base year 2020 socioeconomic database established in the ridership and revenue study were used for the supply side model calibration, and socioeconomic forecasts were used in calculating supply side benefits in the 30-year period from 2020 to 2050.

This information enabled TEMS to use the Cascadia Ultra High Speed Rail network of up to 220-250-mph service from Portland to Seattle Corridor to establish transportation service improvements for the zones in the corridor, and to calculate both the current and future generalized costs. Economic Rents benefits were only calculated for the Seattle to Portland sector stations, which is the yellow shaded segment in Exhibit 9-11.

Exhibit 9-11: 220-250-mph Cascadia Ultra High Speed Rail Network

SUPPLY SIDE ANALYSIS RESULTS: DERIVING ECONOMIC RENT ELASTICITIES

Economic Rent theory proposes that for a transportation project to have value there will be a strong relationship between socioeconomic variables and accessibility. As such, the relationship between accessibility and income, employment and property density in the Cascadia HSR corridor was calculated through regression analysis. This analysis established the level of sensitivity of the region's economy to transportation improvements. Exhibits 9-12, 9-13, and 9-14 show the relationship established between accessibility and employment, income, and real property value, along with the statistical measures indicating the strength of the relationship found.

As can be seen in the relationship exhibits, the relationship between accessibility and socioeconomic characteristics is a linear relationship of the following form:

$$\ln(SE_i) = \beta o + \beta 1 \ln(GC_i) \quad \textbf{Equation 1}$$

Where:

SE_i - Economic rent factor (socioeconomic variable) of zone i;

GC_i - Weighted generalized cost of travel for all purposes from (to) zone i to (from) other zones in the zone system;

βo and $\beta 1$ - Regression coefficients.

Exhibit 9-12: Relation between Accessibility and Employment in Cascadia HSR Corridor

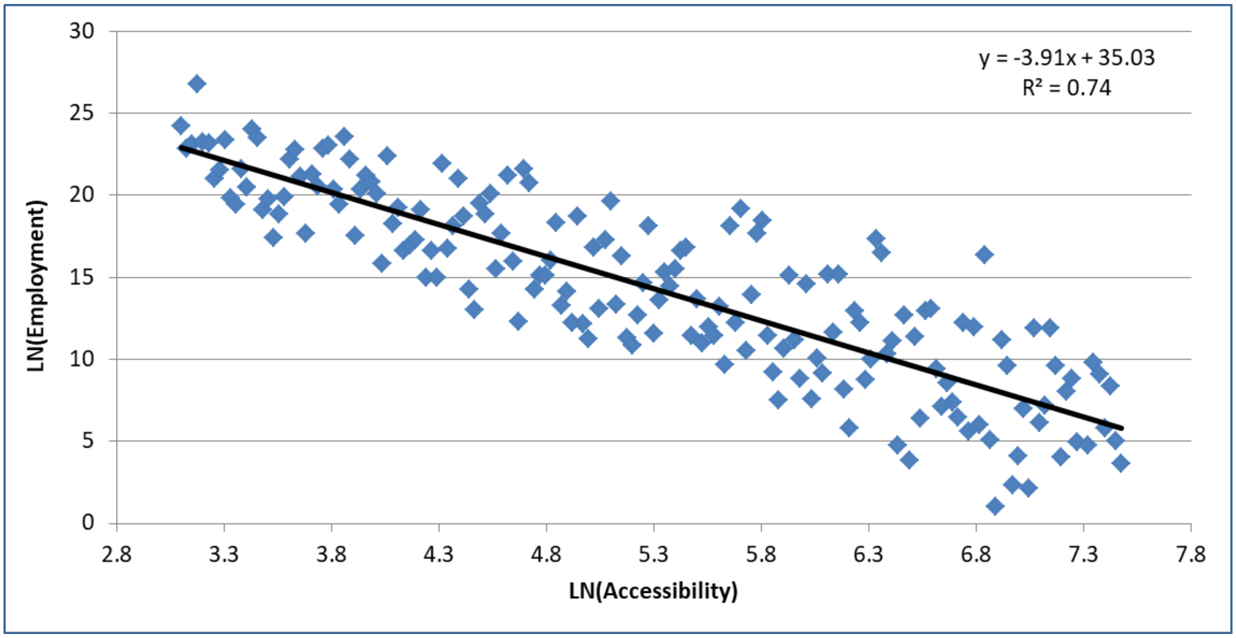


Exhibit 9-13: Relation between Accessibility and Income in Cascadia HSR Corridor

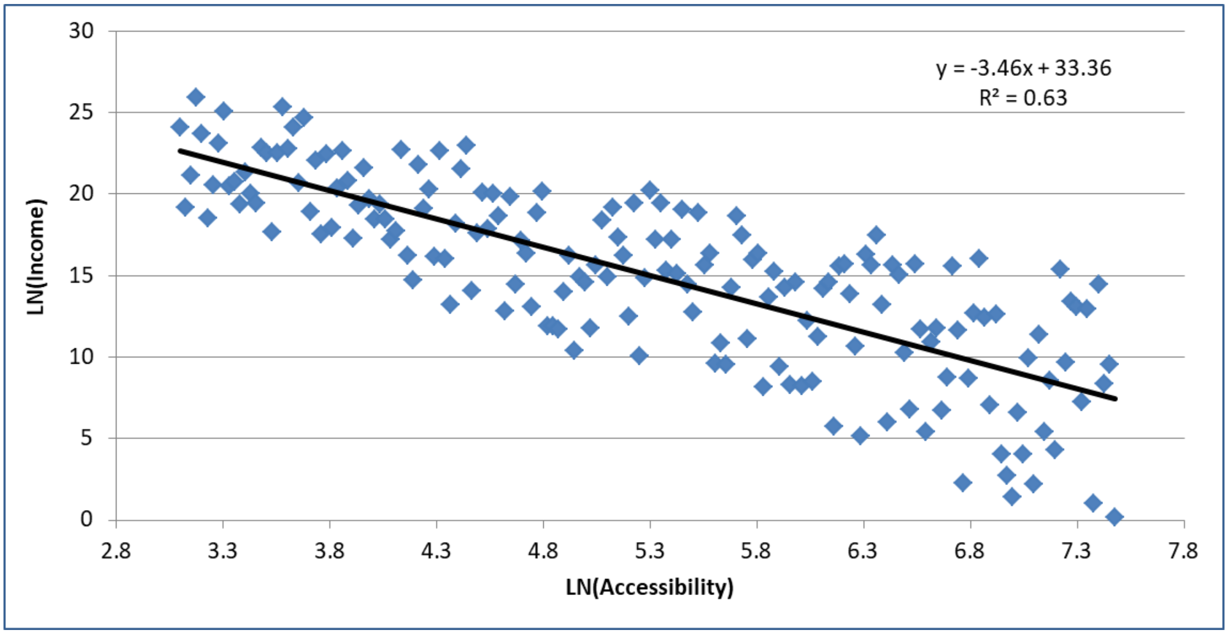
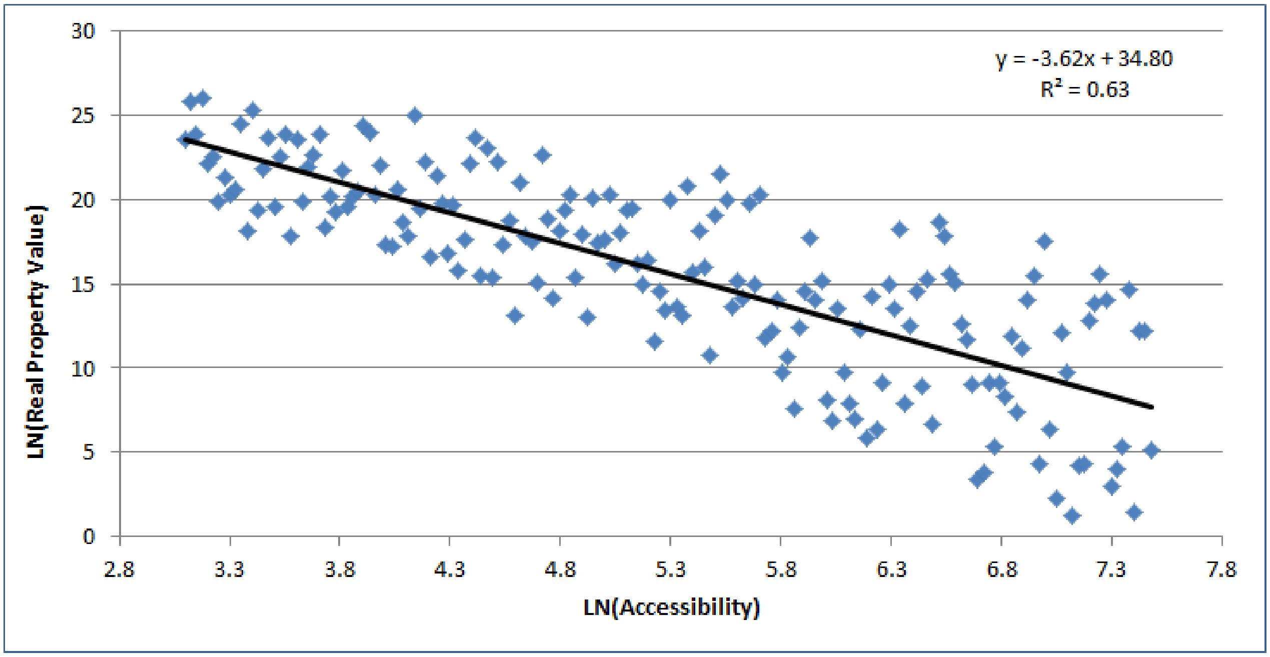


Exhibit 9-14: Relation between Accessibility and Property Value in Cascadia HSR Corridor



The value of the coefficients of determination (R^2) shows how much the dependent variable (e.g., employment) is influenced by the predictor variable (accessibility). In other words, the coefficient of determination measures how well the model explains the variability in the dependent variable. R^2 therefore illustrates the strength of the relationship between the dependent and predictor variables.

