Washington State
Department of Transportation

WSDOT's Handbook for Corridor Capacity Evaluation

1st edition

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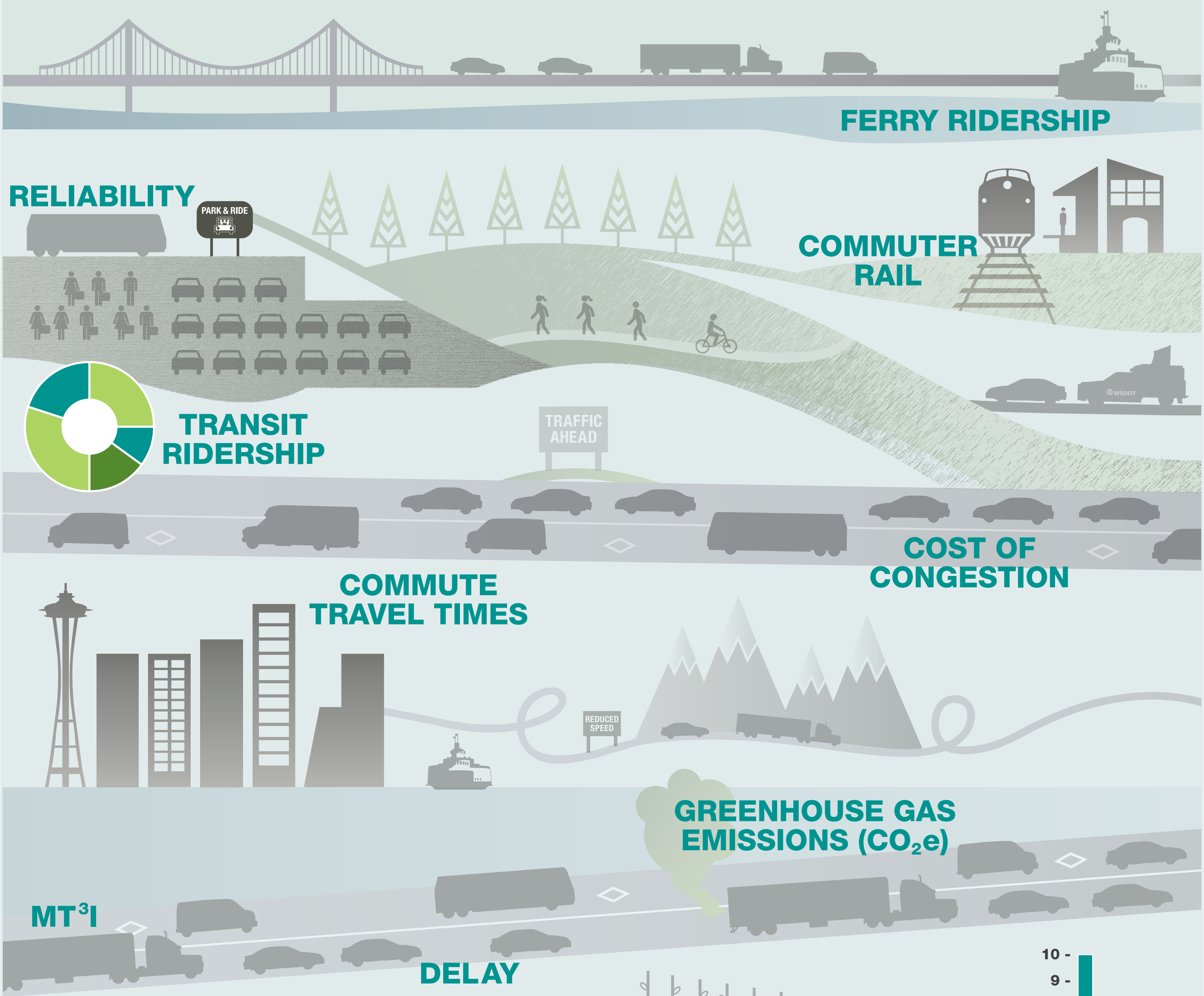

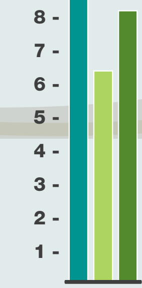

WSDOT's methods for comprehensive analysis of multimodal state highway system performance

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The Washington State Department of Transportation (WSDOT) has been publishing system performance analysis for well over a decade. The annual *Corridor Capacity Report*, previously known as the *Congestion Report*, draws attention from a wide spectrum of people from around the state of Washington and the nation.

Congestion measurements and methods to communicate capacity management results have evolved over the years. As performance measures have become more sophisticated, communicating them has become increasingly challenging. To ensure every reader is informed, WSDOT has created the following methodology document to help users navigate our multimodal analysis of transportation system performance.

This methodology document provides complete descriptions of WSDOT's approach to multimodal system performance evaluation, including our maximum throughput philosophy, multimodal performance measures, and associated thresholds. The first two chapters present these concepts, and the following chapters focus on specific performance measurement areas (such as travel delay, travel times, etc.). These chapters provide detailed measure definitions, step-by-step analysis procedures, equations, sample calculations, data sources and background information to help other agencies produce these measures for their own transportation systems.

The goal of the current document is to serve as the one-stop-shop for WSDOT's methodology used to produce the annual *Corridor Capacity Report*. This document is aimed at anyone interested in or involved with presenting system performance data collection, analysis and evaluation to a broader audience. It could also prove beneficial for technical professionals working to implement system performance measurement and reporting as part of their agency's accountability initiatives and/or Moving Ahead for Progress in the 21st Century (MAP-21) requirements. In that respect, this can be seen as a resource for implementing required MAP-21 system performance measures.

WSDOT is committed to improving its analysis methodology. We welcome and appreciate any feedback that not only helps us but also furthers the national discussion on multimodal system performance evaluation methods.

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Introduction to WSDOT's Transportation System Performance Measurement

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Evaluation Handbook shows how WSDOT creates annual analysis

WSDOT's *Handbook for Corridor Capacity Evaluation* presents how WSDOT completes its annual detailed corridor analysis of where and how much congestion occurs due to capacity constraints in Washington state, and whether it has grown on state highways. The *Corridor Capacity Report* focuses on the most traveled commute routes in the urban areas of the state: central and south Puget Sound areas, Vancouver, Spokane, and the Tri-Cities area and elsewhere around the state where data is available.

WSDOT and University of Washington experts use a two-year span for current and baseline year data in order to more accurately identify changes and trends seen on the state highway system that may be missed by looking at a one-year comparison. For example, in the 2014 *Corridor Capacity Report*, calendar year 2013 was the current analysis year data, while 2011 data was the baseline for comparison.

WSDOT collects real-time traffic data

As of June 2014, WSDOT collects real-time data for 84 commute routes in urban areas around the state, including:

- Central Puget Sound area (52 routes),
- South Puget Sound area (20 routes),
- Vancouver area (8 routes),
- Spokane area (4 routes), and
- Tri-Cities area (in progress).

In the central Puget Sound area alone, data is collected from approximately 6,800 loop detectors embedded in the pavement throughout 235 centerline miles of state highways (1,300 lane miles). Similarly, the south Puget Sound area has 128 active data sensors that stretch along 77 centerline miles (270 lane miles). WSDOT collects data from 165 Spokane area detectors, which stretch along 37 centerline miles (175 lane miles). WSDOT also uses private sector speed data for Vancouver area commute trip analysis to complement the existing WSDOT data set, and also plans to use the private sector speed data in other areas where available. Other urban areas of the state have loop detectors and a variety of other technologies used for traffic data collection such as automated license plate readers (ALPR), Bluetooth, Wavetronix and vehicle detection.

WSDOT's congestion measurement principles

- Use real-time measurements (rather than computer models) whenever and wherever possible.
- Use maximum throughput as the basis for congestion measures.
- Distinguish between and measure both congestion due to incidents (non-recurrent) and congestion due to inadequate capacity (recurrent).
- Show how reducing non-recurrent congestion from incidents will improve the travel time reliability.
- Demonstrate both long-term trends and short-to-intermediate-term results.
- Communicate possible congestion fixes using an "apples-to-apples" comparison with the current situation. For example, "If the trip takes 20 minutes today, how many minutes less will it be if WSDOT improves the interchange?"
- Use "plain English" to describe measurements and results.

The data collected from these WSDOT loop detectors are quality-controlled using a variety of software processes. WSDOT uses this data to analyze system performance. In tracking and communicating performance results, WSDOT adheres to congestion measurement principles including the use of more accurate, real-time data rather than modeled data, and uses language and terminology that is meaningful to the public ("plain English"). See the gray box above for the congestion measurement principles. See pp. 6-7 for a list of performance measures tracked.

Private-sector probe data fills in gaps

WSDOT uses private-sector data to fill the gaps on the fixed point detector coverage on roadways statewide. WSDOT purchased private-sector speed data statewide for the years 2009 through 2013. The Federal Highway Administration (FHWA) has acquired a national (private-sector) data set of average travel times for use in performance measurement. This data set is made available to states and Metropolitan Planning Organizations (MPOs), free of charge, to use for their performance management activities. The data set is available monthly starting September 2013 and is limited to the National Highway System as defined by the federal legislation Moving Ahead for Progress in the 21st Century (MAP-21) (see pp. 46-47).

WSDOT relies on a combination of data sources including WSDOT-collected data and private-sector speed data to support agency activities such as planning, programming, design, construction, and maintenance, as well as Before and After project performance measurement and reporting.

Understanding maximum throughput

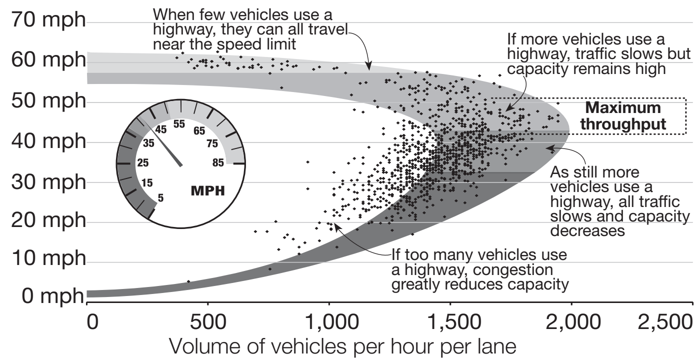
To operate the highway system as efficiently as possible, the speed at which the highest number of vehicles can move through a highway segment (maximum throughput) is more meaningful than posted speed or free-flow speed as the basis of measurement. WSDOT aims to provide and maintain a system that yields the most productivity and efficiency, rather than a system that is free flowing but where fewer vehicles can pass through a segment during peak travel periods.

Maximum throughput is achieved when vehicles travel at speeds between 42 and 51 mph (roughly 70%-85% of a posted 60 mph speed). At maximum throughput speeds, highways are operating at peak efficiency, since at slower speeds drivers feel more comfortable with less distance between vehicles; this allows more vehicles to pass through than at higher speeds, when more space is required to allow for safe stopping should the need arise.

Maximum throughput speeds vary from one highway segment to the next depending on prevailing roadway design (roadway alignment, lane width, slope, shoulder width, pavement conditions, presence or absence of median barriers) and traffic conditions (traffic composition, conflicting traffic movements, heavy truck traffic, etc.).

Understanding maximum throughput: An adaptation of the speed/volume curve

May 2010 weekday volume 6-10 a.m.; I-405 NB at 24th NE; Maximum throughput speed ranges between 70% and 85% of posted 60 mph speed limit



Data source: WSDOT Northwest Region Traffic Office.

Additionally, maximum throughput speed is not static and can change over time as conditions change. Ideally, maximum throughput speeds for each highway segment should be determined through comprehensive traffic studies and validated by field surveys.

Throughput speeds on surface arterials are more difficult to predict due to the influence of traffic signals that interrupt the flow of vehicles. WSDOT, as part of the *Corridor Capacity Report*, does not evaluate system performance on state highways with arterial flow characteristics for two reasons: the lack of detailed traffic flow data and the lack of established thresholds, measures and methodologies for arterial performance measurement.

WSDOT's Multimodal Performance Measurement Thresholds and Key Metrics

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Congestion thresholds refer to a highway's operating speed at which analysts identify the system as being congested or delayed. They are typically expressed as a percentage of the highway's posted speed, in order to allow for the thresholds to be applied to highways of multiple classifications.

See the table below for the thresholds that WSDOT uses to define and communicate congestion and delay on urban commute corridors in the *Corridor Capacity Report.*

Threshold setting considerations

WSDOT sets the travel delay threshold based on established agency practices and factors including: corridor characteristics; local conditions; operational factors; community opinion about the desirability of additional capacity in a corridor; existing capacity; population growth; freight movement goals; rural/urban routes; level of existing revenues; and potential investment required to achieve performance levels.

Agencies use congestion thresholds to address these types of criteria and investment levels. For example, California uses 35 mph on freeways as a threshold to identify serious congestion problems. Washington state uses a maximum productivity-based threshold where about 85% of the posted speed (51 mph) is used to define the point where the maximum vehicle volume per hour per lane occurs; the freeway is not as productive at moving vehicles at speeds above and below this level. Rural areas or areas with less congestion may use the speed limit or free-flow speeds as the basis to identify the magnitude of congestion.

These threshold approaches can be used for communicating the congestion problems or for analysis of potential solutions. They illustrate the effect of a full range of congestion reduction strategies.

WSDOT's performance threshold

WSDOT uses the maximum throughput threshold to measure travel delay relative to a highway's most efficient condition at maximum throughput speeds. See p. 4 for an illustration of this concept.

Maximum throughput speed depends on multiple factors such as roadway geometrics and traffic characteristics. This varies by location and type of roadway. WSDOT's performance evaluation is based on the speed at which the highway system has its maximum throughput productivity. However, maximum throughput speed is different for different measured locations. Typically, the maximum throughput of vehicles on a highway, about 2,000 vehicles per lane per hour, occurs at speeds of 42-51 mph, or about 70%-85% of a posted 60 mph speed limit. This makes it complicated to measure the corridor performance efficiency. For calculation and communication purposes, WSDOT uses 85% of posted speed as the maximum throughput speed.

WSDOT state highway speed thresholds for congestion measurement

Measure	Threshold	Description
Posted speed	60 mph (typical)	Vehicles are moving through a highway segment at the posted speed, but to travel safely and allow sufficient stopping distance, drivers must maintain more space between vehicles than at slower speeds. Fewer vehicles can pass through the segment in a given amount of time and the segment is not operating at maximum efficiency.
Maximum throughput speed (optimal flow speed)	70%-85% of posted speed (about 42-51 mph)	Vehicles are moving slower than the posted speed and the number of vehicles moving through the highway segment is higher. These speed conditions enable the segment to reach its maximum productivity in terms of vehicle volume and throughput (based on the speed/volume curve). This threshold range is used for highway system deficiency analysis.
Duration of congested period (urban commute routes)	Duration of time vehicle speeds are slower than 75% of posted speeds (45 mph)	The average weekday peak time period (in minutes) when average vehicle speeds are slower than 75% of posted speeds (about 45 mph). Drivers have less than optimal spacing between cars, and the number of vehicles that can move through a highway segment is reduced. The highway begins to operate less efficiently under these conditions than at maximum throughput.
Percent of state highway system delayed	Less than 85% of posted speeds (51 mph)	Percent of total state highway lane miles with average speeds slower than 85% of the posted speed limit.
Percent of state highway system congested	Less than 70% of posted speeds (42 mph)	Percent of total state highway lane miles with average speeds slower than 70% of the posted speed limit.
Severe congestion	Less than 60% of posted speed (36 mph)	Speeds and spacing between vehicles continue to decline on a highway segment and highway efficiency operates well below maximum productivity.

Multimodal Performance Measurement Thresholds and Key Metrics

Truck freight performance measures and speed thresholds can be found in WSDOT's Freight Mobility Plan online at http://www.wsdot.wa.gov/Freight/freightmobilityplan.

Additional sources:

WSDOT's Highway System Plan:
http://www.wsdot.wa.gov/NR/rdonlyres/B24AC1DA-8B9A-4719-B344-B083BB3F10FB/0/HSPweb.pdf

Washington Transportation Plan: http://www.wstc.wa.gov/wtp/

WSDOT's key metrics

WSDOT reports on highway system capacity, operations and related topics using a wide range of system-wide and corridor-specific metrics. The table below lists the key metrics WSDOT currently uses. Additional derived and proposed metrics are included later in this document.

Key congestion performance measures
All dollar values are inflation-adjusted using the Consumer Price Index (CPI).

Measure	Definition	Page
Delay metrics		
Per person delay (other forms of delay such as total delay)	The average total daily hours of delay per person based on the maximum throughput speed threshold (85% of posted speed) measured annually for weekdays.	8
Cost of delay	The monetary value for the vehicle hours (person hours) of delay experienced by drivers and businesses based on the increased travel time and vehicle operating costs.	8
Percent of the system delayed or congested	Percent of total state highway lane miles with average speeds slower than 85% of the posted speed limit (delayed) or 70% of posted speed (congested).	9
Travel and lane miles metrics		
Vehicle miles traveled (VMT) (other forms of VMT such as per person)	The number of miles traveled in Washington state annually. Also reporting VMT per person, and VMT on state highways as a subset of all public roads.	11
VMT avoided due to transit	The number of vehicle miles of travel that were not taken in personal vehicles due to the presence and use of transit services.	12, 32
Lane miles for state highways	The number of lane miles of Washington state highways. For example, one mile of a six-lane freeway equals six lane miles.	9
Throughput metrics		
Vehicle throughput	Measures how many vehicles move through a highway segment/spot location in an hour.	13
Person throughput	Measures how many people, on average, move through a highway segment during peak periods.	13
Lost vehicle throughput productivity	Percentage of a highway's vehicle throughput lost due to congestion when compared to the maximum 5-minute weekday flow rate observed at a particular location of the highway for that calendar year.	13
Greenhouse gas emission (GHG) metrics		
Commuter GHG emissions	The pounds of carbon dioxide equivalents (CO_2e) emitted during peak period commutes; the per-person emissions per trip during peak periods.	15
Transit GHG emissions avoided	The emissions avoided by use of transit services.	16, 32
Ferry system emissions	Emissions from ferry vessel operations; emissions avoided by using the ferry instead of driving around the Puget Sound.	17, 37
Statewide transportation emissions	Statewide pounds of CO_2e emitted by transportation, reported as percent of statewide total.	18
Economic indicator metrics		
State population	The number of residents in Washington state according to the national census.	19
Washington unemployment rate	The percent of the adult population who are unemployed and seeking employment.	19
Washington (real) per person income	Real per person income is the total statewide personal income divided by the state population.	19
Gasoline price per gallon	Gas prices represent yearly statewide averages for a gallon of regular unleaded gas.	19
Commuting mode split	The percent of the commuting population who primarily use one of the following modes: drive alone, carpool, public transit and bike or walk. Based on one-year estimates from the American Community Survey (ACS), commuting rates are of workers age 16 and older. WSDOT also includes the annual number of boardings for the WSDOT Ferries Division and all other public transit in the state as reported in the National Transit Database (NTD).	20
Job impacts of highway projects	The number of direct, indirect and induced jobs supported by spending on highway projects from design through construction of the project.	20

Continued on p. 7

Key congestion performance measures, *continued from p. 6*
All dollar values are inflation-adjusted using the Consumer Price Index (CPI).

Measure	Definition	Page
Travel time and commute trip analysis metrics		
Average peak travel time	The average travel time on a route during the peak 5-minute interval for all weekdays of the calendar year, representing the worst average travel time.	21
Maximum Throughput Travel Time Index (MT^3I)	The ratio of average peak travel time compared to maximum throughput speed travel time.	22
Number of commute routes with $MT^3I > 1$	MT^3I greater than 1.0 means the commute route experiences congestion.	22
95th percentile reliable travel time	Travel time with 95% certainty (i.e., on-time 19 out of 20 weekdays).	23
Duration of congestion	The time period in minutes when speeds are slower than 45 mph.	23
Percent of days when speeds are less than 36 mph	Percent of days annually that speeds for one or more 5-minute interval are slower than 36 mph (severe congestion) on key highway segments.	24
Commute congestion cost	Cost due to wasted fuel and time associated with travel during congested conditions (speeds slower than 45 mph).	24
Routinely congested segments	Sections of roadway where traffic demand reaches or exceeds capacity on at least 40% of the weekdays annually.	24
High occupancy vehicle (HOV) lane analysis metrics		
HOV person throughput	Measures how many people, on average, move through a highway segment in HOV lanes compared to the adjacent SOV lane during 6-9 a.m. and 3-6 p.m.	29
HOV lane reliability	An HOV lane is deemed “reliable” when it maintains an average speed of 45 mph for 90% of the peak hour.	30
HOV peak travel time	The HOV trip average travel time on a route during the peak 5-minute interval for all weekdays of the calendar year compared to SOV trip.	30
Transit trip analysis metrics		
Transit ridership (average maximum load)	The annual average peak ridership on transit summed for all transit operating along defined commute corridors during the transit peak periods (6-9 a.m. and 3-6 p.m.).	32
Transit passenger miles traveled	The miles that passengers traveled on transit operating along defined commute corridors during the transit peak periods (6-9 a.m. and 3-6 p.m.).	32
Transit utilization	Average load in percent of available seats that are used on transit serving commute routes.	33
Park and ride lot capacity and use	Number of parking spaces and percent of capacity used on an average annual weekday.	34
Accessibility analysis metrics		
Cumulative opportunities	The number of jobs reachable within an average commute time during the morning peak period, reported by Census Tract or Traffic Analysis Zone (TAZ) for personal car and transit.	35
Transit/automobile accessibility ratio	The cumulative opportunity score for transit divided by the score for personal car.	36
Ferry system use metrics		
Ferry vessel ridership	The number of passengers and vehicles using ferry services on a quarterly or annual basis.	37
Ferry on-time performance	The percent of trips that departed within 10 minutes of the scheduled departure time on a quarterly or annual basis.	37
Ferry trip reliability	The percent of scheduled trips that occurred or were replaced on a quarterly or annual basis.	37
Ferry capacity utilization	The percent of vessel passenger and vehicle capacity that is used on a quarterly or annual basis.	37
Incident Response (IR) metrics		
Average incident clearance time (Statewide)	The time between the first recorded awareness of the incident and when the last responder left the scene for all incidents responded to by WSDOT IR personnel.	40
Roadway clearance time (Statewide)	The time between the first recorded awareness of an incident by a responding agency and when all lanes are available for traffic for all incidents responded to by WSDOT IR personnel.	40
Secondary incidents	The number of unplanned incidents occurring within the original incident scene or within the back-up approaching the scene in either direction.	41
Incident induced delay and associated costs	The time difference between the total delay and the recurrent travel delay at the time and location associated with the impact of the incident.	41
Project before and after analysis metrics		44
Before and After analysis	Metrics to assess performance of congestion relief projects before and after construction include changes in average speed, travel time, traffic volume, or collisions along the affected corridor.	46

3 Travel Delay Methodology

Travel Delay is the amount of extra time spent in traffic due to increased traffic volumes. Travel delay can be calculated for the number of vehicles or people on the road and is measured relative to a speed threshold such as maximum throughput speed or posted speed.

Travel delay measures

WSDOT uses the following metrics to analyze and communicate travel delay in the *Corridor Capacity Report*:

Hours of travel delay

- Annual hours of vehicle delay
- Annual vehicle delay per capita
- Annual person delay
- Annual cost of vehicle delay
- Percent of lane miles delayed
- Percent of lane miles congested

Hours of travel delay:

WSDOT uses the following formula to calculate the hours of delay for any time period or geographic area:

$$\text{Hours of travel delay} = \left(\frac{\text{Vehicle miles traveled}}{\text{Travel speed}}\right) - \left(\frac{\text{Vehicle miles traveled}}{\text{Threshold speed}}\right)$$

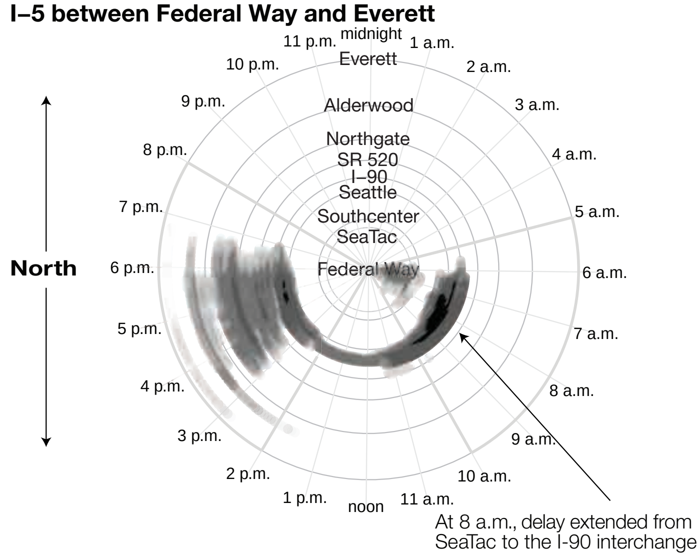
WSDOT uses maximum throughput speed (85% of posted speed limit) as the threshold in order to measure delay relative to a highway's most efficient operating condition. Travel speed is averaged hourly for each weekday by highway segment. Any of the 120 speed data points (5 days x 24 hours) that show speeds slower than the threshold speed would be identified as "experiencing delay".

Spiral graphs provide a graphic visualization of temporal and spatial data that is well suited to time-based traffic metrics. The graph can be read like a standard clock with variables specific to the chosen metric. In the following example, WSDOT modeled vehicle hours of delay by using time of day (measured in 5-minute intervals), location along the chosen corridor and intensity of delay. Darker shading represented more intense delay along the commute corridor. The shading factor was standardized for the aggregate data to allow cross-corridor comparisons. In addition, the spiral graphs were separated by direction along the corridor, supporting more detailed comparisons. Each direction is read in a different manner, as indicated by the arrows. The northbound graph below is read from the center to the edge. The corresponding southbound graph is read from the edge to the center.

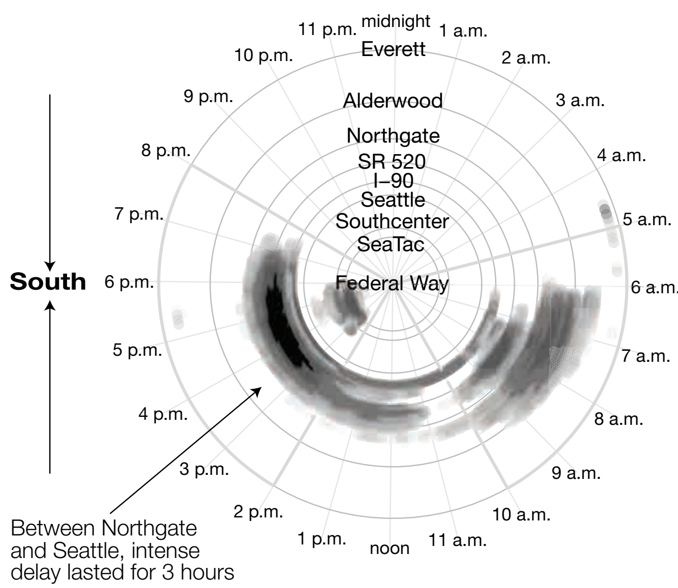
How to read a spiral graph

When and where was the most intense delay as measured by vehicle hours of delay? How does delay differ by direction of travel? What corridors experienced the most noticeable delay?

I–5 between Federal Way and Everett



Between 7 a.m. and 10 a.m. there was intense delay around the Seattle area. Evening delay peaked between 3:30 p.m. and 6:15 p.m. and was widespread along the entire northbound I-5 corridor.



Delay on I-5 southbound was more widespread during the morning but more pronounced during the evening commute. The most intense delay was southbound from Northgate to Seattle in the evening and lasted for about 3 hours.

Data source: Washington State Transportation Center (TRAC) at the University of Washington and WSDOT Office of Strategic Assessment and Performance Analysis.

Annual hours of vehicle delay (AHD) is all travel delay, reported in vehicle hours, experienced for the year. WSDOT reports AHD occurring on highways statewide. This delay is also summarized by urban area and for selected major commute corridors in the central Puget Sound region.

$$\text{Annual hours of vehicle delay} = \sum_{\text{Weekday } i=1}^{250} \left(\frac{\text{Vehicle miles traveled}}{\text{Travel speed}}\right) - \left(\frac{\text{Vehicle miles traveled}}{\text{Threshold speed}}\right)$$

WSDOT also reports AHD on a per capita basis, determined by dividing the total hours of vehicle delay experienced in a region by the corresponding population.

$$\text{Vehicle delay per capita} = \frac{\text{Annual hours of vehicle delay}_{region}}{\text{Population}_{region}}$$

WSDOT reports annual vehicle delay per capita on state highways at the statewide level and also for selected urban areas. An example calculation of statewide vehicle delay per capita in 2012 is shown below.

$$\text{Statewide vehicle delay per capita}_{2012} = \frac{\text{30,900,000 hours of delay}}{\text{6,818,000 residents}}$$

$$= \text{4.5 hours of delay per capita}$$

Annual person delay is the hours of travel delay experienced by users on the road. This figure is calculated by multiplying the average daily hours of vehicle delay experienced on a highway segment by the average number of people in each car (the average vehicle occupants) and the number of working weekdays in a year (about 250 weekdays not including holidays).

$$\text{Annual hours of person delay} = \left(\text{Average hours of daily vehicle delay} \times \text{Average vehicle occupants}\right) \times \text{Work days per year}$$

WSDOT reports annual person delay per corridor user on major urban commute corridors across the state. The number of users is calculated by multiplying the average daily traffic volume by average vehicle occupants (see p. 30).

$$\text{Delay per user}_{\text{Year; Corridor}} = \frac{\text{Annual hours of person delay}}{\left(\text{Average daily traffic volume} \times \text{Average vehicle occupants}\right)}$$

The example below gives the 2012 delay per user on the Interstate 5 (I-5) corridor in the central Puget Sound area.

$$\text{Delay per user}_{\text{2012, I-5 Seattle area}} = \frac{\text{3.13 million hours of person delay}}{\left(\text{333,934 vehicles} \times \text{1.21 occupants per vehicle}\right)}$$

$$= \text{7.73 hours of delay per commuter}$$

Annual cost of vehicle delay is the economic impact to drivers and businesses based on lost productive time, wasted fuel, and additional vehicle maintenance costs due to extra time spent in traffic. The cost of vehicle delay is calculated by applying monetary values to the estimated hours of delay incurred by passenger and truck travel, plus additional vehicle operating costs.

$$\text{Cost of vehicle delay} = \left(\text{Travel costs per hour} \times \text{Change in Consumer Price Index}_{\text{year x - year y}}\right) \times \text{Hours of vehicle delay}$$

Based on WSDOT research, the value of time for passenger trips is assumed to be half of the average wage rate, while it's assumed to be 100% of wage rate plus fringe benefits for truck drivers. The table below contains recommended hourly travel costs from research conducted in 2008 by WSDOT's Urban Planning and Freight offices and the American Transportation Research Institute. The Consumer Price Index (CPI) from the Bureau of Labor Statistics is applied to these values to reflect the influence of inflation.