Student's t statistics were calculated for the two regression coefficients - $\beta 0$ (the intercept) and $\beta 1$ (the slope) indicate the significance of the regression coefficients. A t-statistics above the value of two in absolute terms is generally accepted as statistically significant.

It can be seen that for the Cascadia Ultra High Speed Rail network, the calibration was successful and regression coefficients in each equation were shown to be significant (See Exhibit 9-15). This shows that the economic rent profiles are well developed for the Cascadia High Speed Rail corridor. Each equation has highly significant 't' values and coefficients of determination (R^2). This reflects the strength of the relationship and, given the fact that there is a strong basis for the relationship, shows firstly, that the socioeconomic variables selected provide a reasonable representation of economic rent; and, secondly, that generalized cost is an effective measure of market accessibility.

Exhibit 9-15 shows the detailed calibration results for employment, income, and property values.

Exhibit 9-15: Detailed Calibration Results

Economic Rent Factor	Intercept (βo)	T-statistics for βo	Slope (β1)	T-statistics for β1	Coefficient of Determination – 'R square' (R^2)
Employment	35.03	36.94	-3.91	-22.42	0.74
Income	33.36	30.18	-3.46	-17.04	0.63
Real Property Value	34.80	30.53	-3.62	-17.28	0.63

The impact on the socioeconomic indicators gathered for the current study, with regard to the improvement in accessibility provided by the new Cascadia Ultra High Speed Rail system, is calculated according to the elasticities (i.e., the sensitivity of the socioeconomic parameters to accessibility) established through the differentiation of the economic rent function in Equation (1) with respect to generalized cost. The result of such differentiation is present in Equation 2. It is easy to see that slope β_1E in the regression equation represent economic rent elasticities.

$$\Delta SE_I = \frac{\partial SE_I}{SE_I} = \beta_1^E \frac{\partial GC_I}{GC_I} \qquad \textbf{Equation 2}$$

The resulting elasticities were then applied to each zone pair according to the specific generalized cost improvement calculated for each zone for each phase of the project. This allows for the effect of Cascadia Ultra High Speed Rrail to be calculated from a Supplyside perspective.

The resulting effect on the socioeconomic parameters are presented below. The results are estimated for each zone, and for the purpose of reporting, socioeconomic benefits for each station hinterland will be shown in the following session.

9.6 SOCIOECONOMIC BENEFITS RESULTS

Direct socioeconomic benefits include employment benefits, income benefits, and real property value benefits. Employment benefits are derived from the Cascadia HSR rail corridor transportation service improvement. These are productivity jobs due to improved economic efficiency and not temporary construction jobs associated with building the project. Income benefits are derived from the increased jobs and economic performance of the region due to the accessibility improvement. Income benefits result from both the increase in the number of households in the corridor and the increase in the average household income per household. Real property value benefits result from the increase of the number of properties in the region as well as increase in the average value of commercial and residential buildings due to the growth of the economy.

9.6.1 DIRECT EMPLOYMENT

For Alternative 3, the operation and management of the Cascadia Ultra High Speed Rail service will create 3,000 direct jobs, which over the 25-year life of the project will generate 75,000-person years of work. The annual income from this employment will be $121.7 million per year and over the life of the project will equal $3.65 billion.

9.6.2 INDIRECT EMPLOYMENT, INCOME, AND PROPERTY VALUES

9.6.2.2 EMPLOYMENT GROWTH ESTIMATES

Exhibit 9-16 shows that the total employment growth in man year from 2025 to 2054 in the Cascadia Corridor for Alternative 3 of nearly 166,520-person years of work. This is due to improved productivity of the economy due to a more efficient transport system, and improved accessibility due to the Cascadia Ultra High Speed Rail network. The urban areas of Seattle and Portland will see an increase of 130,000-person years of work over the life of the project. SEA-TAC and Tacoma will see an increase of over 20,000-person years of employment, and Vancouver WA over 7,000-person years.

Exhibit 9-16: Indirect Employment Improvement by Station Coverage Area

Station Name	Alternative #1 Employment Improvement (man year) 2030~2055	Alternative #2 Employment Improvement (man year) 2030~2055	Alternative #3 Employment Improvement (man year) 2030~2055
Seattle, WA	36,137	60,016	76,743
SEA-TAC, WA	5,850	9,762	12,446
Tacoma, WA	3,916	6,567	8,348
Olympia/Lacey, WA	2,283	3,846	4,875
Centralia, WA	645	1,092	1,380
Longview/Kelso, WA	860	1,464	1,844
Vancouver, WA	3,443	5,887	7,396
Portland, OR	24,848	42,705	53,487
Total	**77,982**	**131,338**	**166,520**

9.6.2.3 PERSONAL INCOME GROWTH ESTIMATES

The personal income growth is shown in Exhibit 9-17. For Alternative 3, It can be seen that the total income growth in the Cascadia HSR corridor will be $11.5 billion from 2025 to 2054. Nearly $9 billion will be in Seattle and Portland where most jobs will be created, these two cities will receive much of the income growth due to the project. However, given the new accessibility of the two principal cities, some of that income will be diverted to the other communities of the corridor. Commuters will take advantage of the opportunity to work in the big cities, but live and spend their income in communities along the corridor.

Exhibit 9-17: Indirect Personal Income Improvement by Station Coverage

Station Name	Alternative #1 Income Improvement 2030~2055 (million $)	Alternative #2 Income Improvement 2030~2055 (million $)	Alternative #3 Income Improvement 2030~2055 (million $)
Seattle, WA	2,160	3,910	5,235
SEA-TAC, WA	354	644	860
Tacoma, WA	241	439	585
Olympia/Lacey, WA	135	248	330
Centralia, WA	40	73	97
Longview/Kelso, WA	53	97	129
Vancouver, WA	211	391	517
Portland, OR	1,512	2,812	3,714
Total	**4,706**	**8,615**	**11,468**

9.6.2.4 PROPERTY VALUE IMPROVEMENT BY STATION COVERAGE AREA

Exhibit 9-18 shows the real property value growth in the Cascadia HSR rail corridor from 2025 to 2054. The real property value in the corridor will also increase as result of the proposed passenger rail service. The total amount of real property value for Alternative 3 for example, from 2025 to 2054 will be $11.3 billion. Seattle and Portland will see an increase of over $8 billion, while SEA-TAC, Tacoma, and Vancouver, WA will each receive over $600 million. Olympia will receive nearly $400 million. In each case the station areas will achieve significant economic boost and new property development will occur at each station. Examples of the new transit-oriented development are given in Chapter 6.

Exhibit 9-18: Property Value Improvement by Station Coverage Area

Station Name	Alternative #1 Property Value Improvement (million $)	Alternative #2 Property Value Improvement (million $)	Alternative #3 Property Value Improvement (million $)
Seattle, WA	2,247	3,549	4,434
SEA-TAC, WA	365	578	721
Tacoma, WA	304	483	601
Olympia/Lacey, WA	188	299	371
Centralia, WA	72	115	142
Longview/Kelso, WA	90	144	178
Vancouver, WA	304	488	602
Portland, OR	2,154	3,466	4,270
Total	**5,724**	**9,121**	**11,320**

9.7 TRANSFER PAYMENTS (TAX BENEFITS)

Since transfer payments (e.g., federal grants) are not a real economic benefit as the money could be spent elsewhere, they can play a major role and have a strong impact on a local community. As such, transfer payments play an exceptional role in the overall project evaluation. The tax benefits include real property tax increase as result of real property value appreciation, the federal and local income taxes will also benefit as result of personal income increase in the corridor. The rates used reflect current 2019 tax rates.

9.7.1 REAL PROPERTY TAX GROWTH ESTIMATES

Exhibit 9-19 shows the real property tax increase in the Cascadia HSR corridor from 2025 to 2054. The real property tax in the corridor will increase as result of the increased real property value in the corridor. The total amount of real property tax paid to governments will increase from 2025 to 2054 to be $2.8 billion.

Exhibit 9-19: Property Tax Improvement by Station Coverage Area

Station Name	Alternative #1 Property Value Tax Improvement 2030~2055 (million $)	Alternative #2 Property Value Tax Improvement 2030~2055 (million $)	Alternative #3 Property Value Tax Improvement 2030~2055 (million $)
Seattle, WA	523	825	1,031
SEA-TAC, WA	85	134	168
Tacoma, WA	91	144	179
Olympia/Lacey, WA	51	81	100
Centralia, WA	16	25	31
Longview/Kelso, WA	24	38	47
Vancouver, WA	78	124	154
Portland, OR	560	901	1,110
Total	**1,426**	**2,272**	**2,819**

9.7.2 FEDERAL INCOME TAX GROWTH ESTIMATES

The federal income tax growth as result of income growth in the Cascadia HSR rail corridor is shown in Exhibit 9-20. For Alternative 3 it can be seen that the total federal income tax growth in the corridor will be over $1.8 billion from 2025 to 2054. Seattle, SEA-TAC and Portland will contribute over $1.5 billion over the same period.

Exhibit 9-20: Federal Tax Improvement by Station Coverage Area

Station Name	Alternative #1 Federal Tax Improvement 2030~2055 (million $)	Alternative #2 Federal Tax Improvement 2030~2055 (million $)	Alternative #3 Federal Tax Improvement 2030~2055 (million $)
Seattle, WA	370	669	896
SEA-TAC, WA	61	110	147
Tacoma, WA	37	68	91
Olympia/Lacey, WA	20	37	49
Centralia, WA	5	9	12
Longview/Kelso, WA	7	13	17
Vancouver, WA	30	56	75
Portland, OR	220	410	541
Total	**750**	**1,373**	**1,828**

9.8 CONCLUSIONS

Below is a summary of each set of benefits calculated for the project. As seen in the analysis, each Alternative of the proposed CHSR project will not only generate financial and demand side economic benefits but will provide a strong stimulus the economy of the Cascadia HSR Corridor. Supply side benefits are the estimated benefits to business and the economy due to the increase in accessibility provided by improvements in transport infrastructure. It is based on the relationship (the elasticity) that the economy exhibits today to transportation accessibility (i.e., sensitivity to improved accessibility). Given the circular nature of the economy, supply side benefits under economic theory are equal to the demand side benefits due to the integrated nature of the economy. The project will create long-term well-paid service and manufacturing employment due to improved productivity. Furthermore, it will benefit the general population through higher incomes and higher real property values. The federal and local government will be able to recoup a large part of their contribution to the project from income and property tax base expansion. In a 50/50 public/private partnership for Alternative 3, this would amount to about 50 percent of their upfront capital costs contribution. This excludes local income and sales tax base increases, which would provide even more revenue to state and local governments. Exhibit 9-21 shows the overall socioeconomic and transfer payment benefits of the Cascadia corridor for the 30-year period from 2025 to 2054.

Exhibit 9-21: Indirect Socioeconomic and Transfer Payments Improvement Summary

Economic Supply Side Items	Economic Supply Side Improvements		
Indirect Socioeconomic Benefits	**Alternative #1**	**Alternative #2**	**Alternative #3**
Employment (2030~2055, man year)	77,982	131,338	166,520
Income (2030~2055, million $)	4,706	8,615	11,468
Property Value (million $)	5,724	9,121	11,320
Transfer Payments (Tax Benefits)	**Alternative #1**	**Alternative #2**	**Alternative #3**
Federal Income Tax (2030~2055, million $)	750	1,373	1,828
Property Tax (2030~2055, million $)	1,426	2,272	2,819

9.9 SUMMARY

Estimates over the 25-year life of the project are:

- Long-term productivity indirect employment will rise by 166,520 person years with an additional 75,000 person years of direct employment. The jobs will be created in transportation, business services, logistics, maintenance, health care and retail sectors.
- $15.12 billion increase in personal income over 25 years throughout the corridor. This is nearly 75 percent of the cost of the project.
- Property Values are estimated to rise by $11.3 billion, with an opportunity for significant Transit Oriented Development (TOD) in the city centers of Cascadia HSR corridor communities.

The economic impacts of the project in terms of transfer payments are:

- $1.8 billion new federal tax over 25 years will be generated.
- $2.8 billion in property tax will be collected at the local level over the 25-year life of the project.
- Increased state and local income tax and sales tax (as yet unquantified).

10. CONCLUSIONS AND NEXT STEPS

The key finding of the study is that the corridor can sustain the development of a Cascadia Ultra High Speed Rail system from Portland to Seattle. The financial and economic results show that of the three alternatives, a 110-mph Diesel option, a 160-mph Electric option, and a 220-mph Electric option, Alternative 3 the Ultra High-Speed Rail option has the best financial and economic return. This includes the best financial return with an operating ratio at 3.86, and operating surplus at $758 million in 2040, and the best economic return with a cost benefit ratio of 2.10 (at a 3 percent discount rate) and 1.26 (at a 7 percent discount rate). The economic return at a 3 percent discount rate has a Net Present Value surplus of $26.1 billion, far higher than the Net Present Value of Alternative 1 and 2, which are respectively $6.6 billion and $20.1 billion. Both Alternative 2 and 3 produce a Net Present Value over the life of the project greater than the Total Cost of the project at respectively $16.4 billion and $23.7 billion. It should be noted that the cost of Alternative 3 has been artificially inflated by the decisions to use a 75-foot cut limit on hills associated with the development of the new Cascadia Ultra High Speed Rail alignment, and its costs could be further reduced if in the Tier 2 EIS it is found that deeper cuts similar to highway cuts of Interstate 5 could be adopted. As such, Alternative 3 offers a strong case for moving forward to further analysis and assessment as required to complete the Environmental and Engineering work that will be needed to finalize the planning and engineering design of the corridor.

10.1 SYSTEM BENEFITS

The Tier 1 EIS study shows that –

- The proposed Alternative 3 option would meet the USDOT FRA public/private partnership financial and economic benefit requirements making the system:
  - Eligible for Federal Funds
  - Providing “High-Speed” 220-250-mph service from Portland to Seattle with travel times under one hour and a service of 22 trains per day.
  - A strong candidate for a public/private partnership (P3) that would allow the private sector to participate in the development and operation of the system.
  - A potential candidate for TIFIA Assistance through the Transportation Infrastructure Assistance Finance and Innovation Act (TIFIA) program.
  - Developable using largely new “greenfield” “tunnel” and “cut” routes between the major cities of Portland and Seattle. The system would provide a significant increase in capacity for both intercity passenger travel and intercity express parcel traffic, taking autos and trucks off Interstate 5.
- The system would provide a strong boost to the economies of the towns and cities along the Interstate 5 corridor and the overall region. Over the 25-year life of the project the economy could be increased by:
  - 200,000 person years of work in direct jobs and productivity jobs along the corridor
  - $15.12 billion increase in household incomes
  - Transit oriented development of $11.3 billion at station sites along the corridor
  - Federal income tax base expansion of $1.8 billion
  - Property tax expansion of $2.8 billion

- The system will provide the base platform for expanding Cascadia Ultra High Speed Rail to Eugene in the south and Vancouver British Columbia in the north giving independent utility to both additional segments despite lower population levels to the south and high engineering costs to the north.

10.2 CHALLENGES

In today's market, to advance and implement major ultra high-speed rail improvements takes the combined resources of the region and support of all interested parties. The interested parties whose support should be sought out for the Cascadia High Speed Rail project include the two state administrations, the heads of local Metropolitan Organizations, local and regional political leaders including the mayors of cities along the corridor, the leaders of research installations or facilities who could benefit from or be users of the rail system (e.g., software development firms, logistics firms, and financial sector firms, etc.), local chambers of commerce, community leaders, etc.

The implementation of the new Ultra High-Speed Rail System for Cascadia will involve a number of critical challenges:

- An effective financing and funding approach that meets USDOT FRA requirements needs to be developed.
- Given the overburdening of the USDOT and FRA with ARRA and PRIIA grants, and the time needed for completing environmental analyses, the processing requirements have been extended and are having an adverse impact on project timelines. However, the FRA has suggested that some of these timelines may be shortened in the future as the USDOT FRA gears up to process high-speed rail applications.
- The development of potential greenfield alignments should be further examined to determine the feasibility of advancing improved service and to provide alternative ways for potentially mitigating freight railroad, environmental and community concerns.
- The Project needs to maintain its currently strong base of community and regional support; and an effective case needs to be put forth that clearly and strongly demonstrates the potential benefits of bringing high-speed rail to the local communities along the Cascadia High Speed Rail corridor and to the overall region.