Recommended hourly-based travel cost estimation
Dollars per hour in 2008 dollars

Type of cost	Area	Auto	Truck type: Light	Heavy	Mixed
Vehicle operation	Central Puget Sound	$9.50	$33.80	$48.00	$36.60
	Statewide	$9.50	$33.80	$48.00	$36.60
Travel time	Central Puget Sound	$12.40	$20.80	$27.70	$22.20
	Statewide	$11.20	$20.50	$26.80	$21.80
Total	Central Puget Sound	**$21.90**	$54.60	$75.70	$58.80
	Statewide	$20.70	$54.30	$74.80	$58.40

Data source: WSDOT Urban Planning Office.

WSDOT's Urban Planning office recommends using $26.52/hour of delay (in 2013 dollars) when assessing the cost of delay for traffic that is a mixture of vehicle types.

WSDOT reports the cost of delay aggregated to the statewide level, the cost of delay per person and cost of delay by urban area. For an example, see the calculation of statewide travel delay costs in 2012 below:

$$\text{Statewide cost of vehicle delay}_{2012} = \left(\text{\$26.52 per hour} \times 1.15\ \Delta\text{CPI}_{2008\text{-}2012}\right) \times \text{30.9 million hours of delay}$$

$$= \text{\$942 million for statewide vehicle delay costs in 2012}$$

The **percent of lane miles delayed or congested** is the portion of all lane miles that experience hourly travel speeds slower than the threshold speed (averaged for the year). WSDOT considers a highway segment delayed when the average hourly traffic speed is slower than 85% of the posted speed limit. If the average speed is slower than 70% of the posted speed limit, the segment is considered congested. WSDOT uses the following equations to calculate percent of lane miles delayed and percent of lane miles congested:

$$\text{Percent lane miles } \textit{delayed} = \left(\frac{\text{Lane miles with speed} < 85\% \text{ of posted speed}}{\text{Total lane miles}_{\textit{region}}}\right)$$

$$\text{Percent lane miles } \textit{congested} = \left(\frac{\text{Lane miles with speed} < 70\% \text{ of posted speed}}{\text{Total lane miles}_{\textit{region}}}\right)$$

Percent of lane miles delayed and percent of lane miles congested is reported for all state highway lane miles statewide and is broken down into urban and rural lane miles. For example, the equation below gives the percent of state highway lane miles congested statewide in 2012:

$$\text{Percent lane miles } \textit{congested}_{\textit{State highways}} = \left(\frac{\text{1,045 lane miles congested}}{\text{18,659 state highway lane miles}}\right)$$

$$= \text{5.6\% of state highway lane miles congested}$$

Travel delay data

WSDOT uses the following data to calculate travel delay:

- Vehicle miles traveled (VMT) – WSDOT uses VMT data available from the Highway Performance Monitoring System (HPMS). Data is collected for highway segments on an hourly basis to estimate traffic volumes for each of the 24 hours during each of the seven days of the average week. WSDOT VMT data are available here: http://www.wsdot.wa.gov/mapsdata/tdgo_home.htm
- Travel speed – WSDOT uses travel speed data from the Highway Performance Monitoring System (HPMS) data set. WSDOT is also investigating private sector speed data provided to states by FHWA. In the Puget Sound area WSDOT uses its own data collected from in-pavement loop detectors located on area highways.
- Population – Population data for these areas comes from the Washington State Office of Financial Management. These figures are available from the OFM website: www.OFM.wa.gov/pop
- Lane miles – Highway and roadway lane miles data is available online from WSDOT's Transportation Data and GIS Office (TDGO): http://www.wsdot.wa.gov/mapsdata/tdgo_home.htm
- Average vehicle occupants – Data on the average number of occupants per vehicle are based on direct visual counts made by teams of observers from 1992 through 2012 in a sampling of vehicles in the SOV and HOV lanes at selected locations, during the peak periods and in both directions of travel. Each vehicle was categorized by type and number of occupants. See p. 30 in the High Occupancy Vehicle chapter for more detail.
- Consumer Price Index (CPI) – The CPI is available from the U.S. Bureau of Labor Statistics website: http://www.bls.gov/data/inflation_calculator.htm

Uses of travel delay as a performance measure and indicator

State DOTs and MPOs incorporate delay into many different calculations, some of which are noted above, as high level measures of system performance. Better operations, shorter trips, improved transit and mixed land uses that promote non-motorized travel can reduce delay. Shorter trips (or vehicle trips that are not made) in particular will decrease regional and corridor delay by decreasing person trips and miles traveled.

As a concept, delay is easy to communicate and understand and it is sensitive enough to account for the effects of many types of transportation investments, travel patterns and land use changes. Vehicle hours of delay is a facility-based measure that can also be used as input to calculate person hours of delay for a region, or hours of delay per lane mile to identify congested road sections. Delay can also be calculated for public transportation, making it a good basis for a multimodal performance measure.

While delay has many variables, it can also serve as an indicator of the impacts from external factors. An analysis that compares delay to change in gross metropolitan product might be a good way to illustrate the impact of economic activity on delay.

Miles Traveled Methodology 4

Miles traveled is the cumulative distance traveled on public roads, reported in miles, within a specific time frame or geographic region.

Miles traveled measures

WSDOT uses the following metrics to analyze and communicate miles traveled in the *Corridor Capacity Report:*

Vehicle miles traveled

- Vehicle miles traveled per person
- Person miles traveled

Transit passenger miles traveled

- Vehicle miles avoided due to transit use

Vehicle miles traveled

Vehicle miles traveled (VMT) is the cumulative number of miles traveled by all automobiles on public roads typically reported for a calendar year. VMT is calculated by multiplying traffic volumes occurring on highway segments by segment length in miles.

$$\textbf{Vehicle miles traveled} = \text{Traffic volume} \times \text{Route length}$$

WSDOT evaluates VMT statewide by route type (all public roads, state highways only) and for specific urban corridors. The example below gives the VMT in 2012 for the Interstate 5 (I-5) Everett to Seattle commute route using all day traffic volumes:

$$\textbf{Vehicle miles traveled}_{\text{2012; All-day I-5 Everett to Seattle}} = 79{,}088 \text{ daily traffic volume} \times 24 \text{ miles} = 1{,}898{,}112 \text{ vehicle miles traveled}$$

Vehicle miles traveled per person is the total vehicle miles traveled within a corridor or region divided by population. The sample population may correspond to a region or a particular group of commuters.

$$\textbf{Vehicle miles traveled per person} = \left(\frac{\text{Vehicle miles traveled}}{\text{Population}}\right)$$

WSDOT evaluates VMT per person on a statewide basis as well as by specific urban corridors. The example below gives the statewide VMT per person in 2012 on state highways:

$$\textbf{State highways VMT per person}_{2012} = \left(\frac{31.214 \text{ billion VMT}}{6.818 \text{ million population}}\right) = 4{,}578 \text{ VMT per person}$$

Person miles traveled is the cumulative number of miles traveled by all people on a specified commute corridor, including solo drivers, those who carpool and those who take transit. This figure is derived by multiplying vehicle miles traveled by average vehicle occupancy.

$$\textbf{Person miles traveled} = \text{Vehicle miles traveled} \times \text{Average vehicle occupancy}$$

WSDOT reports person miles traveled for high-demand commute corridors in the state's urban areas either for the entire corridor or per person. The calculation below gives the aggregate person miles traveled for the I-5 corridor in 2012:

$$\textbf{Person miles traveled}_{\text{2012; I-5 corridor}} = 7{,}683{,}000 \text{ VMT} \times 1.21 \text{ occupants per vehicle} = 9{,}296{,}430 \text{ person miles traveled}$$

Vehicle miles traveled data

- WSDOT uses the following data to calculate vehicle miles traveled and related measures:
- Traffic volume - Traffic volume is a vehicle count at a given roadway location. It is measured by a detector in each lane at the location. WSDOT has loop detectors spaced at roughly half-mile intervals throughout the central Puget Sound area freeway network and at various locations on the highway system statewide. http://www.wsdot.wa.gov/mapsdata/travel/annualtrafficreport.htm
- Distance traveled - WSDOT calculates the length of highway segments using locations of loop detectors mentioned above. Highway and roadway lane miles data is available online from WSDOT's Transportation Data and GIS Office: http://www.wsdot.wa.gov/mapsdata/tdgo_home.htm
- Population or number of commuters - State population data is available for the per-capita analysis from the Washington State Office of Financial Management website: http://www.ofm.wa.gov/pop/.
- Average vehicle occupants - Data on the average number of occupants per vehicle are based on direct visual counts made by teams of observers from 1992 through 2012 in a sampling of vehicles in the SOV and HOV lanes at selected locations, during the peak periods and in both directions of travel. Each vehicle was categorized by type and number of occupants. See p. 30 in the High Occupancy Vehicle chapter for more detail.

Transit passenger miles traveled

Transit passenger miles traveled is the person miles traveled specifically by transit riders (excluding the driver). WSDOT works with local transit agencies to evaluate the transit ridership along the high-demand commute corridors in urban areas statewide. This collaborative analysis results in a total number of passengers using transit on the commute corridor during peak periods (see pp. 32-34 for more details on the transit analysis methodology).

Transit passenger miles traveled is calculated the same way as person miles traveled, by multiplying vehicle occupancy by the distance traveled. WSDOT multiplies the average maximum load of passengers for each transit trip by the trip distance. The passenger miles traveled can then be summed up for any time period or geographic area.

$$\textbf{Transit passenger miles traveled} = \sum_{\text{Time period}}^{\text{Commute trip}} \left(\textbf{Average maximum load}_{\text{Transit trip}} \ \textbf{X} \ \textbf{Distance traveled}_{\text{Transit trip}} \right)$$

WSDOT reports transit passenger miles traveled using the equation above for major commute corridors in urban areas. Statewide transit passenger miles traveled are pulled from the National Transit Database. The calculation below illustrates the transit passenger miles traveled on the I-5 Everett to Seattle commute route 5-10 a.m. in 2012:

$$\textbf{Transit passenger miles traveled}_{2012} = \sum_{\text{Morning peak period}}^{\text{I-5 Everett to Seattle}} \left(\textbf{832}_{\text{ST 510 @ 4:11 am}} + \textbf{1,214}_{\text{ST 510 @ 4:41 am}} \ldots + \textbf{1,181}_{\text{CT 412@ 10:00 am}} \right)$$

$$= \textbf{137,646 transit passenger miles traveled}$$

Vehicle miles avoided by transit use is the approximate number of miles that were not traveled in a single occupant vehicle (SOV) due to people taking transit instead. King County Metro provided WSDOT with the factor that approximately 62% of transit miles traveled would have been taken as equivalent SOV trips if transit services were not available. This takes into consideration the average rate of ridesharing in the central Puget Sound area served by Metro's transit services. Multiplying the passenger miles traveled by 0.62 results in the estimated SOV miles avoided due to transit services.

$$\textbf{Vehicle miles avoided through transit} = \textbf{Transit passenger miles traveled} \ \textbf{X} \ \textbf{0.62 SOV miles per transit passenger mile}$$

For example, applying King County Metro's conversion factor to the transit passenger miles traveled for the 2012 Everett to Seattle commute yields the SOV miles avoided.

$$\textbf{Vehicle miles avoided through transit}_{\text{2012; Morning peak I-5 Everett to Seattle}} = \textbf{137,646 transit passenger miles traveled} \ \textbf{X} \ \textbf{0.62 SOV miles avoided per transit passenger mile}$$

$$= \textbf{81,795 SOV miles avoided through transit use}$$

Transit data

All of the data for the transit trip analysis comes directly from the transit agencies WSDOT works with including Community Transit, C-Tran, InterCity Transit, King County Metro, Pierce Transit, Spokane Transit Authority and Sound Transit. See pp. 32-34 in the Transit Trip Analysis chapter for further details.

Vehicle miles traveled background

VMT is useful as a large-scale measure of change in travel demand over time. It is used for long term planning to address increasing demand; forecasting revenues; analyzing vehicle emissions; national reporting and development of state and national transportation policies and legislation; transportation research; and for other analytical purposes.

WSDOT's Transportation Data and GIS Office (TDGO) collects and reports several different types of road and street data to the Federal Highway Performance Monitoring System (HPMS) each year. Traffic data for state highways, county roads and city streets are a requirement for HPMS reporting; they are a major factor in the formula used to determine how much federal fuel tax revenue Washington state receives. TDGO collects traffic data for state highways and relies on local jurisdictions to provide traffic data for their roads and streets.

For state highways, TDGO collects data using short duration counts at approximately 4,400 locations with 1/3 of the sites getting counted each year, and Permanent Traffic Recorders (PTR) at 160 locations that count continuously all year. These count locations are a representative sample of traffic across all regions of the state and all types of highways, from low volume rural routes to high volume urban freeways. A short count is normally 48 or 72 hours long, and is not able to capture day of week or seasonal traffic variability. PTR sites do capture this variability because they are collecting data every day of the year, 24 hours each day. The short counts are adjusted to represent AADT by statistically factoring in seasonal variability and other variables using PTR data as the baseline.

VMT is only an estimate and the accuracy is highly dependent on the amount of resources available to collect traffic data. State highway VMT is a statistically valid estimate that should be within ± 5% of actual travel. The accuracy for county roads and city streets varies greatly depending on size of jurisdiction, resources available and level of need for traffic data.

Throughput Methodology 5

Throughput productivity measures the efficient use of the existing highway capacity. It can be reported for vehicles or for persons, making it a very adaptive metric. WSDOT uses the maximum throughput standard as a basis for measurement to assess travel delay relative to a highway's most efficient speed of about 85% of posted speed.

Throughput measures

WSDOT uses the following metrics to analyze and communicate throughput in the *Corridor Capacity Report:*

Traffic volume

Throughput

- Vehicle throughput
- Person throughput
- Throughput productivity
- Lost throughput productivity
- Remaining capacity

Traffic volume metric:

Traffic volume is the number of vehicles that pass a specific point in a defined timeframe, typically expressed as "vehicles per hour per lane".

Throughput metrics

Vehicle throughput is the number of vehicles that pass a specific point within a defined timeframe. The typical benchmark is the maximum throughput measured for every defined location. Maximum throughput depends on factors such as roadway geometry (number of lanes, curves, hills, on- or off-ramp spacing), typical driving behavior and speed limit.

$$\text{Vehicle throughput} = \frac{\text{Traffic volume}}{\text{Number of lanes}}$$

Because throughput is affected by roadway geometry and other factors, WSDOT takes the approach of measuring throughput on every route that is routinely analyzed for congestion. WSDOT tracks the vehicle throughput using in-pavement loop detectors on the major commute corridors in the primary urban areas around the state. For each segment of these corridors, WSDOT conducts an assessment and identifies the largest volume flowing through the area in a 5-minute interval on each route. That measurement is then converted into "vehicles per hour per lane," and identified as the maximum throughput for that route. This calculated value is dynamic and changes year to year.

WSDOT calculates vehicle throughput annually, and uses the highest value for vehicles per hour per lane as the basis for evaluation in the annual *Corridor Capacity Report*.