Because the identified benefits of the CHSR system are so robust while the complexity of the FRA funding process for completion of environmental analyses stresses project timelines, there is a strong benefit to continuing to push forward and advance the development of a Cascadia Ultra High Speed Rail for the Cascadia corridor.

10.3 NEXT STEPS

To move towards implementing the project, the following are the next steps:

- Develop the institutional framework to support a process for public/private partnership development throughout the environmental process. This involves holding regular workshops with potential P3 partners through the Tier 2 environmental process.
- Continue development of the Cascadia HSR proposed route option. Work still remains to be completed for defining and refining route options, as well as working with the railroads on capacity analysis issues.
- Identify the potential financial parameters for a public/private partnership considering: Design, Build, Operate, Maintain and Finance (DBOM-F) options.

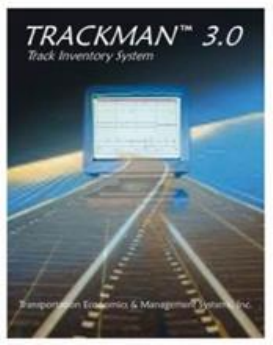
- Develop partnership with freight railroads for engaging in right-of-way discussions.
- Develop partnerships with the local communities regarding station development in order to evaluate potential transit connections and auto requirements.

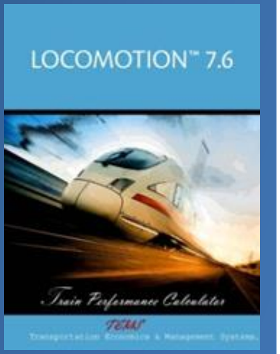
Key documentation required for FRA application for High-Speed Rail funds includes:

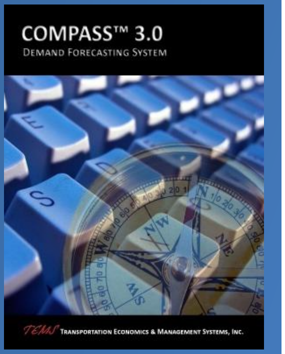
- Service Development Plan
- Environmental Documentation (Service NEPA)
- Railroad Agreements where existing rail rights-of-way will be used
- Agreements with local communities on station development
- Financial and Funding Plan
- Documentation of work with the USDOT FRA considered as part of the team to adopt 220-250-mph trains.

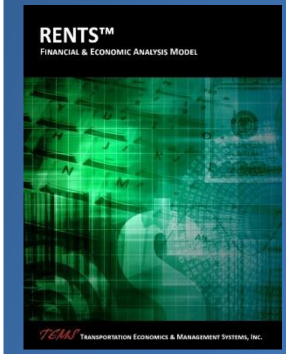
APPENDICES: Appendix A:

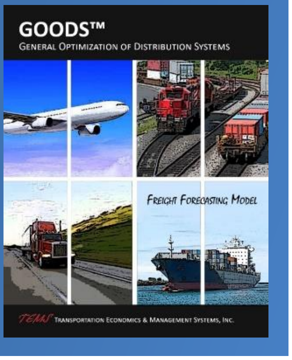
RightTrack™ Software











RightTrack™ Passenger Rail Planning System

TRACKMAN™ (Track Inventory System) is a corridor track inventory and assessment system that analyzes track infrastructure and estimates the cost of upgrading for various scenarios. It stores, on a milepost-by-milepost basis, data on track condition and track geometry such as curvature, gradient, and turnouts; structures such as bridges, crossings, and stations; maximum operating speeds; and unit costs for engineering improvements.

LOCOMOTION™ (Train Performance Calculator) provides the rail operations planner with a highly sophisticated, yet easy-to-use tool for creating and analyzing rail operations schedules. **LOCOMOTION™** also provides a single, easily accessible source of detailed information on rail corridor characteristics and attainable train speeds. The system creating and altering train technologies enables users to describe their acceleration and deceleration profiles. With **LOCOMOTION™**, it is possible to model rail corridors, create timetables for different train technologies, and produce speed profile and operating diagrams. **LOCOMOTION™** interfaces with **TRACKMAN™**, producing a complete graph profile for a given route.

MISS-IT™ (Major Interlocking Signaling System-Interactive Train Planner) is an event-based conflict resolution model designed to increase rail system efficiency. The system draws together track infrastructure data stored in **TRACKMAN™** and the timetables generated with **LOCOMOTION™** to determine the interaction of trains on a specified corridor. **MISS-IT™** uses data on existing infrastructure, such as sidings and double-track, and makes decisions regarding delays and procedures based on given priorities. **MISS-IT™** tests the effects of additional infrastructure on a given route and determines whether these changes create or alleviate bottlenecks within the system. The system is capable of displaying outputs in an animated graphics mode.

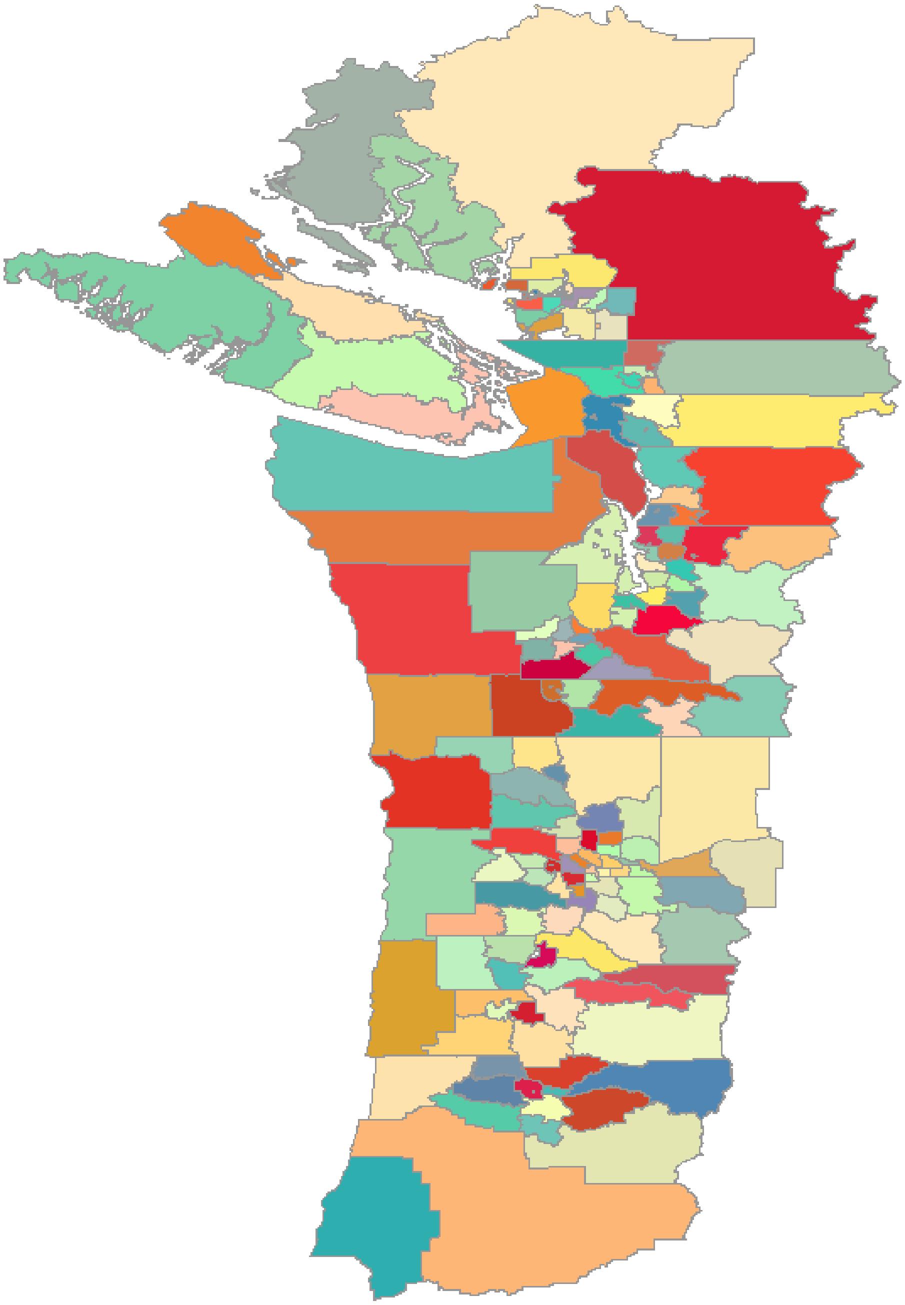
COMPASS™ (Demand Forecasting System) is a comprehensive strategic policy planning tool that assists rail, highway, air, and transit management in planning their systems. **COMPASS™** generates ridership forecasts; revenue estimates; and rail, highway, air, and transit market shares over a given timeframe for a variety of conditions. Forecasts are made over a 25-year time frame and fares can be optimized using revenue yield analysis. **COMPASS™** provides both sensitivity and risk analysis.

RENTS™ (Financial & Economic Analysis Model) uses output from **COMPASS™** to estimate the financial and economic benefits of a project. This includes financial return (operating ratio, NPV and IRR), economic return (gross and net consumer surplus, NPV, and cost benefit ratio), and community benefits (changes in household income, employment by sector, property values, and population) that result from infrastructure and technology improvements or train and fare modifications.

GOODS™ (General Optimization of Distribution Systems) is a modeling framework designed to support the analysis of freight traffic flows at the regional or urban level. The model uses data on current traffic flows, regional economic growth potentials, and specific industrial development proposals to develop total freight traffic flows and forecasts.

APPENDIX B: ZONE SYSTEM AND SOCIOECONOMIC DATA

Study Area Zone System



*Colors indicate the different TAZ zones defined by TEMS

Socioeconomic Data by Zone (Base Year 2020)

Zone ID	Zone Name	Population	Employment	Mean Household Income (2019$)
1	Whatcom WA-1	10,854	4,844	93,692
2	Whatcom WA-2	58,253	28,552	122,028
3	Whatcom WA-3	33,424	16,907	133,777
4	Whatcom WA-4	29,819	15,649	119,995
5	Whatcom WA-5	10,578	5,576	105,861
6	Whatcom WA-6	9,444	4,819	141,097
7	Whatcom WA-7	89,450	49,511	104,840
8	Skagit WA-1	25,239	12,323	125,400
9	Skagit WA-2	12,393	6,284	107,803
10	Skagit WA-3	35,451	19,966	121,185
11	Skagit WA-4	61,110	31,068	113,485
12	Snohomish WA-1	44,505	19,491	135,766
13	Snohomish WA-2	157,468	67,666	127,333
14	Snohomish WA-3	157,801	70,602	126,332
15	Snohomish WA-4	415,260	190,894	141,745
16	Snohomish WA-5	56,450	23,673	187,424
17	Kitsap WA-1	280,499	133,566	136,254
18	King WA-1	12,989	10,178	162,670
19	King WA-2	380,988	319,022	160,811
20	King WA-3	201,958	157,284	197,185
21	King WA-4	249,713	219,045	169,829
22	King WA-5	179,721	131,745	219,854
23	King WA-6	256,464	192,209	138,219
24	King WA-7	153,835	116,331	193,433
25	King WA-8	167,091	121,049	115,323
26	King WA-9	154,851	113,747	153,400
27	King WA-10	217,167	153,864	120,487
28	King WA-11	77,993	55,186	152,311
29	King WA-12	170,273	120,472	256,955
30	King WA-13	39,308	29,377	178,403

Socioeconomic Data by Zone (Base Year 2020)

Zone ID	Zone Name	Population	Employment	Mean Household Income (2019$)
31	King WA-14	2,956	2,389	176,016
32	Pierce WA-1	103,747	46,201	177,488
33	Pierce WA-2	127,041	63,018	138,902
34	Pierce WA-3	257,309	118,569	107,609
35	Pierce WA-4	326,421	158,593	147,528
36	Pierce WA-5	64,204	29,711	129,626
37	Pierce WA-6	3,576	1,858	146,435
38	Thurston WA-1	16,672	7,944	175,473
39	Thurston WA-2	16,710	7,990	148,015
40	Thurston WA-3	29,573	13,222	115,650
41	Thurston WA-4	12,286	5,102	113,979
42	Thurston WA-5	24,245	11,030	116,593
43	Thurston WA-6	66,088	31,289	131,473
44	Thurston WA-7	65,030	33,142	121,480
45	Thurston WA-8	15,360	6,856	168,212
46	Thurston WA-9	61,575	29,376	119,443
47	Lewis WA-1	32,198	14,367	91,767
48	Lewis WA-2	26,307	11,605	103,962
49	Lewis WA-3	3,793	1,880	105,482
50	Lewis WA-4	8,710	3,893	97,770
51	Lewis WA-5	4,351	1,891	97,638
52	Lewis WA-6	2,916	1,068	83,298
53	Lewis WA-7	3,013	1,059	81,090
54	Cowlitz WA-1	9,430	4,126	115,814
55	Cowlitz WA-2	31,841	14,616	122,835
56	Cowlitz WA-3	65,433	27,935	91,731
57	Columbia OR-1	14,221	4,374	107,698
58	Columbia OR-2	10,381	3,780	124,517
59	Columbia OR-3	28,766	10,025	113,145
60	Clark WA-1	62,452	24,090	130,853

Socioeconomic Data by Zone (Base Year 2020)

Zone ID	Zone Name	Population	Employment	Mean Household Income (2019$)
61	Clark WA-2	23,966	8,207	133,541
62	Clark WA-3	78,134	31,923	122,270
63	Clark WA-4	92,030	36,643	128,931
64	Clark WA-5	202,756	83,529	99,852
65	Clark WA-6	105,908	42,071	147,051
66	Multnomah OR-1	2,751	2,391	164,978
67	Multnomah OR-2	124,672	108,811	120,666
68	Multnomah OR-3	9,410	7,577	291,848
69	Multnomah OR-4	79,509	71,583	154,864
70	Multnomah OR-5	49,628	41,865	168,611
71	Multnomah OR-6	135,095	109,739	114,230
72	Multnomah OR-7	114,669	104,488	117,060
73	Multnomah OR-8	164,703	117,142	92,459
74	Multnomah OR-9	5,852	4,181	107,110
75	Multnomah OR-10	85,012	64,514	105,525
76	Multnomah OR-11	4,715	3,039	132,053
77	Washington OR-1	13,429	6,859	147,281
78	Washington OR-2	2,636	1,296	121,766
79	Washington OR-3	29,222	14,010	101,806
80	Washington OR-4	23,018	11,992	104,777
81	Washington OR-5	90,784	47,726	124,592
82	Washington OR-6	193,580	107,498	141,525
83	Washington OR-7	27,253	13,538	146,060
84	Washington OR-8	212,849	118,097	126,648
85	Washington OR-9	59,942	30,244	117,533
86	Clackamas OR-1	218,540	136,897	151,862
87	Clackamas OR-2	48,427	28,559	159,807
88	Clackamas OR-3	37,019	22,459	139,975
89	Clackamas OR-4	78,931	47,191	153,384
90	Clackamas OR-5	26,923	15,411	117,883

Socioeconomic Data by Zone (Base Year 2020)

Zone ID	Zone Name	Population	Employment	Mean Household Income (2019$)
91	Clackamas OR-6	222	209	82,375
92	Clackamas OR-7	10,784	6,963	140,949
93	Yamhill OR-1	50,435	25,278	135,357
94	Yamhill OR-2	48,179	22,238	105,054
95	Yamhill OR-3	11,865	4,611	93,198
96	Marion OR-1	44,606	25,010	110,336
97	Marion OR-2	29,912	15,845	121,533
98	Marion OR-3	222,414	123,138	114,486
99	Marion OR-4	42,529	22,567	130,252
100	Marion OR-5	2,430	1,306	118,175
101	Polk OR-1	34,455	11,199	116,740
102	Polk OR-2	41,986	13,799	89,367
103	Polk OR-3	9,421	3,380	86,349
104	Benton OR-1	12,973	9,086	152,265
105	Benton OR-2	68,950	47,492	110,586
106	Benton OR-3	7,915	5,024	114,861
107	Linn OR-1	12,013	5,660	113,976
108	Linn OR-2	42,419	19,159	96,110
109	Linn OR-3	47,239	21,650	88,583
110	Linn OR-4	7,071	3,442	108,298
111	Linn OR-5	16,700	6,684	84,846
112	Lane OR-1	19,548	8,157	76,796
113	Lane OR-2	13,866	7,427	95,236
114	Lane OR-3	21,359	11,278	105,777
115	Lane OR-4	1,632	948	99,264
116	Lane OR-5	8,711	4,542	134,627
117	Lane OR-6	217,889	120,343	100,527
118	Lane OR-7	60,070	33,583	87,289
119	Lane OR-8	16,719	8,715	113,124
120	Lane OR-9	18,231	8,422	78,959

Socioeconomic Data by Zone (Base Year 2020)