Person throughput follows a similar concept: it is the number of people that pass a specific point within a defined timeframe (people per hour per lane). This metric is based on observational studies that track the average number of occupants in each vehicle, and is frequently used to compare high-occupancy vehicle lane performance to adjacent single-occupant vehicle lane performance. In addition to the data for vehicle throughput, "person throughput" requires an estimate of the average number of vehicle occupants (see p. 30).

$$\text{Person throughput} = \frac{\text{Traffic volume X Vehicle occupants}}{\text{Number of lanes}}$$

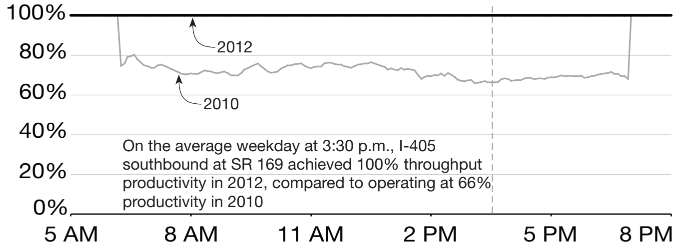
Throughput productivity is the efficiency of a highway segment, expressed as a percentage of the maximum throughput recorded at that particular highway location.

$$\text{Throughput productivity} = \left(\frac{\text{Actual throughput}}{\text{Maximum throughput}}\right)$$

Highways are engineered to move specific volumes of vehicles based on the number of lanes and other design aspects. Highways are not operating at their maximum efficiency when all vehicles are moving at 60 mph – the typical urban highway posted speed limit in Washington state. As congestion increases, speeds decrease, and fewer vehicles pass through the corridor. Throughput may decline from a maximum of about 2,000 vehicles per hour per lane traveling at speeds between 42 and 51 mph (100% efficiency) to as low as 700 vehicles per hour per lane (35% efficiency) at speeds slower than 30 mph.

Lost throughput productivity is the percentage of a highway's vehicle throughput lost due to congestion when compared to the maximum 5-minute weekday flow rate observed at a particular location of the highway for that calendar year.

Vehicle throughput productivity on southbound I-405 at SR 169 (milepost 4.0) improves to 100% in 2012
2010 and 2012; Based on the highest observed 5-minute flow rate; Vehicles per hour per lane (vphpl); Southbound = 1,790 vphpl



Data source: WSDOT Urban Planning Office.

Lost throughput productivity is the remaining capacity available if the system were to operate at optimal conditions. The graphic above illustrates one such situation, and compares the throughput productivity from two years.

$$\textbf{Lost throughput productivity}_{\text{5-min}} = \textbf{100\%} - \textbf{Throughput productivity}_{\text{5-min}}$$

Remaining capacity is the number of vehicles that could be added to the highway to reach the maximum throughput flow. It may also be used to discuss the potential remaining capacity in terms of person throughput if the roadway operated with less congestion.

Throughput and vehicle occupant data

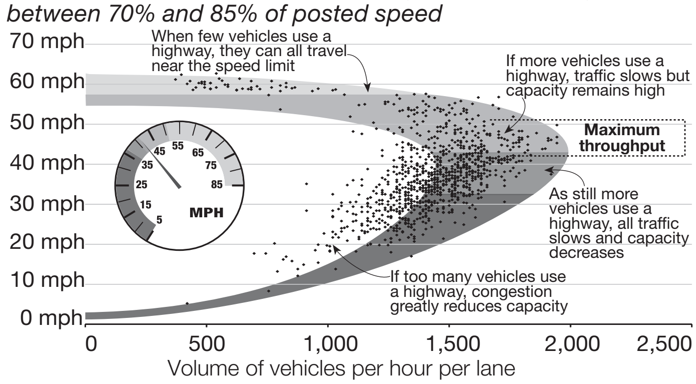
Quality-controlled volume and speed data for 16 sample locations throughout the Puget Sound area freeway network are downloaded from the TRACFLOW database (see p. 25). This data is further analyzed to calculate vehicle throughput. WSDOT's approach to estimating vehicle occupants is described in more detail on p. 30.

Background information on throughput

To operate the highway system as efficiently as possible, the speed at which the highest number of vehicles can move through a highway segment (maximum throughput) is more meaningful than posted speed as the basis of measurement. WSDOT aims to provide and maintain a system that yields the most productivity and efficiency, rather than a system that is free flowing but where fewer vehicles can pass through a segment during peak travel periods.

On freeways, maximum throughput is achieved when vehicles travel at speeds between 42 and 51 mph (roughly 70%-85% of a posted 60 mph speed limit). At maximum throughput speeds, highways are operating

Understanding maximum throughput: An adaptation of the speed/volume curve
May 2010 weekday volume 6-10 a.m.; I-405 NB at 24th NE; Speed limit 60 mph; Maximum throughput speed ranges between 70% and 85% of posted speed



Data source: WSDOT Northwest Region Traffic Office.

at peak efficiency because more vehicles are passing through the segment than at posted speeds. This happens because drivers at maximum throughput speeds can safely travel with a shorter distance between vehicles than they can at posted speeds.

Maximum throughput speeds vary from one highway segment to the next depending on prevailing roadway design (roadway alignment, lane width, slope, shoulder width, pavement conditions, presence or absence of median barriers) and traffic conditions (traffic composition, conflicting traffic movements, heavy truck traffic, etc.). The maximum throughput speed is not static and can change over time as conditions change. Ideally, maximum throughput speeds for each highway segment should be determined through comprehensive traffic studies and validated by field surveys. For surface arterials (interrupted flow facilities), maximum throughput speeds are difficult to predict because they are influenced by interruptions in flow due to the conflicting traffic movements at intersections.

WSDOT uses the maximum throughput standard as a basis for measurement to assess travel delay relative to a highway's most efficient condition at maximum throughput speeds (70%-85% of posted speed). For more information on changes in travel delay performance, see pp. 8-10.

WSDOT also uses maximum throughput as a basis for evaluating the system through the following measures:

- Total delay and per person delay (see p. 8)
- Percent of the system that is delayed, congested (see p. 9)
- Maximum Throughput Travel Time Index – MT^{3}I (see p. 22)
- Duration of the congested period (see p. 23)
- Commute congestion cost (see p. 24)

Greenhouse Gas Emissions Methodology

6

Greenhouse gases (GHG) are emitted by natural and man-made processes, and include a wide range of gases such as methane and nitrous oxide. The primary sources include generating electric power (except for hydro-electric, wind, and solar power generators); transporting goods, services, and people; industry (manufacturing of goods); agriculture; and commercial/ residential energy use. Carbon dioxide (CO_2) accounts for the majority of emissions by weight, and is frequently used as the primary metric for reporting GHG emissions. WSDOT converts multiple other GHG emissions into carbon dioxide equivalents (CO_2e) based on their relative global warming potential compared to carbon dioxide.

Emissions measures

WSDOT uses the following metrics to analyze and communicate transportation-related greenhouse gas emissions in the *Corridor Capacity Report:*

Corridor emissions for all vehicles

- Emissions in a 5-minute interval
- Peak period emissions
- All-day emissions
- Emissions per person per trip

Corridor emissions for transit

- Emissions avoided due to transit

Ferry vessel emissions

- Ferry system emissions
- Emissions saved by taking the ferry instead of driving

Statewide emissions

- Annual emissions from all sources statewide
- Portion of all emissions that come from transportation sources annually

Corridor emissions for all vehicles:

Emissions in a 5-minute interval is expressed in pounds of carbon dioxide equivalents (CO_2e), and is evaluated for every 5-minute interval for each commute corridor. Different emissions factors are applied based on the mix of trucks and passenger vehicles and the average speed during that time of day.

$$\text{5-minute GHG emissions} = \text{Trip length} \times \text{5-min traffic volume} \left(\text{Truck\% X Truck emission factor} + \text{Car\% X Car emission factor} \right)$$

The following example calculates the pounds of CO_2e emitted from 7:25 to 7:30 a.m. in 2013 on the Federal Way to Seattle commute corridor, based on the values in the table below.:

$$\text{5-minute GHG emissions} = \underset{\substack{\text{Federal Way-Seattle} \\ \text{7:25 - 7:30 a.m.}}}{\text{431 vehicles}} \times \text{21.85 miles} \left(\begin{array}{c} \text{4\% X 2.781 + 4\% X 5.300} \\ \text{+92\% X 0.972 lbs } CO_2\text{e per mile} \end{array} \right)$$

$$= \text{11,876 pounds of } CO_2\text{e in peak 5 minutes}$$

Peak period and all-day emissions are expressed in pounds of CO_2e emitted during the defined timeframe for each commute corridor, using the equation below:

$$\text{Peak period GHG emissions} = \sum_{\substack{\text{All 5-min intervals} \\ \text{during peak period}}} \left(\text{5-minute GHG emissions} \right)$$

For example, the calculation for pounds of CO_2e emitted during the 5-10 a.m. morning commute peak period in 2013 on the Federal Way to Seattle commute corridor is abbreviated below, based on the values in the table below:

$$\text{Peak period GHG emissions} = \sum_{\substack{\text{All 5-min intervals} \\ \text{5:00 - 9:55 a.m.}}} \left(\begin{array}{c} 5{,}502+6{,}251+7{,}218+...+12{,}025+11{,}876 \\ +11{,}762+...+9{,}252+9{,}049+8{,}922 \end{array} \right)$$

$$= \text{626,562 pounds of } CO_2\text{e in peak period}$$

Example calculations for corridor emissions

2013 weekdays only; Morning commute peak period 5-10 a.m.; Federal Way to Seattle; Emissions in pounds of carbon dioxide equivalents (CO_2e)

Route length = 21.85 miles — Medium truck = 4%

1.154 people per vehicle,on average — Heavy truck = 4%

Time of day	Average speed	Traffic volume	Emission factors: Medium truck	Heavy truck	Passenger vehicle	Pounds of CO_2e
4:55	60	230	1.887	3.913	0.816	5,107
5:00	60	248	1.887	3.913	0.816	5,502
5:05	60	282	1.887	3.913	0.816	6,251
5:10	59	326	1.887	3.913	0.816	7,218
...						
7:20	27	437	2.781	5.300	0.972	12,025
7:25 (peak 5-min interval)	**27**	**431**	**2.781**	**5.300**	**0.972**	**11,876**
7:30	27	427	2.781	5.300	0.972	11,762
...						
9:45	41	380	2.298	4.379	0.881	9,252
9:50	42	372	2.298	4.379	0.881	9,049
9:55	42	367	2.298	4.379	0.881	8,922
10:00	43	363	2.207	4.334	0.869	8,696
10:05	44	364	2.207	4.334	0.869	8,727
					Total peak period emissions:	**626,562**
					All day emissions:	**1,994,536**

Data source: WSDOT Office of Strategic Assessment and Performance Analysis; Washington State Transportation Center (TRAC) at the University of Washington; Regional planning organizations.

All-day emissions are calculated using the same formula noted previously, summed for the 288 5-minute intervals in the day.

Emissions per person per trip looks at the CO_2e emitted during peak period commutes for each person on the route at that time.

$$\text{Emissions per person per trip} = \frac{\text{Peak period GHG emissions}}{\text{Peak period traffic volume X Vehicle occupancy}}$$

Illustrated below is the pounds of CO_2e emitted for every person taking a trip on the Federal Way to Seattle commute corridor during the 5-10 a.m. morning commute peak period in 2013. The trip length is 21.85 miles, so there is roughly one pound of CO_2e emitted for every mile of travel per person.

$$\text{Emissions per person per trip} = \frac{\text{626,562 pounds of } CO_2e}{\text{25,062 vehicles X 1.154 people per vehicle}}$$

$$= \text{21.7 pounds of } CO_2e \text{ per person per trip}$$

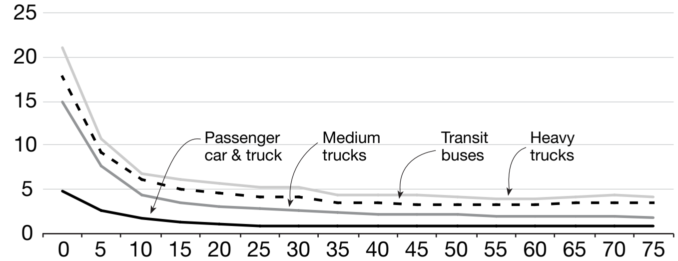
Vehicle emissions data

- Emissions factors - Regional planning agencies such as the Puget Sound Regional Council provide average emissions factors by vehicle type and travel speed.
- Truck percents - Mix of trucks (heavy, medium) along the corridor - available in WSDOT's Annual Traffic Report under the Annual Average Daily Traffic Volumes section. "medium trucks" = single axle, "heavy trucks" = double or triple axle. See http://www.wsdot.wa.gov/mapsdata/travel/pdf/Annual_Traffic_Report_2012.pdf for details.
- Traffic volume and average travel speed for every 5-minute interval (see pp. 25-28 for details on the data sources).
- Trip length for the analysis corridor.
- Vehicle occupancy data (field observed or estimated), p. 30.
- Peak period definitions - typically 5-10 a.m. and 2-8 p.m., although they may vary by urban area.

Background information:

CO_2e emissions from vehicles are directly related to the speed at which the vehicle is traveling, as shown in the example graph on this page. For speeds slower than 25 mph, the emissions quickly escalate to more than five times as many pounds of CO_2e per mile compared to at faster speeds. However, there is little variation in emissions

Example greenhouse gas emissions factors for four categories of vehicles decline with increasing speed
Carbon dioxide equivalent emissions in pounds of CO_2e per vehicle mile traveled; Speed in miles per hour



Data source: Puget Sound Regional Council.
Note: Factors for 2012 restricted access urban roadways. Emissions factors do not reflect relative emissions per person mile traveled by the different modes of transportation.

per vehicle mile traveled between 35 and 65 mph, the typical range of speeds on Washington highways. Emissions also vary by the type of vehicles: medium and large trucks emit more CO_2e per mile than a typical passenger car. Total emissions on a roadway during the peak period fluctuate more with the volume of vehicles on the roadway year to year, than with the changes in average speed, unless the average speeds are slower than 25 mph.

Corridor emission for transit:

Emissions avoided due to transit is the net pounds of CO_2e emissions avoided due to transit ridership.

This value is the difference between what is not emitted when people take transit instead of driving a personal vehicle, and the emissions from transit vehicle operations.

$$\underset{\text{Due to transit use}}{\text{Emissions avoided}} = \text{Transit ridership} \text{ X } \text{Trip length} \text{ X } \text{0.62 SOV miles per transit passenger mile} \text{ X } \text{1 lb } CO_2e \text{ per mile traveled}$$

$$- \sum_{\text{All transit trips}} \left(\text{Transit trip length} \text{ X } \text{Transit vehicle GHG factor} \right)$$

The example below illustrates the pounds of CO_2e avoided due to transit ridership during the 6-9 a.m. morning commute peak period in 2012 on the Everett to Seattle corridor on service provided by Community Transit:

$$\underset{\text{Due to transit use}}{\text{Emissions avoided}} = \text{4,842 riders} \text{ X } \text{23.66 miles} \text{ X } \text{0.62 SOV miles per transit passenger mile} \text{ X } \text{1 lb } CO_2e \text{ per mile traveled}$$

$$- \sum_{\text{All transit trips}} \left(\text{16.18 X 5.448 + 15.77 X 5.448 + 21.93 X 5.448 + 23.66 X 5.448 + 21.88 X 5.448 + ...} \right)$$

$$= \text{48,413 pounds of } CO_2e \text{ emissions avoided each weekday during the morning peak period}$$

Transit emissions data

- King County Metro provided the factor used to estimate the emissions avoided due to transit use: 0.62 miles of solo driving are avoided on public roadways for every mile of transit service used by a passenger.
- Factors for transit vehicle fleet emissions were provided by Community Transit, Intercity Transit, Sound Transit, King County Metro, and Spokane Transit Authority, listed below.
- The trip length is the commute corridor length instead of the entire bus route length, unless the particular bus route travels on only a portion of the commute corridor.

Washington state transit agencies provided transit ridership data following detailed, collaborative discussions with WSDOT:

- C-Tran (Vancouver area), Development and Public Affairs
- Community Transit (central Puget Sound), Strategic Planning office
- Intercity Transit (south Puget Sound), Planning Division
- King County Metro, Strategic Planning and Analysis office
- Sound Transit (central Puget Sound), Service Planning office
- Spokane Transit Authority, Planning Division

http://www.watransit.com/Pages/OurMembers.aspx

Converting transit emission factors from CO_2 to CO_2e
Greenhouse gas emissions in pounds of carbon dioxide equivalents (CO_2e) per vehicle mile traveled

Transit vehicle type[1, 2]	CO_2 value	Conversion[3]	CO_2e value
GP vehicle[1]	1.000	1.00295	1.00295
C-Tran	4.070	1.00047	4.07192
Community Transit	5.445	1.00047	5.44757
Spokane Transit Authority	4.046	1.00047	4.04837
Spokane Transit Authority	5.431	1.00047	5.43385
King County Metro - 1	4.220	1.00047	4.22199
King County Metro - 2	4.920	1.00047	4.92232
King County Metro - 3	5.800	1.00047	5.80274
King County Metro - 4	5.860	1.00047	5.86277
King County Metro - 5	6.700	1.00047	6.70316
King County Metro - 6	7.010	1.00047	7.01331
CO_2e values provided by transit agencies:			
Intercity Transit			2.15000
Sound Transit - bus			4.63000
Sound Transit - train			16.03000
Sound Transit - light rail			1.54000

Data source: WSDOT Office of Strategic Assessment and Performance Analysis, Puget Sound Regional Council, and transit agencies in Washington state.
Notes: 1 "GP vehicle" is based on passenger cars and passenger trucks operating at 45 mph. 2 Transit is based on "Intercity Buses" operating at 45 mph. 3 Conversion factors from CO_2 to CO_2e are based on the percent difference in emissions factors provided by the Puget Sound Regional Council for CO_2 and CO_2e in 2013.

Ferry vessel emissions:

Emissions from operating ferry vessels are reported in kilograms of carbon dioxide equivalents (CO_2e) annually for the entire fleet of ferry vessels. It can also be reported on a per-vessel or a per-trip level.

Operating ferry vessels more efficiently helps WSDOT reduce greenhouse gas emissions. WSDOT's Ferries Division's efforts to reduce ferry emissions center on two strategies: 1) using cleaner fuel and 2) using fuel more efficiently. With $63.4 million spent on ferry fuel in fiscal year 2012 (July 1, 2012 through June 30, 2013), conserving fuel both lowers emissions and saves money.

$$\textbf{Ferry vessel emissions} = \textbf{Fuel use in gallons of diesel} \times \left(\textbf{9.70 kilograms } CO_2e \textbf{ per gallon of diesel}\right)$$

The equation above can be used to calculate emissions for a single vessel per trip, or for higher-level metrics like the entire fleet. For fiscal year 2012, the fleet-wide emissions were calculated as follows:

$$\textbf{Ferry vessel emissions} = \underbrace{\textbf{17,471,178 gallons}}_{\text{FY 2012 fleet fuel use}} \times \left(\textbf{9.70 kilograms } CO_2e \textbf{ per gallon of diesel}\right)$$

$$= \textbf{169,470,427 kg of } CO_2e \textbf{ in FY2012}$$

To convert this value to pounds of CO_2e, multiply the total by the factor of 2.205 pounds per kilogram.

Ferry emissions data

- WSDOT tracks the fuel expenditures for ferry vessel operations and the gallons of fuel used by type, such as biodiesel (B99) and ultra low sulfur diesel (ULSD).

The benefits of riding the ferry compared to driving include saving time, money and emissions. See pp. 38-39 in the Ferries chapter for details on the time and cost savings.

WSDOT's Ferries Division examined the six busiest commuter routes in the ferry system (representing 71% of all ferry commuters) to compare the time, cost and greenhouse gas emissions of a commuter driving around the Puget Sound versus taking a ferry. The emissions savings are detailed below:

$$\underbrace{\textbf{Emissions avoided}}_{\text{By taking the ferry instead of driving}} = \left(\textbf{Car trip fuel use in gallons of gas} \times \textbf{7.97 kilograms } CO_2e \textbf{ per gallon of gasoline}\right) - \left(\frac{\textbf{Ferry trip fuel use in gallons of diesel}}{\textbf{Average passengers per ferry trip}} \times \textbf{9.70 kilograms } CO_2e \textbf{ per gallon of diesel}\right)$$

Greenhouse Gas Emissions

Commuting by ferry saves time, costs and emissions
Time in minutes; Greenhouse gas emissions (GHG) in kilograms of carbon dioxide equivalents; Savings compared to driving around the Puget Sound

Highest volume commute routes in the Puget Sound[1]	Daily round trip savings		
	Time	Cost	GHG
Bainbridge - Seattle	119	$32	66
Bremerton - Seattle	39	$21	40
Poulsbo - Seattle	87	$23	51
Port Townsend - Seattle	75	$21	41
Langley - Everett	219	$19	67
Hansville - Everett	194	$14	72

Data source: WSDOT Washington State Ferries Division.
Notes: 1 Trips to Seattle assume ferry commuters are walk-on passengers and some routes involve driving to the ferry terminal. Trips to Everett assume commuters drive a vehicle onto the ferries.

For example, each passenger who chose to take the round-trip on the ferry between Bainbridge Town Center and Seattle Westlake instead of driving alone around the Puget Sound saved 66 kilograms of CO_2e from being emitted, as shown below:

$$\text{Emissions avoided by ferry use}_{\text{Round-trip between Bainbridge and Seattle}} = \left(\frac{181\text{ miles}}{20.3\text{ miles/gallon}} \times \frac{7.97\text{ kg }CO_2e}{\text{gallon of gas}}\right) - \left(\frac{0.488\text{ gallons}}{\text{Ferry rider}} \times \frac{9.70\text{ kg }CO_2e}{\text{gallon of diesel}}\right)$$

$$= 66\text{ kg of }CO_2e\text{ avoided per person per trip}$$

The evaluation of emissions avoided by riding the ferry instead of driving around the Puget Sound does not apply to all ferry routes. Specifically, riders served by ferry routes to and from Vashon and the San Juan Islands do not have an alternative to drive as these islands are not connected to the mainland by bridges.

Emissions avoided data for ferries

- The "Drive or Sail" folio can be found online at http://www.wsdot.wa.gov/Ferries/Environment/default.htm.
- The following emission factors were applied to fuel consumption by mode: Driving: 7.97 kg carbon dioxide equivalents (CO_2e) per gallon of gasoline, and Ferries: 9.70 kg CO_2e per gallon of B5 diesel. These values were updated after WSDOT published the "Drive or Sail folio" in 2012, above.
- Fuel efficiency is calculated for various vehicle models every year. The analysis used 20.3 miles per gallon for a 2000 model year vehicle from the U.S. Energy Information Administration, available at http://www.eia.gov/consumption/archive/rtecs/nhts_survey/2001/tablefiles/page_a05.html.
- The Puget Sound Air Emissions Inventory is a collaborative study of trends in Puget Sound maritime air emissions between 2005 and 2011. WSDOT participated in the study, which can be found in its entirety at http://www.pugetsoundmaritimeairforum.org/.

Statewide emissions:

Statewide greenhouse gas emissions (GHG) are typically reported as million metric tons of carbon dioxide equivalents ($MMtCO_2e$) emitted. The primary sources include generating electric power (except for hydro-electric, wind, and solar power generators); transporting goods, services, and people; industry (manufacturing of goods); agriculture; and commercial/residential energy use.

Statewide transportation emissions represent the portion of statewide greenhouse gas emissions that come from the transportation of goods, services and people. It is reported as the percent of all statewide emissions and calculated as follows:

$$\%\text{ transportation emissions}_{\text{Of statewide emissions}} = \frac{\text{Emissions from transportation in }MMtCO_2e}{\text{Statewide emissions in }MMtCO_2e}$$

$MMtCO_2e$ = million metric tons of carbon dioxide equivalents

The portion of all emissions in Washington state in 2010 that came from transportation sources is calculated as follows:

$$\%\text{ of all emissions}_{\text{Transportation emissions in 2010}} = \frac{42.2\ MMtCO_2e}{96.1\ MMtCO_2e} = \text{43.9\% of all emissions in Washington were from transportation sources in 2010}$$

Transportation accounts for about 27% nationally of all greenhouse gas emissions, according to the Environmental Protection Agency. The local percentage of all emissions is higher than the national average due to the carbon neutral hydroelectric power plants in Washington state. Many other states have power plants that use non-renewable energy, resulting in much higher emissions for the energy generation sector.

Statewide emissions data

- Washington State Department of Ecology, http://www.ecy.wa.gov/climatechange/ghg_inventory.htm.
- Environmental Protection Agency, http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

Economic Indicators Affecting Travel Methodology

7

Economic indicators are metrics that affect travel behavior, such as changes in employment status, total statewide population, gasoline prices and income. For example, if unemployment is high, fewer people will be on the roads commuting. If personal income is low or gas prices are high, then more people make extra effort to take public transit or carpool instead of driving alone to work. There are many direct and indirect effects that are well documented elsewhere.

Economic indicator measures

WSDOT uses the following metrics to analyze and communicate the economic indicators that affect travel behavior in the *Corridor Capacity Report:*

Population and employment metrics

- State population
- Employment
- Unemployment rate
- Real personal income
- Real personal income per capita

Other economic indicator metrics

- Gasoline price
- Mode-split commuting rates

Job impacts of highway projects

- Direct job impacts
- Indirect job impacts
- Induced job impacts

Population and employment metrics:

State population is the number of Washington state residents as of April 1 of a given year.

Employment quantifies the annual number of people in Washington state who are employed in non-farm work.

Unemployment rate is the annual percent of the statewide labor force who are unemployed and seeking employment.

Personal income is the income received by persons from participation in production, from government and business transfer payments, and from government interest. Real personal income is personal income adjusted for inflation.

Real per-person/per-capita income is the personal income divided by the population and adjusted for inflation.

Population and employment data

The Local Area Unemployment Survey (LAUS) provides state and regional estimates of employment, unemployment and the unemployment rate nationally. The state monthly model estimates combine current and historical data from the Current Population Survey (CPS), the Current Employment Statistics (CES), and State Unemployment Insurance systems. The state monthly model estimates are controlled to sum to the national monthly labor force estimates. The CPS is based on a nationwide sample of 60,000 households. Non-farm employment data is available from the U.S. Bureau of Labor Statistics from the Current Employment Statistics dataset here: http://www.bls.gov/sae/, while unemployment rate data is available from the Local Area Unemployment Statistics dataset here: http://www.bls.gov/lau/

The number of Washington state residents is defined by the U.S. Census Bureau as of April 1 of a given year. This includes persons in housing units, military personnel and their dependents, persons living in correctional institutions, persons living in residential care facilities, and college students. State population data is available from Washington State's Office of Financial Management (OFM) here: http://www.ofm.wa.gov/pop/april1/default.asp for the annual April 1 official population estimates.

Data on per person income is available from the U.S. Bureau of Economic Analysis by state, county or metropolitan area here: http://bea.gov/regional/index.htm.

The Consumer Price Index (CPI) is used to adjust monetary values (such as gasoline prices and personal income) for inflation. Numbers adjusted for inflation are reported in terms of the report year. For example, the 2013 *Corridor Capacity Report* compares 2012 to 2010 data. In this report, monetary values adjusted for inflation are reported in 2012 dollars. CPI data is obtained from the Bureau of Labor Statistics here: http://www.bls.gov/cpi/.

Other economic indicator metrics

Gasoline price is the annual average price per gallon for regular unleaded gasoline statewide. Gasoline price data are used to calculate weighted average price estimates at the city, state, regional and national levels using sales and delivery volume data.

Mode-split commuting rates track the percent of people statewide who commute primarily by driving alone, carpooling, public transit (buses, trains, ferries), and bicycling or walking.

The American Community Survey (ACS) is an ongoing statistical survey that samples a small percentage of the population every year. It collects basic demographic information, plus elements such as income, education, home and work locations, and how people get to work.

The Census Bureau extrapolates data collected from the survey, and develops statistics for each state (and smaller geographic areas such as "metropolitan statistical areas"). WSDOT also includes the number of boardings for the WSDOT Ferries Division and all other public transit in the state from the National Transit Database alongside ACS data. WSDOT uses this data to track overall trends in how people are commuting between home and work.

Other economic indicators data

Every Monday, retail prices for all three grades of gasoline are collected by telephone from a sample of approximately 800 retail gasoline outlets. The prices are published around 5:00 p.m. eastern time Monday. The reported price includes all taxes and is the pump price paid by a consumer as of 8:00 a.m. Monday. This price represents the self-serve price except in areas having only full-service stations. Delivery volume data are available from other Energy Information Administration surveys:
http://www.eia.gov/dnav/pet/TblDefs/pet_pri_gnd_tbldef2.asp

Since these are monetary values, they are adjusted for inflation using the CPI, as noted above.

The American Community Survey data for Washington state is available here: http://www.census.gov/acs/www/

Job impacts of highway projects

WSDOT works with the Washington state Office of Financial Management (OFM) economists to estimate the number of jobs created or saved due to highway construction projects. OFM maintains a nationally-recognized model that is based on state data (typically updated every 5-10 years) that can be used to estimate the employment impact of highway construction projects.

The number of jobs created or supported by a transportation project depends on expenditures for a given fiscal year by project phase:

- Preliminary engineering (planning, design, cost estimating)
- Right of way purchasing
- Construction

These phases can occur over a number of years and carry different job-creation multipliers that are updated periodically by OFM. Project expenditures for each phase are divided by \$1,000,000 and then multiplied by a job impact multiplier. The multipliers estimate the number of jobs created for every \$1,000,000 in project spending for each project phase in a given fiscal year.

$$\underset{\text{In fiscal year (FY) x}}{\textbf{Jobs created}} = \sum_{\text{For each project phase}} \frac{\left(\textbf{Spending X Impact multiplier}\right)_{\text{Phase x, FY x}}}{\textbf{\$1,000,000}}$$

After the project's job impacts are calculated for each fiscal year in which the project is expected to have expenditures, the peak year job impact and the average yearly job impact are calculated. Jobs are never summed across years; the job impact of a project is only conveyed in terms of average annual job impact and peak year job impact.

Any time a multiplier is used, it is important to remember that it is only an estimate. Using the job multiplier at the beginning of a project gives a statewide "ballpark" estimate of the total number of jobs created or saved. The estimate produced by the multiplier includes direct, on-the-project jobs, as well as indirect and induced jobs.

Direct jobs are the actual jobs created or saved from the new investment in highway construction. Examples of these types of jobs include highway construction workers and project engineers.

Indirect jobs are created or saved in industries supporting the direct spending. Examples of these types of jobs include workers in industries supplying asphalt and steel.

Induced jobs are jobs created by the spending of worker income on consumer goods and services, including food, clothing and recreation.

Job multipliers data

The Forecasting and Research Office at OFM provides the job multiplier factors to WSDOT.

Travel Time Trends
Corridor Capacity Analysis Methodology

8

Commute trip analysis refers to

WSDOT's calculation of various congestion performance measures using custom-built tools such as web-based TRACFLOW and WSDOT's Mobility Analysis Software using the Microsoft Excel Visual Basic platform. WSDOT transforms traffic data into performance measures that tell the commute congestion story for urban travel.