Zone ID	Zone Name	Population	Employment	Mean Household Income (2019$)
121	Lane OR-10	7,567	3,283	78,935
122	Lane OR-11	5,512	2,608	92,585
123	Lane OR-12	5,734	2,942	101,657
124	Clatsop OR	38,584	26,331	100,557
125	Coos OR	64,470	32,276	91,633
126	Douglas OR	110,948	52,766	87,986
127	Hood River OR	24,709	18,318	111,552
128	Lincoln OR	48,292	28,946	96,676
129	Tillamook OR	26,052	14,235	97,167
130	Clallam WA	77,740	37,892	101,498
131	Grays Harbor WA	75,682	31,396	91,713
132	Island WA	85,734	36,481	117,235
133	Jefferson WA	31,923	14,153	112,351
134	Mason WA	68,142	22,044	94,275
135	Pacific WA	21,920	9,407	86,290
136	San Juan WA	18,725	12,154	137,112
137	Skamania WA	11,879	3,290	109,619
138	Wahkiakum WA	4,029	1,737	91,345
139	Greater Vancouver-1	242,915	132,414	130,541
140	Greater Vancouver-2	95,230	50,543	124,170
141	Greater Vancouver-3	88,878	46,456	122,494
142	Greater Vancouver-4	87,585	44,516	117,961
143	Greater Vancouver-5	77,800	40,459	117,171
144	Greater Vancouver-6	76,835	40,447	122,608
145	Greater Vancouver-7	110,178	59,128	122,845
146	Greater Vancouver-8	82,746	44,939	126,948
147	Greater Vancouver-9	99,004	52,939	115,972
148	Greater Vancouver-10	81,156	43,657	126,782
149	Greater Vancouver-11	79,091	43,023	125,261
150	Greater Vancouver-12	109,098	58,559	125,105

Socioeconomic Data by Zone (Base Year 2020)

Zone ID	Zone Name	Population	Employment	Mean Household Income (2019$)
151	Greater Vancouver-13	78,261	39,821	123,311
152	Greater Vancouver-14	87,474	44,489	120,167
153	Greater Vancouver-15	74,413	38,949	118,640
154	Greater Vancouver-16	87,231	44,563	124,782
155	Greater Vancouver-17	88,841	48,046	125,189
156	Greater Vancouver-18	95,418	50,077	118,063
157	Greater Vancouver-19	74,555	40,272	121,277
158	Greater Vancouver-20	111,227	55,628	121,339
159	Greater Vancouver-21	105,708	53,619	118,858
160	Greater Vancouver-22	93,657	49,770	116,828
161	Greater Vancouver-23	90,531	48,061	127,653
162	Greater Vancouver-24	80,507	43,779	126,702
163	Greater Vancouver-25	80,646	43,935	120,549
164	Greater Vancouver-26	95,780	49,258	127,525
165	Greater Vancouver-27	82,235	41,656	125,166
166	Capital	359,032	172,386	99,222
167	Cowichan Valley	80,118	41,485	101,994
168	Nanaimo	146,184	75,000	102,464
169	Alberni-Clayoquot	30,978	15,236	100,268
170	Comox Valley	63,369	32,422	99,973
171	Powell River	19,853	9,656	99,471
172	Sunshine Coast	28,543	14,097	97,007
173	Squamish-Lillooet	38,069	18,695	96,302
174	Fraser Valley	276,854	138,023	98,613

APPENDIX C: COMPASS™ MODEL

The COMPASS™ Model System is a flexible multimodal demand-forecasting tool that provides comparative evaluations of alternative socioeconomic and network scenarios. It also allows input variables to be modified to test the sensitivity of demand to various parameters such as elasticities, values of time, and values of frequency. This section describes in detail the model methodology and process used in the study.

C.1 DESCRIPTION OF THE COMPASS™ MODEL SYSTEM

The COMPASS™ model is structured on two principal models: Total Demand Model and Hierarchical Modal Split Model. For this study, these two models were calibrated separately for three trip purposes, which are Business, Commuter, and Other. For each market segment, the models were calibrated on base year origin-destination trip data, existing network characteristics and base year socioeconomic data.

Since the models were calibrated on the base year data, when applying the models for forecasting, an incremental approach known as the “pivot point” method is used. By applying model growth rates to the base data observations, the “pivot point” method is able to preserve the unique travel flows present in the base data that are not captured by the model variables. Details on how this method is implemented are described below.

C.2 TOTAL DEMAND MODEL

The Total Demand Model, shown in Equation 1, provides a mechanism for assessing overall growth in the travel market.

Equation 1:

$$T_{ijp} = e^{\beta 0p}(SE_{ijp})^{\beta 1p} e^{\beta 2p\, U_{ijp}}$$

Where,

T_{ijp} = Number of trips between zones *i* and *j* for trip purpose *p*
SE_{ijp} = Socioeconomic variables for zones *i* and *j* for trip purpose *p*
U_{ijp} = Total utility of the transportation system for zones *i* to *j* for trip purpose *p*
$\beta_{0p}, \beta_{1p}, \beta_{2p}$ = Coefficients for trip purpose *p*

As shown in Equation 1, the total number of trips between any two zones for all modes of travel, segmented by trip purpose, is a function of the socioeconomic characteristics of the zones and the total utility of the transportation system that exists between the two zones. For this study, trip purposes include Business, Commuter and Other. The socioeconomic characteristics consist of population, employment, and income. The utility function provides a measure of the quality of the transportation system in terms of the times, costs, reliability, and level of service provided by all modes for a given trip purpose. The Total Demand Model equation may be interpreted as meaning that travel between zones will increase as socioeconomic factors such as population and income rise or as the utility (or quality) of the transportation system is improved by providing new facilities and services that reduce travel times and/or costs. The Total Demand Model can therefore be used to evaluate the effect of changes in both socioeconomic and travel characteristics on the total demand for travel.

C.2.1 SOCIOECONOMIC VARIABLES

The socioeconomic variables in the Total Demand Model show the impact of economic growth on travel demand. The COMPASS™ Model System, in line with most intercity modeling systems, uses three variables (population, employment, and average income) to represent the socioeconomic characteristics of a zone. Different combinations were tested in the calibration process and it was found, as is typically found elsewhere, that the most reasonable and statistically stable relationships consist of the following formulations:

Trip Purpose	***Socioeconomic Variable***
Business	$E_i E_j (I_i + I_j) / 2$
Commuter	$(P_i E_j+P_j E_i) / 2 (I_i+I_j) / 2$
Other	$P_i P_j (I_i + I_j) / 2$

The Business formulation consists of a product of employment in the origin zone, employment in the destination zone, and the average per household income of the two zones. Since business trips are usually made between places of work, the presence of employment in the formulation is reasonable. The Commuter formulation consists of all socioeconomic factors, this is because commuter trips are between homes and places of work, which are closely related to population and employment. The formulation for Other consists of a product of population in the origin zone, population in the destination zone and the average per household income of the two zones. Social and leisure trips encompass many types of trips, but the majority is home-based and thus, greater volumes of trips are expected from zones from higher population and income.

C.2.2 TRAVEL UTILITY

Estimates of travel utility for a transportation network are generated as a function of generalized cost (GC), as shown in Equation 2:

Equation 2:

$$U_{ijp} = f(GC_{ijp})$$

Where,

GC_{ijp} = Generalized Cost of travel between zones *i* and *j* for trip purpose *p*

Because the generalized cost variable is used to estimate the impact of improvements in the transportation system on the overall level of trip making, it needs to incorporate all the key attributes that affect an individual's decision to make trips. For the public modes (i.e., rail and bus), the generalized cost of travel includes all aspects of travel time (access, egress, in-vehicle times), travel cost (fares), and schedule convenience (frequency of service, convenience of arrival/departure times). For auto travel, full average cost of operating a car is used for Business, while only the marginal cost is used for Commuter and Other trips. In addition, tolls and parking charges are used where appropriate.

The generalized cost of travel is typically defined in travel time (i.e., minutes) rather than dollars. Costs are converted to time by applying appropriate conversion factors, as shown in Equation 3. The generalized cost (GC) of travel between zones *i* and *j* for mode m and trip purpose p is calculated as follows:

Equation 3:

$$GC_{ijmp} = TT_{ijm} + \frac{TC_{ijmp}}{VOT_{mp}} + \frac{VOF_{mp} * OH}{VOT_{mp} * F_{ijm}}$$

Where,

TT_{ijm} = Travel Time between zones *i* and *j* for mode *m* (in-vehicle time + station wait time + connection wait time + access/egress time + interchange penalty), with waiting, connect and access/egress time multiplied by a factor (greater than 1) to account for the additional disutility felt by travelers for these activities
TC_{ijmp} = Travel Cost between zones *i* and *j* for mode *m* and trip purpose *p* (fare + access/egress cost for public modes, operating costs for auto)
VOT_{mp} = Value of Time for mode *m* and trip purpose *p*
VOF_{mp} = Value of Frequency for mode *m* and trip purpose *p*
F_{ijm} = Frequency in departures per week between zones *i* and *j* for mode *m*
OH = Operating hours per week

Station wait time is the time spent at the station before departure and after arrival. On trips with connections, there would be additional wait times incurred at the connecting station. Wait times are weighted higher than in-vehicle time in the generalized cost formula to reflect their higher disutility as found from previous studies. Wait times are weighted 70 percent higher than in-vehicle time.