Corridor capacity analysis measures

WSDOT uses the following metrics to analyze and communicate commute trips in the *Corridor Capacity Report:*

Daily commutes

- Peak period
- Peak 5 minutes of commuter rush

Travel times

- Average peak travel time
- Travel time at posted speed
- Travel time at maximum throughput speed
- Maximum Throughput Travel Time Index (MT^3I)

Reliability

- Average travel time
- Median travel time (50th percentile)
- 80th percentile reliable travel time
- 90th percentile reliable travel time
- 95th percentile reliable travel time

Congestion

- Duration of congestion
- Severe congestion
- Commute congestion cost

Congested segments

- Routinely congested segments
- Loop / Lane occupancy

Vehicle miles traveled

Daily commute metrics

The table at right helps explain the analysis and performance measures using the sample data for the 9.76-mile commute from Auburn to Renton.

Peak period is the daily timeframe during which travel demand is the greatest, leading to frequent recurrent congestion or delay. Capacity and WSDOT's traffic analyses focus on these peak hours of traffic volume, because they represent the most critical period for operations and have the highest capacity requirements.

WSDOT defines peak periods differently for different regions in the state based on the region specific congestion experienced. In the central and south Puget Sound areas peak periods are defined as 5-10 a.m. and 2-8 p.m. while in Spokane and Vancouver peak periods are defined as 7-10 a.m. and 3-6 p.m.

Peak 5 minutes of commuter rush is the 5-minute interval that has the longest average commute travel time during the peak period (morning or evening), also known as the peak 5-minute interval.

For example, in the table below, 7:35 a.m. is defined as the peak 5-minute interval for the Auburn to Renton route during the morning commute in 2010, as it had the longest average travel time of 16.96 minutes.

Travel time metrics

Average travel time is the ratio of the route length to the average speed along the route. The average speed along the commute corridor is calculated for every 5-minute interval of the day (12 intervals each hour X 24 hours each day = 288 intervals) on each commute corridor, using the speed data from up to 261 weekdays i.e., all available weekdays of a calendar year.

$$\textbf{Average travel time} = \frac{\textbf{Trip length}}{\textbf{Average speed}}$$

Example calculations for commute corridor performance
2010 weekdays only; Peak of morning commute period; Auburn to Renton; 9.76 miles; Travel times in minutes; Speed in miles per hour

	Time of day	Average speed	Average travel time	95th %ile travel time	% of days <45 mph	% of days <36 mph
	4:55	59.48	9.85	10.69	0%	0%
Morning peak period	5:00	59.37	9.86	10.97	0%	0%
Morning peak period	5:05	58.89	9.94	10.78	0%	0%
Morning peak period	...					
Morning peak period	7:30	34.75	16.85	26.73	83%	42%
Morning peak period	**7:35** (peak 5-min interval)	**34.53**	**16.96**	**26.51**	**84%**	**43%**
Morning peak period	7:40	34.82	16.82	26.29	85%	42%
Morning peak period	...					
Morning peak period	9:50	46.46	12.60	20.44	20%	9%
Morning peak period	9:55	47.42	12.35	19.66	17%	8%
	10:00	48.44	12.09	18.88	13%	8%

Data source: WSDOT Office of Strategic Assessment and Performance Analysis; Washington State Transportation Center (TRAC) at the University of Washington.

Travel Time Trends and Corridor Capacity Analysis

Average peak travel time is the longest travel time within the morning and evening peak periods. The corresponding 5-minute intervals become the peak 5-minute intervals as defined above.

$$\text{Average peak travel time} = \frac{\text{Trip length}}{\text{Average speed}_{\text{Peak 5-min}}}$$

WSDOT compares average peak travel time to travel times at the posted speed and maximum throughput speed.

$$\text{Travel time}_{\text{Posted speed}} = \frac{\text{Trip length}}{\text{Posted speed}}$$

$$\text{Travel time}_{\text{Max. throughput speed}} = \frac{\text{Trip length}}{\text{Maximum throughput speed}}$$

Maximum Throughput Travel Time Index (MT³I) helps compare travel times on routes of different lengths. The MT³I incorporates the expected travel time under maximum throughput conditions and the travel time at the peak 5-minute interval, therefore taking into account the length of the route. An MT³I of 1.0 would indicate a highway operating at maximum efficiency. As the MT³I value increases, travel time performance deteriorates.

$$\text{Maximum throuput travel time index (MT}^3\text{I)} = \frac{\text{Average travel time}_{\text{Peak 5-min}}}{\text{Travel time}_{\text{Max. throughput speed}}}$$

For instance, the I-405/I-90/I-5 Bellevue to Seattle and the I-90/I-5 Issaquah to Seattle evening commutes had average travel times of 27 and 29 minutes, respectively. At a glance, the routes appear roughly equal. However, the first route is 10 miles long and the second is 15 miles; this difference means that using average travel times alone is not a meaningful comparison.

In this example, the Bellevue to Seattle via I-90 evening commute has an MT³I of 2.24, which means that the commute on average takes two-and-a quarter times longer than it would normally take at the maximum throughput speed. On the other hand, the Issaquah to Seattle via I-90 evening route has an MT³I of 1.58, which means that the commute on average takes 58% longer than at the maximum throughput speed. The Bellevue to Seattle via I-90 evening route is the more congested commute of the two.

Example calculation of average and percentile reliable travel times by time of day

2012 weekdays only; Morning commute peak period 5-10 a.m.; Evening commute peak period 2-8 p.m.; Auburn to Renton; 9.76 miles

Time of day	Average	50th %	80th %	90th %	95th %	WKD 1	WKD 2	WKD 3	WKD 4	WKD 20	WKD 258	WKD 259	WKD 260
0:00													
0:05													
...													
5:00	9.88	9.77	9.97	10.10	10.25	9.76	9.76	9.76	9.76	N/A	10.17	9.76	9.76
5:05	10.12	10.06	10.33	10.45	10.72	9.76	10.23	9.90	9.94	N/A	10.17	9.76	9.76
...													
7:40	17.57	15.79	21.76	24.72	28.32	9.76	13.77	15.69	14.68	N/A	10.83	13.44	9.92
7:45	17.54	15.73	21.47	25.38	28.67	9.76	13.39	14.85	15.16	N/A	11.77	12.15	9.76
7:50	17.50	15.67	21.70	24.70	29.65	9.76	14.09	14.58	14.97	N/A	11.04	10.73	9.76
...													
9:55	12.19	10.81	12.07	15.24	21.62	9.76	10.38	10.59	10.92	N/A	11.39	10.14	9.76
10:00	11.93	10.77	11.82	14.18	19.55	11.22	10.77	10.64	10.96	N/A	10.87	10.45	9.76
...													
13:55													
14:00													
14:05													
...													
19:55													
20:00													
...													
23:50													
23:55													

288 5-minute intervals for each day

Cells with good data are averaged for an entire year for each 5-minute interval to generate the "average travel time"

Analyze up to 261 weekdays annually with good data

For the respective percentile reliable travel times, the cells with good data are arranged in ascending order for an entire year for each 5-minute interval, and then the travel time value at the mid-point is selected as the 50th percentile reliable travel time, and so on for the other reliability metrics.

For example, the 50th percentile (median) would be 10.77 minutes if the entire data set at 10:00 a.m. consisted of these seven sample values:

9.76 10.45 10.64 10.77 10.87 10.96 11.22

However, the average (mean) of these seven values is 10.67 minutes.

Data source: WSDOT Office of Strategic Assessment and Performance Analysis; Washington State Transportation Center (TRAC) at the University of Washington.

Reliability metrics

Reliability is an important metric for highway users because it provides information that allows travelers to plan for on-time arrival with a higher degree of certainty. Commuters can plan the daily trips to work during peak hours, parents can plan the afternoon run to the daycare center, businesses know when a just-in-time shipment must leave the factory, and transit agencies can develop reliable schedules.

Travel time reliability is measured in percentiles. WSDOT uses the 95th percentile reliable travel time as its key reliability metric for the commute trips monitored statewide. Average, median, 80th and 90th reliable percentiles are also calculated.

- **Average travel time (the mean)** is the average of all the recorded travel times. This measure describes the "average" experience on the road that year.
- **50th percentile travel time (the median)** is the middle value of all the recorded travel times. The median is not affected by very long travel times as an average is, so it gives a better sense of actual conditions.
- **80th percentile travel time** will ensure the traveler is on time four out of five weekday trips. WSDOT uses this percentile to track changes in reliable travel times over the years at a finer level, to better evaluate operational improvements.
- **90th percentile travel time** means 90% of all the recorded travel times were shorter than this duration.
- **95th percentile travel time** means the traveler will be on time approximately 19 out of 20 weekday trips. WSDOT uses this percentile as its key reliability metric.

WSDOT uses the following steps to identify the reliability metrics for each 5-minute interval on every commute route analyzed:

- Divide the day into 288 5-minute intervals.
- Assess the data for all weekdays in the calendar year (up to 261), and discard any data that is invalid.
- For each of these 5-minute intervals, arrange the travel times for all weekdays in the analysis period in ascending order. (For example, arrange all 261 weekday travel time data points for 7:05 a.m. in ascending order).
- From this list, select the 50th, 80th, 90th, and 95th percent worst travel times. These will be the annual average 50th, 80th, 90th, and 95th percentile reliable travel times for that 5-minute interval.
- Repeat for the other 287 5-minute intervals.
- The peak 5-minute interval is identified as the interval with the longest average commute travel time during a peak period (morning or evening).
- From the peak 5-minute interval (defined above), report the 50th, 80th, 90th, and 95th percentile reliable travel times.

Congestion metrics

Duration of congestion (DOC) captures the amount of time a commute corridor typically experiences speeds slower than 75% of the posted speed (45 mph when the posted speed is 60 mph) on an average weekday for the analysis period.

$$\underset{\substack{\text{Morning}\\ \text{or}\\ \text{Evening}}}{\textbf{Duration of congestion}} = \sum_{\substack{\text{Midnight to noon}\\ \text{or}\\ \text{Noon to midnight}}} \left(\textbf{Time for all intervals with speeds < 45 mph} \right)$$

WSDOT calculates the duration of congestion using the 5-minute interval data averaged over all weekdays in a year. The congested period is the summation of all 5-minute intervals when the average speed is slower than 45 mph.

Example calculations for commute corridor performance
2010 weekdays only; Peak of morning commute period; Auburn to Renton; 9.76 miles; Travel times in minutes; Speed in miles per hour

	Time of day	Average speed	Average travel time	95th %ile travel time	% of days <45 mph	% of days <36 mph
	6:20	45.17	12.96	16.15	39%	4%
Duration of congestion	6:25	44.09	13.28	17.36	46%	10%
Duration of congestion	6:30	43.46	13.47	17.43	47%	11%
Duration of congestion	…					
Duration of congestion	7:30	34.75	16.85	26.73	83%	42%
Duration of congestion	**7:35** (peak 5-min interval)	**34.53**	**16.96**	**26.51**	**84%**	**43%**
Duration of congestion	7:40	34.82	16.82	26.29	85%	42%
Duration of congestion	…					
Duration of congestion	8:55	43.99	13.31	21.14	32%	13%
Duration of congestion	9:00	44.94	13.03	21.21	30%	11%
(Excluded from duration)	9:05	45.79	12.79	20.44	27%	9%
(Excluded from duration)	9:10	45.92	12.75	19.78	22%	10%
(Excluded from duration)	9:15	45.56	12.85	19.41	21%	12%
(Excluded from duration)	9:20	45.66	12.82	19.20	22%	9%
(Excluded from duration)	9:25	45.13	12.98	19.52	24%	10%
Included	9:30	44.94	13.03	20.75	23%	11%
Included	9:35	44.95	13.03	20.76	23%	10%
	9:40	45.27	12.94	21.52	24%	10%

Data source: WSDOT Office of Strategic Assessment and Performance Analysis; Washington State Transportation Center (TRAC) at the University of Washington.

For example, using data from the table on p. 23, the duration of congestion for the Auburn to Renton morning commute in 2010 is 2 hours 50 minutes.

$$\text{Duration of congestion} = \sum_{\substack{\text{Auburn to Renton} \\ \text{Morning, 2010}}} \left(\text{34 5-minute intervals with speeds} < 45\text{ mph}\right) = \text{2 hours 50 minutes}$$

Duration of congestion is calculated separately for the morning and evening, and it includes all the 5-minute intervals with speeds slower than 45 mph even if they fall beyond the defined peak period.

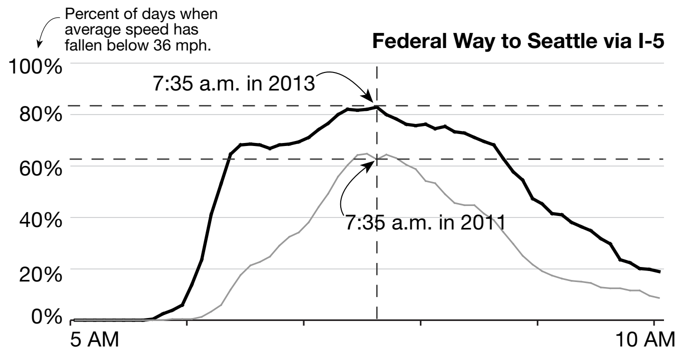
Severe congestion occurs when weekday travel speeds are slower than 60% of the posted speed, or about 36 mph.

Percent of days with severe congestion is the proportion of days annually where observed speeds for one or more 5-minute intervals is slower than 60% of the posted speed. The data calculated is displayed as a "stamp graph," shown in the graphic below left.

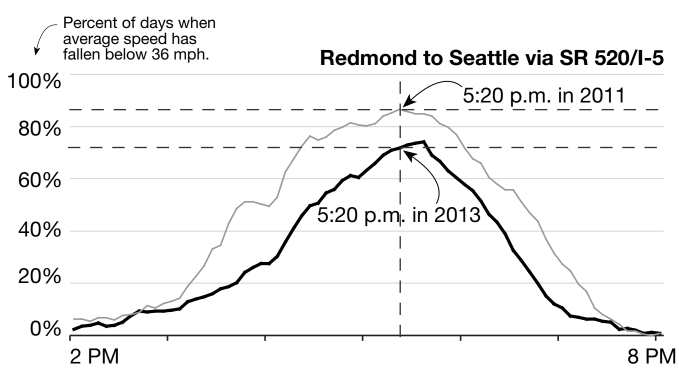
$$\text{Percent of days with severe congestion} = \frac{\text{Number of days with severe congestion}}{\text{Number of days with good data}}$$

How to read a stamp graph: Percent of days when speeds were slower than 36 mph

How frequently (and when) was the average trip speed slower than 36 mph? How have those conditions changed from 2011 to 2013?



At 7:35 a.m. in 2011, you had about a 63% chance that traffic would be moving slower than 36 mph. In 2013, the situation worsened (black line above gray line); your chance that traffic would be moving slower than 36 mph was about 83% in 2013.



At 5:20 p.m. in 2011, you had about a 87% chance that traffic would be moving slower than 36 mph. In 2013, the situation improved (black line below gray line); your chance traffic would be moving slower than 36 mph was about 72% in 2013.

Data source: WSDOT Office of Strategic Assessment and Performance Analysis.

Commute congestion cost is the economic impact of time and fuel wasted from extra travel time incurred by drivers during congested periods. WSDOT calculates commute congestion cost by applying monetary values to the extra travel time and vehicle operating costs drivers experience during congested periods (see pp. 8-9).

$$\text{Commute congestion cost} = \sum_{\substack{\text{For duration} \\ \text{of congestion}}} \left(\underset{\text{5-min interval}}{\text{Average travel time}} - \text{Travel time at threshold speed}\right) \times \underset{\text{5-min interval}}{\text{Traffic volume}} \times \text{Cost per minute}$$

Commute congestion cost is computed for every 5-minute interval within the time that a particular commute is experiencing congestion. This methodology underestimates commute congestion cost because it does not capture the periodic slowdowns (when speeds are slower than 45 mph) briefly experienced during individual trips along the length of the commute. The commute congestion cost computation is based on the duration of congestion calculation for a particular commute route.

$$\underset{\substack{\text{Auburn to Renton} \\ \text{Morning, 2012 at} \\ \text{peak 5-min interval} \\ \text{(7:40 a.m.)}}}{\text{Commute congestion cost}} = \left(\underset{\substack{\text{Average travel} \\ \text{time at the peak} \\ \text{5-min interval}}}{17.57\text{ min}} - \underset{\substack{\text{Travel time at} \\ \text{the maximum} \\ \text{throughput speed}}}{11.72\text{ min}}\right) \times \underset{\substack{\text{For peak} \\ \text{5-min interval}}}{240\text{ vehicles}} \times \frac{\$21.9/\text{hour}}{60\text{ min/hour}}$$

$$= \$514 \text{ in the peak 5-minute interval, or } \$12{,}431 \text{ per day}$$

Congested segments metrics

Routinely congested segments are specific sections of the urban highway system that regularly experience speeds slower than 75% of posted speed due to constrained conditions. WSDOT tracks how often demand exceeds capacity on the highway system, and documents the frequency and length of time (duration) the route is congested. This type of congestion is not related to incidents or collisions, although such occurrences accentuate the recurrent congestion.

A routinely congested segment, for a 5-minute interval, is a segment that experiences greater than 19% loop occupancy (see p. 25) for 40% or more of all weekdays in a year. A segment is defined as the distance between two in-pavement loop detectors which are usually about a half-mile apart. Loop occupancy is a measure of traffic density, and 19% loop occupancy is roughly equivalent to cars traveling less than 45 mph.

For example, the half-mile segment on I-5 between milepost 150.0 and milepost 150.5 is considered as congested during the 6:30-6:35 a.m. 5-minute interval during the morning peak as the loop occupancy for that roadway section exceeds 19% on at least 40% of all weekdays in the year.

Lane/Loop occupancy is the percentage of time that a six-foot square loop sensor is activated, or occupied, by vehicles traveling over it. Lane or loop occupancy is measured by sampling the loop detector at a rate of 60 times per second. A counter is incremented once for each “loop occupied” response. After 20 seconds, the total number of “loop occupied” responses is divided by 1,200 (the total number of samples in a 20-second period). The result is known as occupancy or loop occupancy.

Corridor vehicle miles traveled metric

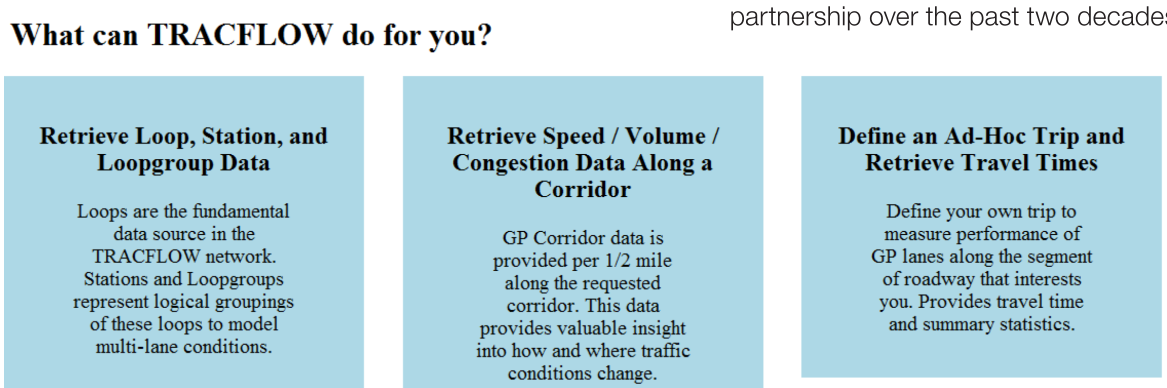
Corridor-based vehicle miles traveled (VMT) is computed on a corridor as well as a commute route basis for WSDOT’s performance analysis. See pp. 11-12 for more details on the VMT methodology.

Background information and data sources

Measures that matter to drivers: speed, travel time and reliability

Speed is a metric that carries importance not only with WSDOT, but also with the general public. Similarly, measuring the time to get from point A to point B is one of the most easily understood system performance measures. Travel time reliability also matters to commuters and businesses because it is important for people and goods to be on time all the time.

WSDOT’s *Corridor Capacity Report* examines travel times on the 84 commute trips around the state, with a particular focus on 40 high-demand routes in the central Puget Sound area.



The TRACFLOW interface online.

Travel times for high occupancy vehicle (HOV) lanes along many of these same corridors are also reported (pp. 29-31).

The metrics used in the commute trip analysis include the average peak travel time, the 95th percentile reliable travel time, the duration of congestion, and the percent of weekdays when average travel speeds are slower than 36 mph. The performance of an individual route compares data for the current analysis year to the baseline year, typically two years prior.

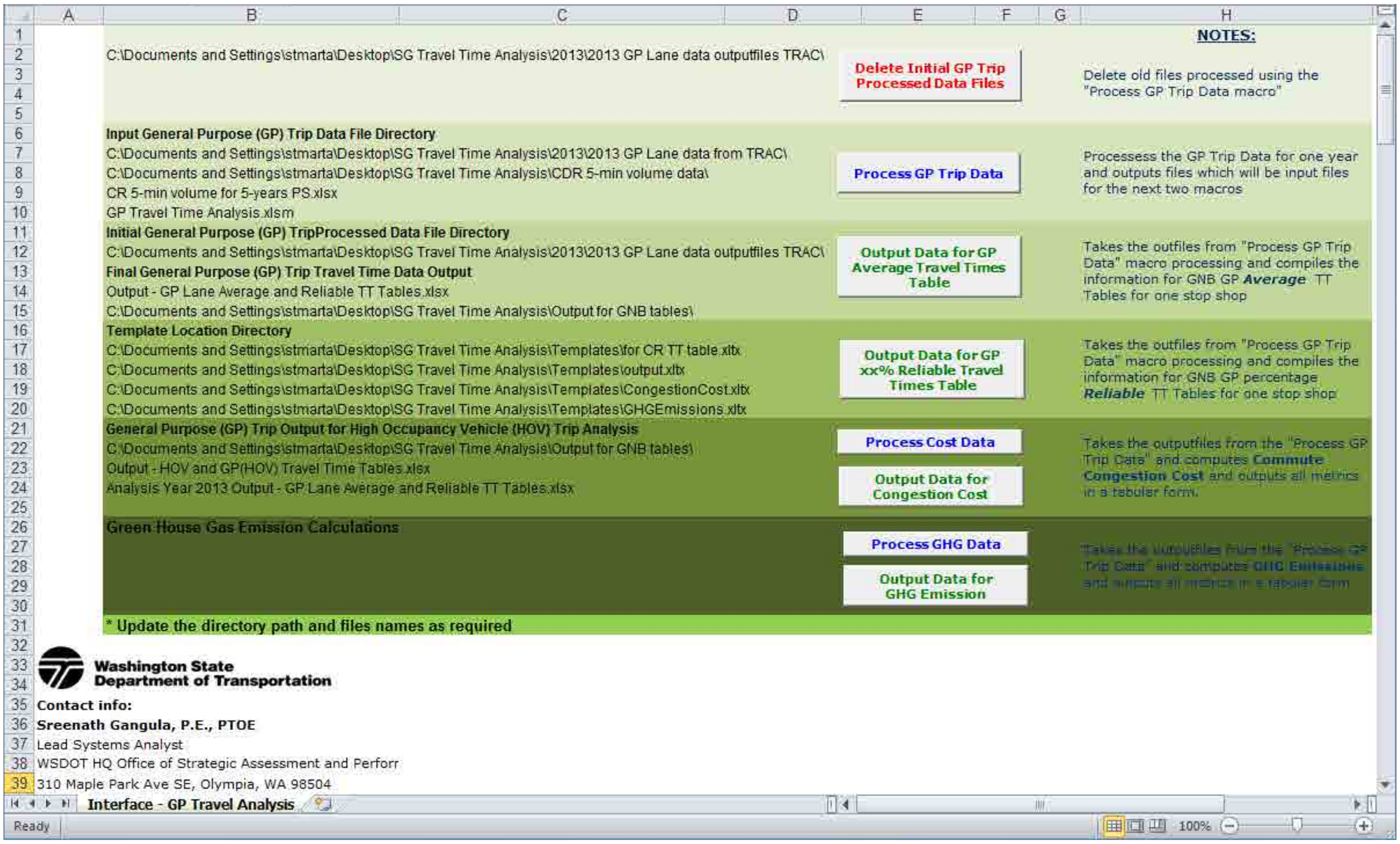
WSDOT’s previously published person-based measures (per capita for statewide measures) include per person vehicle miles traveled and per person hours of delay in traffic (statewide, urban area, and corridor based), along with the per person trip travel time on commute corridors.

Real-time travel times for key commute routes in central and south Puget Sound areas, Spokane, and Vancouver are available to the public and updated every 5 minutes on the WSDOT website at: [www.wsdot.wa.gov/traffic/.](www.wsdot.wa.gov/traffic/)

Travel time related data

In the central Puget Sound area alone, WSDOT collects data from about 6,800 loop detectors embedded in the pavement throughout 235 centerline miles of state highways (1,300 lane miles). Similarly, the south Puget Sound area has 128 active data sensors along 77 centerline miles (270 lane miles). Additionally, WSDOT collects data from 165 Spokane area detectors, along 37 centerline miles (175 lane miles). Other urban areas of the state have loop detectors and other technologies used for traffic data collection. WSDOT also uses private sector speed data for Vancouver area commute trip analysis to complement the existing WSDOT data set.

The Washington State Transportation Center (TRAC) at the University of Washington works closely with WSDOT in travel data evaluation for the Puget Sound area. This partnership over the past two decades has developed standards and procedures for data quality control and evaluation. Recently, TRAC automated data quality control procedures and developed



WSDOT's custom Mobility Analysis Software interface.

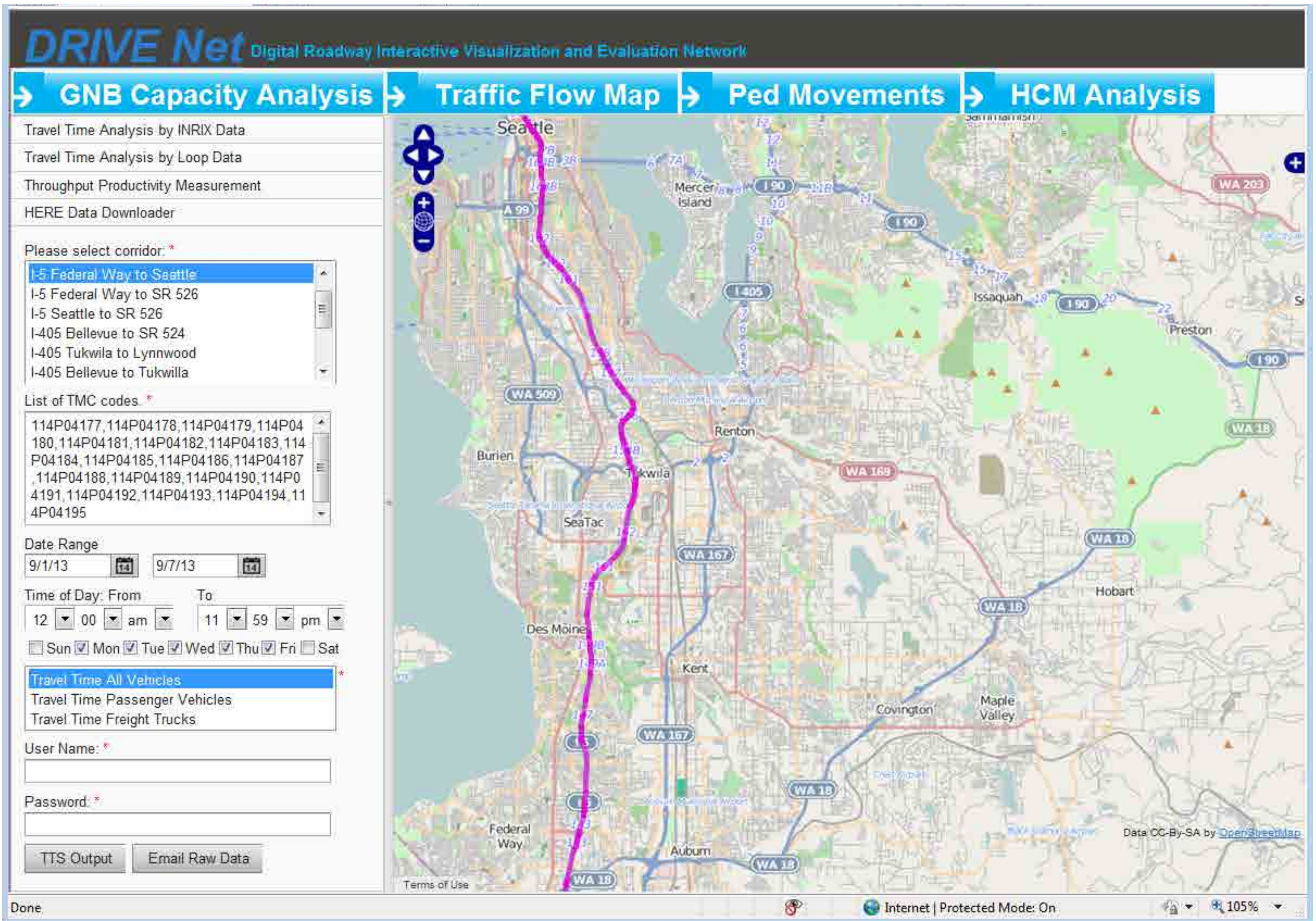
an online TRACFLOW database that allows access to in-pavement loop detector data in order to evaluate corridor performance. TRACFLOW software produces Excel spreadsheets for data output with various performance measurement information for each 5-minute interval of an average day based on the days of the week and time of the year selected for analysis. The TRACFLOW website can be accessed at http://trac29.trac.washington.edu/dotfreewaydata/. See the TRACFLOW interface graphic on p. 25.

WSDOT uses Mobility Analysis Software (a custom-built tool developed in house using Visual Basic in Microsoft Excel) to further process the output produced by the TRACFLOW software. Mobility Analysis Software calculates various performance measures reported in the *Corridor Capacity Report*. Example performance measures include average and reliable travel times, Maximum Throughput Travel Time Index (MT^{3}I), duration of congestion, commute congestion cost and greenhouse gas emissions.

WSDOT is developing procedures to use downloadable private sector probe speed data for system performance measurement. Using new dynamic data processing templates, the private sector speed data will be converted into a format that resembles the output Excel file from TRACFLOW. This conversion allows WSDOT to evaluate the private sector data using the Mobility Analysis Software with some modifications. See the graphic above.

WSDOT and the Smart Transportation Applications and Research Laboratory (STAR Lab) at the University of Washington are collaborating to develop a new online platform for transportation data sharing, visualization, modeling, analysis and decision support. This online platform is called DRIVE Net, which stands for Digital Roadway Interactive Visualization and Evaluation Network. It can be accessed at http://wsdot.uwdrive.net/WSDOT. See p. 27.