Similarly, access/egress time has a higher disutility than in-vehicle time. Access time tends to be more stressful for the traveler than in-vehicle time because of the uncertainty created by trying to catch the flight or train. Based on previous work, access time is weighted 80 percent higher for rail and bus travel.

The third term in the generalized cost function converts the frequency attribute into time units. Operating hours divided by frequency is a measure of the headway or time between departures. Tradeoffs are made in the stated preference surveys resulting in the value of frequencies on this measure. Although there may appear to some double counting because the station wait time in the first term of the generalized cost function is included in this headway measure, it is not the headway time itself that is being added to the generalized cost. The third term represents the impact of perceived frequency valuations on generalized cost. TEMS has found it very effective to measure this impact as a function of the headway.

C.2.3 Calibration of the Total Demand Model

In order to calibrate the Total Demand Model, the coefficients are estimated using linear regression techniques. Equation 1, the equation for the Total Demand Model, is transformed by taking the natural logarithm of both sides, as shown in Equation 4:

Equation 4:

$$\log(T_{ijp}) = \beta_{0p} + \beta_{1p}\log(SE_{ijp}) + \beta_{2p}(U_{ijp})$$

Equation 4 provides the linear specification of the model necessary for regression analysis.

The segmentation of the database by trip purpose resulted in two sets of models. The results of the calibration for the Total Demand Models are displayed in Exhibit C-1.

Exhibit C-1: Total Demand Model Coefficients (1)

Business	$\log(T_{ij})$	=	-9.5680	+	0.3589	$\log(SE_{ij})$	+	0.6813	U_{ij}	R^2=	0.76
			(-109.70)		(127.44)			(280.56)			
	where U_{ij}=Log[Exp(		-2.4897	+	0.9945	U_{Public})	+	Exp(-0.0076 GC_{Auto})]			
Commuter	$\log(T_{ij})$	=	-9.6123	+	0.3601	$\log(SE_{ij})$	+	0.7107	U_{ij}	R^2=	0.80
			(-95.37)		(118.23)			(303.16)			
	where U_{ij} =Log[Exp(		-3.1732	+	0.9721	U_{Public})	+	Exp(-0.0062 GC_{Auto})]			
Other	$\log(T_{ij})$	=	-9.7955	+	0.3646	$\log(SE_{ij})$	+	0.7588	U_{ij}	R^2=	0.72
			(-90.26)		(108.63)			(343.76)			
	where U_{ij} =Log[Exp(		-3.8765	+	0.9607	U_{Public})	+	Exp(-0.0059 GC_{Auto})]			

(1) *t-statistics are given in parentheses.*

In evaluating the validity of a statistical calibration, there are two key statistical measures: t-statistics and R2. The t-statistics are a measure of the significance of the model's coefficients; values of 1.96 and above are considered "good" and imply that the variable has significant explanatory power in estimating the level of trips. R^2 is a statistical measure of the "goodness of fit" of the model to the data; any data point that deviates from the model will reduce this measure. It has a range from 0 to a perfect 1, with 0.5 and above considered "good" for large data sets. Based on these two measures, the total demand calibrations are good. The t-statistics are high, aided by the large size of the data set. The R2 values imply good fits of the equations to the data.

As shown in Exhibit 1, the socioeconomic elasticity value for the Total Demand Model is 0.36, meaning that each one percent growth in the socioeconomic term generates approximately a 0.36 percent growth in the total travel market.

The coefficient on the utility term is not strictly elasticity, but it can be considered an approximation. The utility term is related to the scale of the generalized costs, for example, utility elasticity can be high if the absolute value of transportation utility improvement is significant. This is not untypical when new transportation systems are built. In these cases, a 20 percent reduction in utility is not unusual and may impact more heavily on longer origin-destination pairs than shorter origin-destination pairs.

C.2.4 INCREMENTAL FORM OF THE TOTAL DEMAND MODEL

The calibrated Total Demand Models could be used to estimate the total travel market for any zone pair using the population, employment, per household income, and the total utility of all the modes. However, there would be significant differences between estimated and observed levels of trip making for many zone pairs despite the good fit of the models to the data. To preserve the unique travel patterns contained in the base data, the incremental approach or "pivot point" method is used for forecasting. In the incremental approach, the base travel data assembled in the database are used as pivot points, and forecasts are made by applying trends to the base data. The total demand equation as described in Equation 1 can be rewritten into the following incremental form that can be used for forecasting (Equation 5):

Equation 5:

$$\frac{T_{ijp}{}^{f}}{T_{ijp}{}^{b}} = \left(\frac{SE_{ijp}{}^{f}}{SE_{ijp}{}^{b}}\right)^{\beta_{1p}} \exp(\beta_{2p}\,(U_{ijp}{}^{f} - U_{ijp}{}^{b}))$$

Where,

T^f_{ijp} = Number of Trips between zones *i* and *j* for trip purpose *p* in forecast year *f*
T^f_{ijp} = Number of Trips between zones *i* and *j* for trip purpose *p* in base year *b*
SE^f_{ijp} = Socioeconomic variables for zones *i* and *j* for trip purpose *p* in forecast year *f*
SE^b_{ijp} = Socioeconomic variables for zones *i* and *j* for trip purpose *p* in base year *b*
U^f_{ijp} = Total utility of the transportation system for zones *i* to *j* for trip purpose *p* in forecast year *f*
U^b_{ijp} = Total utility of the transportation system for zones *i* to *j* for trip purpose *p* in base year *b*

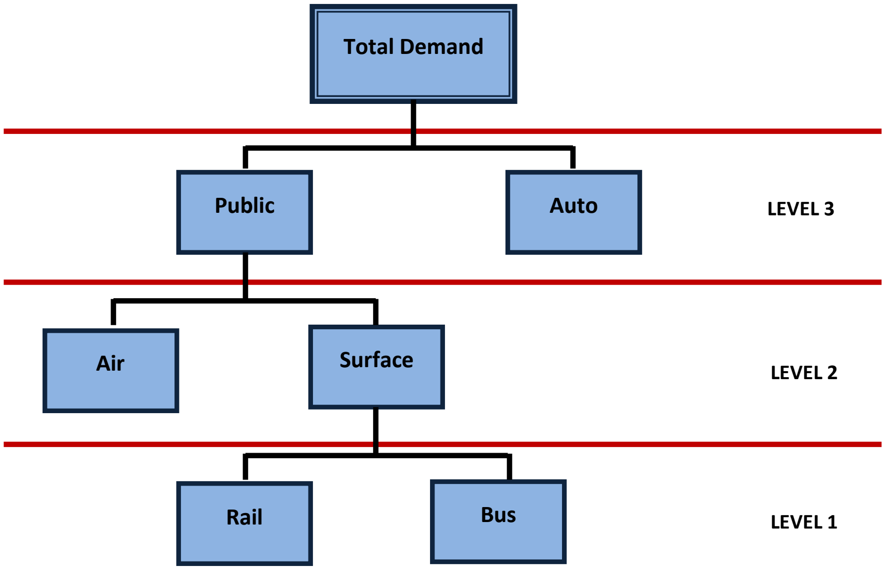
In the incremental form, the constant term disappears and only the elasticities are important.

C.3 HIERARCHICAL MODAL SPLIT MODEL

The role of the Hierarchical Modal Split Model is to estimate relative modal shares, given the Total Demand Model estimate of the total market that consists of different travel modes available to travelers. The relative modal shares are derived by comparing the relative levels of service offered by each of the travel modes. The COMPASS™ Hierarchical Modal Split Model uses a nested logit structure, which has been adapted to model the interurban modal choices available in the study area.

The hierarchical modal split model is shown in Exhibit C-2.

Exhibit C-2: Hierarchical Structure of the Modal Split Model

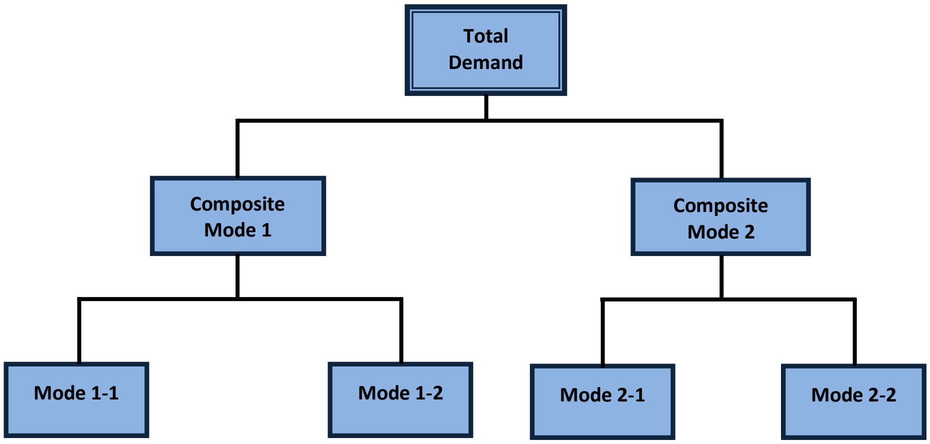


The main feature of the Hierarchical Modal Split Model structure is the increasing commonality of travel characteristics as the structure descends. The upper level of the hierarchy separates private auto travel – with its spontaneous frequency, low access/egress times, low costs, and highly personalized characteristics – from the public modes. The lower separates Maglev – a faster and more comfortable public mode from Transit, which provides slower conventional rail and bus services within the corridor.

3.3.1 BACKGROUND OF THE HIERARCHICAL MODAL SPLIT THEORY

The modal split models used by TEMS derived from the standard nested logit model. Exhibit C-3 shows a typical two-level standard nested model. In the nested model shown in Exhibit C-3, there are four travel modes that are grouped into two composite modes, namely, Composite Mode 1 and Composite Mode 2.

Exhibit C-3: A Typical Standard Nested Logit Model



Each travel mode in the above model has a utility function of U_j, $j = 1, 2, 3, 4$. To assess modal split behavior, the logsum utility function, which is derived from travel utility theory, has been adopted for the composite modes in the model. As the modal split hierarchy ascends, the logsum utility values are derived by combining the utility of lower-level modes. The composite utility is calculated by –

$$U_{N_k} = \alpha_{N_k} + \beta_{N_k} \log \sum_{i \in N_k} \exp(\rho U_i) \qquad (1)$$

Where,

N_k is composite mode k in the modal split model,
i is the travel mode in each nest,
U_i is the utility of each travel mode in the nest,
ρ is the nesting coefficient.

The probability that composite mode k is chosen by a traveler is given by

$$P(N_k) = \frac{\exp(U_{N_k} / \rho)}{\sum_{N_i \in N} \exp(U_{N_i} / \rho)} \qquad (2)$$

The probability of mode i in composite mode k being chosen is

$$P_{N_k}(i) = \frac{\exp(\rho U_i)}{\sum_{j \in N_k} \exp(\rho U_j)} \qquad (3)$$

A key feature of these models is a use of utility. Typically, in transportation modeling, the utility of travel between zones i and j by mode m for purpose p is a function of all the components of travel time, travel cost, terminal wait time and cost, parking cost, etc. This is measured by generalized cost developed for each origin-destination zone pair on a mode and purpose basis. In the model application, the utility for each mode is estimated by calibrating a utility function against the revealed base year mode choice and generalized cost.

Using logsum functions, the generalized cost is then transformed into a composite utility for the composite mode (e.g., public modes in Exhibit C-2). This is then used at the next level of the hierarchy to compare the next most similar mode choice (e.g., in Exhibit C-2, Public mode is compared with Auto mode).

C.3.2 CALIBRATION OF THE HIERARCHICAL MODAL SPLIT MODEL

Working from the lower level of the hierarchy to the upper level, the first analysis is that of the Rail mode versus the Bus mode. As shown in Exhibit C-4, the model was effectively calibrated for the two trip purposes, with reasonable parameters and R^2 and t values. All the coefficients have the correct signs such that demand increases or decreases in the correct direction as travel times or costs are increased or decreased, and all the coefficients appear to be reasonable in terms of the size of their impact.

Exhibit C-4: Rail versus Bus Modal Split Model Coefficients (1)

Business	$\log(P_{Rail}/P_{Bus})$	=	0.9332	-	0.0049	GC_{Rail}	+	0.0012	GC_{Bus}	R^2= 0.75
			(28.29)		(-221.53)			(367.79)		
Commuter	$\log(P_{Rail}/P_{Bus})$	=	0.7172	-	0.0041	GC_{Rail}	+	0.0012	GC_{Bus}	R^2= 0.72
			(23.56)		(-226.73)			(351.79)		
Non-Business	$\log(P_{Rail}/P_{Bus})$	=	0.5619	-	0.0039	GC_{Rail}	+	0.0011	GC_{Bus}	R^2= 0.73
			(19.15)		(-224.95)			(363.44)		

(1) *t-statistics are given in parentheses.*

The coefficients for the upper levels of the hierarchy of Surface mode versus Air mode and Public versus Auto mode are given in Exhibits C-5 and C-6 respectively. The utility of the composite modes is obtained by deriving the logsum of the utilities of lower-level modes from the model. The model calibrations for both trip purposes are statistically significant, with good R^2 and t values, and reasonable coefficients.

Exhibit C-5: Surface versus Air Modal Split Model Coefficients (1)

Business	$\log(P_{Surface}/P_{Air})$	=	-6.0037	+	0.5732	U_{Surf}	+	0.0031	GC_{Air}	R^2= 0.79
			(-40.87)		(9.48)			(803.06)		
	where U_{Surf} = Log[Exp(		0.9332	-	0.0049	GC_{Rail})	+	Exp(-0.0012 GC_{Bus})]		
Commuter	$\log(P_{Surface}/P_{Air})$	=	-4.0021	+	0.5001	U_{Surf}	+	0.0026	GC_{Air}	R^2= 0.76
			(-36.53)		(9.18)			(813.07)		
	where U_{Surf} = Log[Exp(		0.7172	-	0.0041	GC_{Rail})	+	Exp(-0.0012 GC_{Bus})]		
Non-Business	$\log(P_{Surface}/P_{Air})$	=	-3.2281	+	0.4100	U_{Surf}	+	0.0024	GC_{Air}	R^2= 0.79
			(-26.67)		(8.49)			(779.79)		
	where U_{Surf} = Log[Exp(		0.5619	-	0.0039	GC_{Rail})	+	Exp(-0.0011 GC_{Bus})]		

(1) *t-statistics are given in parentheses.*

Exhibit C-6: Public versus Auto Modal Split Model Coefficients (1)

Business	log(P_{Public}/P_{Auto}) =	-2.4897	+	0.9945	U_{Public}	+	0.0076	GC_{Auto}	R^2= 0.75
		(-136.93)		(174.47)			(635.47)		
	where U_{public} = Log[Exp(	-6.0037	+	0.5732	U_{Surf})	+	Exp(-0.0031	GC_{Air})]	
Commuter	log(P_{Public}/P_{Auto}) =	-3.1732	+	0.9721	U_{Public}	+	0.0062	GC_{Auto}	R^2= 0.78
		(-130.03)		(173.26)			(519.47)		
	where U_{public} = Log[Exp(	-4.0021	+	0.5001	U_{Surf})	+	Exp(-0.0026	GC_{Air})]	
Non-Business	log(P_{Public}/P_{Auto}) =	-3.8765	+	0.9607	U_{Public}	+	0.0059	GC_{Auto}	R^2= 0.78
		(-127.54)		(178.87)			(419.44)		
	where U_{public} = Log[Exp(	3.2281	+	0.4100	U_{Surf})	+	Exp(-0.0024	GC_{Air})]	

(1) *t-statistics are given in parentheses.*

C.3.3 INCREMENTAL FORM OF THE MODAL SPLIT MODEL

Using the same reasoning as previously described, the modal split models are applied incrementally to the base data rather than imposing the model estimated modal shares. Different regions of the corridor may have certain biases toward one form of travel over another and these differences cannot be captured with a single model for the entire system. Using the "pivot point" method, many of these differences can be retained. To apply the modal split models incrementally, the following reformulation of the hierarchical modal split models is used (Equation 6):

Equation 6:

$$\frac{(\frac{P_A^f}{P_B^f})}{(\frac{P_A^b}{P_B^b})} = e^{\beta(GC_A^f - GC_B^b) + \gamma(GC_B^f - GC_B^b)}$$

For hierarchical modal split models that involve composite utilities instead of generalized costs, the composite utilities would be used in the above formula in place of generalized costs. Once again, the constant term is not used and the drivers for modal shifts are changed in generalized cost from base conditions.

Another consequence of the pivot point method is that it prevents possible extreme modal changes from current trip-making levels as a result of the calibrated modal split model, thus that avoid over- or under-estimating future demand for each mode.

C.4 INDUCED DEMAND MODEL

Induced demand refers to changes in travel demand related to improvements in a transportation system, as opposed to changes in socioeconomic factors that contribute to growth in demand. The quality or utility of the transportation system is measured in terms of total travel time, travel cost, and worth of travel by all modes for a given trip purpose. The induced demand model used the increased utility resulting from system changes to estimate the amount of new (latent) demand that will result from the implementation of the new system adjustments. The model works simultaneously with the mode split model coefficients to determine the magnitude of the modal induced demand based on the total utility changes in the system. It should be noted that the model will also forecast a reduction in trips if the quality of travel falls due to increased congestions, higher car operating costs, or increased tolls. The utility function is acting like a demand curve increasing or decreasing travel based on changes in price (utility) for travel. It assumes travel is a normal good and subject to the laws of supply and demand.

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