DRIVE Net is designed using the "e-science transportation principle" to facilitate data mining and data fusion along both temporal and spatial dimensions. This project is in progress; WSDOT and the STAR Lab are currently working on Phase 2 of this project to add more data and analytical functions. For the Phase 1 report, see http://depts.washington.edu/trac/bulkdisk/pdf/823.1.pdf.



The DRIVE Net interface available online.

How reliability percentiles are used

A benefit to using percentile measures is they are not affected by outlier values, generally the longest travel times. Using a range of percentiles – from the 50th (median) to the 95th – allows WSDOT to track changes in reliable travel times over the years at a finer level in order to evaluate operational improvements more accurately. Travel times in the 80th and 90th percentiles represent trips that are affected by routine incidents and other factors that the agency can influence with operational strategies. See the 2014 *Corridor Capacity Report Appendix*, pp. 13-14 for detailed reliability data.

The 95th percentile reliability travel time includes near worst-case travel times. The 50th percentile travel time, or median, means that half of the days of the year were faster, and half were slower. WSDOT uses the 95th percentile reliable travel time as its key reliability metric to communicate the near worst-case scenario to drivers to help them plan their trips successfully.

Cost of travel background and data

WSDOT quantifies commute congestion cost at the individual commuter level to answer the question: "how much does congestion cost a daily commuter?" Commute congestion cost is based on the duration of congestion during which users can expect to travel at speeds slower than 45 mph (75% of posted speed) during their daily commute. While daily commuters may build extra time

Recommended hourly-based travel cost estimation
Dollars per hour in 2008 dollars

Type of cost	Area	Auto	Truck type: Light	Heavy	Mixed
Vehicle operation	Central Puget Sound	$9.50	$33.80	$48.00	$36.60
	Statewide	$9.50	$33.80	$48.00	$36.60
Travel time	Central Puget Sound	$12.40	$20.80	$27.70	$22.20
	Statewide	$11.20	$20.50	$26.80	$21.80
Total	Central Puget Sound	**$21.90**	$54.60	$75.70	$58.80
	Statewide	$20.70	$54.30	$74.80	$58.40

Data source: WSDOT Urban Planning Office.

and operating costs into their routines and budgets to account for traveling during congested periods, congestion still represents costs, lost opportunities, and lost productivity that negatively affect individuals and society.

The table on p. 27 illustrates the respective costs of travel for different types of vehicles. WSDOT typically uses $21.90 per hour for general calculations in the Puget Sound area. The dollar value used for the commute congestion cost calculation is the same as the cost of delay computation. See pp. 8-9 for the “Cost of Delay” definition and methodology.

Population data

State population data is available for the per-capita analysis from the Washington State Office of Financial Management here: http://www.ofm.wa.gov/pop/

Congested segments background and data

Specific sections of the urban highway system experience routine congestion due to constrained conditions. The *Corridor Capacity Report* identifies the geographic extent and temporal duration of “congested roadway segments.” These segments are contiguous sections of roadway within which congestion routinely forms during either the morning or evening peak period.

The extent and duration of congestion are determined using loop occupancy data stored in the TRACFLOW database, and collected from WSDOT loop detectors. For each corridor, the TRACFLOW software can retrieve congestion data that describes roadway congestion by half-mile interval for every 5 minutes of every day. One of these half-mile sections is considered “congested” for a specific 5-minute interval if lane occupancy is above 19% for at least 40% of all weekdays within the selected analysis period. The “congested segments” described in the *Corridor Capacity Report* are aggregations of these individual 5-minute by half-mile roadway sections.

High Occupancy Vehicle Trip Analysis Methodology

9

High occupancy vehicle (HOV)

lane performance analysis is performed as part of the greater commute trip analysis. Since this is a unique concept it is covered under its own chapter.

WSDOT owns and operates more than 310 lane-miles of HOV system in the central Puget Sound area. HOV lanes are designed to provide faster and more reliable travel options for travelers that choose to rideshare (carpool, vanpool, transit), and enhance the efficient operation of the freeway network by moving more people in fewer vehicles, compared to adjacent single occupant vehicle (SOV) freeway lanes.

HOV lane performance measures

WSDOT uses the following metrics to analyze and communicate HOV lane performance in the *Corridor Capacity Report:*

HOV lane performance and reliability standard

HOV travel times compared to adjacent SOV lane

Average number of occupants per vehicle

- Person throughput on HOV versus SOV lanes

HOV lane performance and reliability

The **HOV lane performance and reliability standard** for freeway HOV lanes was adopted by WSDOT and the Puget Sound Regional Council to maintain an average speed of 45 mph or greater, during 90% of the peak hour of travel.

WSDOT processes the loop data on major central Puget Sound area corridors to evaluate speed and reliability performance by using similar tools and processes outlined in the Travel Time Trends chapter (pp. 21-28). The specific corridors evaluated and the performance results are tabulated as shown in the table at the upper right. The shaded cells indicates the 90% goal to maintain average speed of 45 mph or more was not realized and the number indicates the percent of time the 45 mph average speed was achieved.

WSDOT compares the percent of weekdays that HOV and adjacent SOV lane speeds are slower than 45 mph using stamp graphs. HOV and adjacent SOV lanes are evaluated using the percent of days annually that observed speeds for one or more 5-minute interval are slower than 75% of posted speed (defined as congestion). The data calculated is displayed graphically as shown above for HOV lanes, reversible lanes and SOV lanes, showing that HOV lanes typically experience congested conditions less frequently than the adjacent SOV lanes.

$$\textbf{Percent of days with congestion} = \frac{\textbf{Number of days experiencing congestion}}{\textbf{Number of days with good data}}$$

HOV lane speed and reliability performance on major central Puget Sound corridors

2008 through 2012; Goal is to maintain 45 mph for 90% of peak hour

= Goal not met

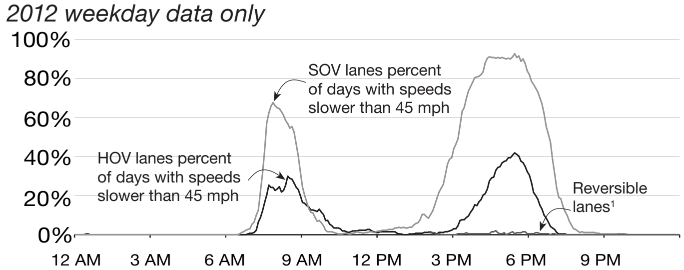
Commute routes	2008	2009	2010	2011	**2012**
Morning peak direction commutes					
I-5, Everett to Seattle SB	60%	69%	61%	64%	**54%**
I-5, Federal Way to Seattle NB	67%	92%	86%	72%	**51%**
I-405, Lynnwood to Bel SB	92%	94%	92%	94%	**76%**
I-405, Tukwila to Bellevue NB	49%	99%	99%	98%	**93%**
I-90, Issaquah to Seattle WB	100%	96%	100%	100%	**100%**
SR 520, Redmond to Bel WB	99%	94%	94%	97%	**51%**
SR 167, Auburn to Renton NB[1]	99%	99%	100%	99%	**96%**
Evening peak direction commutes					
I-5, Seattle to Everett NB	64%	49%	55%	76%	**68%**
I-5, Seattle to Federal Way SB	57%	67%	77%	82%	**63%**
I-405, Bel to Lynnwood NB	58%	71%	77%	74%	**56%**
I-405, Bellevue to Tukwila SB	35%	70%	74%	60%	**43%**
I-90, Seattle to Issaquah EB	100%	95%	99%	99%	**100%**
SR 520, Redmond to Bel WB	68%	71%	61%	70%	**54%**
SR 167, Renton to Auburn SB[1]	98%	99%	99%	99%	**98%**

Data source: Washington State Transportation Center (TRAC).

Notes: HOV reliability performance standards are based on the peak hour, the one-hour period during each peak period when average travel time is slowest. To meet the standard, a speed of 45 mph must be maintained for 90% of the peak hour. Numbers represent the percentage of the peak hour when speeds are above 45 mph. TRAC analyzes performance data for all complete segments of HOV lanes that have a loop detector. In some cases, data cannot be analyzed for the very beginning and ends of the lanes because there are no detectors at these locations. The year with worst congestion is 2007 prior to the economic recession. NB = Northbound; SB = Southbound; EB = Eastbound; WB = Westbound. "Bel" stands for Bellevue. 1 High occupancy toll (HOT) lanes replaced regular HOV lanes May 3, 2008.

Stamp graph for I-5/I-90/I-405 Seattle to Bellevue

2012 weekday data only



Data source: WSDOT Office of Strategic Assessment and Performance Analysis.

Note: 1 I-90 express reversible lanes hours of operation Monday-Friday: Westbound - 1 a.m. to 12:30 p.m.; Eastbound - 2 p.m. to midnight.

HOV travel times compared to SOV

HOV travel times compared to adjacent SOV lane travel times demonstrates the ability of HOV lanes to move more people, faster than the adjacent SOV lanes. Average travel time and 95th percentile reliable travel time are the metrics employed to compare HOV and SOV lane performance. The definitions and the methodology for getting accurate, as well comparable numbers, is similar to the methodology defined in the Travel Time Trends chapter under sections Average Travel Time and Reliability (pp. 22-23).

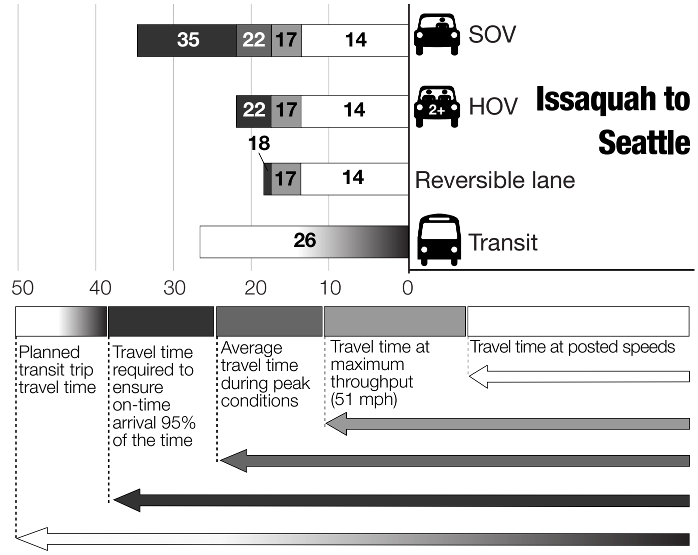
WSDOT calculates the average travel time and 95th percentile reliable travel time for HOV lanes at the peak 5-minute interval identified for the comparable SOV lane trip. This allows for direct comparisons between trips in SOV lanes and trips in the HOV lanes.

In some situations, HOV trips have modified trip lengths compared to the corresponding standard SOV trips in the central Puget Sound area, due to the lack of data at the HOV trip's endpoints. Affected trips are on northbound I-5 from Federal Way to Seattle, and I-90 trips between Seattle and Issaquah, and between Bellevue and Seattle (both eastbound and westbound). In each case, to enable a direct comparison, the lengths of the corresponding SOV trips have been adjusted to match the HOV trip length as closely as possible; this means travel times and time stamps for the peak of the commuter rush for these modified SOV trips will not necessarily match those in the SOV trip tables. HOV trips with the same endpoints as SOV lane trips, but differing lengths, do not require any adjustment, since the difference in lengths is the result of HOVs using different roadways than SOVs (e.g., an HOV only interchange ramp).

Additionally, commute routes on I-5 and I-90 include reversible lanes, also called "express lanes," (morning or evening). Reversible lanes are only analyzed during the peak period and direction for which they are in effect. Their hours of operation in each direction are available online at: www.wsdot.wa.gov/Northwest/King/ExpressLanes.

WSDOT also expanded the peak 5-minute comparison from HOV and SOV lane performance to include planned transit trip times to further illustrate the transportation options and relative travel times on each corridor. An example graphic is shown at the upper right.

Representative travel times by transportation mode choice for the I-90 Issaquah to Seattle commute
2012 weekday data only; Travel time in minutes



Average number of vehicle occupants

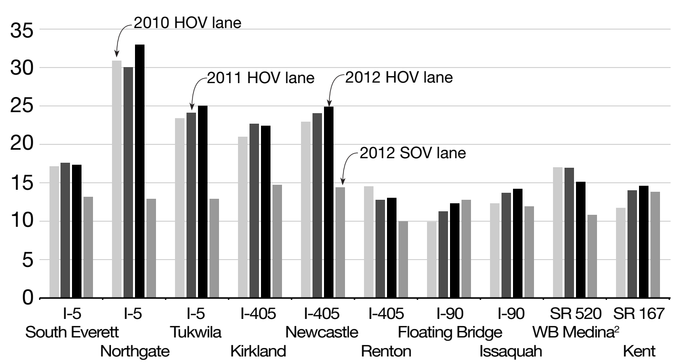
Increasing the average number of occupants per vehicle is the primary purpose of HOV lanes, as this increases overall system efficiency in terms of moving people and goods in fewer lanes with less delay. The following steps are used to calculate the average number of vehicle occupants for the HOV system.

- Average vanpool and bus transit ridership data are updated each year by the regional transit agencies using their passenger counting systems.
- Vehicle occupancy and mode splits for the remaining modes are based on direct visual observations made by teams of observers from 1992 through 2012 who counted the number of vehicle occupants in the SOV and HOV lanes during the morning and evening peak periods, in both directions of travel, at the selected reporting locations.
- Each observed vehicle was categorized by type and occupancy. These occupancy and mode split statistics are held constant at each reporting location until additional funding for data collection is available, as these values have been shown to be fairly stable over time.

Person throughput is the number of people moved during the peak periods past a defined location on the highway. WSDOT uses person throughput across multiple modes as a proxy for overall transportation system efficiency. Person throughput is a key metric for HOV lane performance; higher values indicate the system is efficiently moving people in fewer vehicles. WSDOT estimates average vehicle occupancy based on sample data collected at specific monitoring locations for HOV lanes and adjacent SOV lanes. This occupancy data along with traffic volumes are used to determine person throughput in HOV lanes compared to adjacent SOV lanes. WSDOT uses the following procedure to estimate person throughput:

- Estimate total vehicle volume at analysis locations using WSDOT's archived real-time traffic data processed by the TRACFLOW freeway performance database (see p. 25).
- Estimate mode split using historical field observations for vehicle type categories: Number of 1-person, 2-person, 3-person and 4+person cars, number of vanpools, transit buses, non-transit buses, trucks and motorcycles.
- For each vehicle type except buses (which are ignored at this point in the analysis), the resulting vehicle volume is then multiplied by the average number of occupants per vehicle, to produce an estimated person volume for that vehicle type. (Refer to the methodology described above for estimating average number of occupants per vehicle).
- Sum person volumes for all vehicle types (except buses).
- Obtain the bus transit person volumes at each of the reporting locations and add this value to produce an estimate of total person throughput.
- For SOV lanes, total person throughput is converted to the number of persons per hour per lane, to enable direct comparisons of person throughput for the HOV lane and a single neighboring SOV lane.

Person throughput[1] on HOV lanes generally outperforms SOV lanes
2010 through 2012; Morning and evening peak period volumes, combined; Volume in thousands of people



Data source: Washington State Transportation Center (TRAC).
Notes: Beginning in 2009, all person volume estimates are based on a more comprehensive transit ridership database that includes more information about private employer bus services. Person volume estimates are based on most recent 2011/2012 transit ridership and other data. 1 Person throughput is the sum of people using all HOV and SOV lanes from 6-9 a.m. and 3-7 p.m. in the peak direction of the commute at a point location. 2 SR 520 results based on modified location because of effects on data availability of nearby construction.

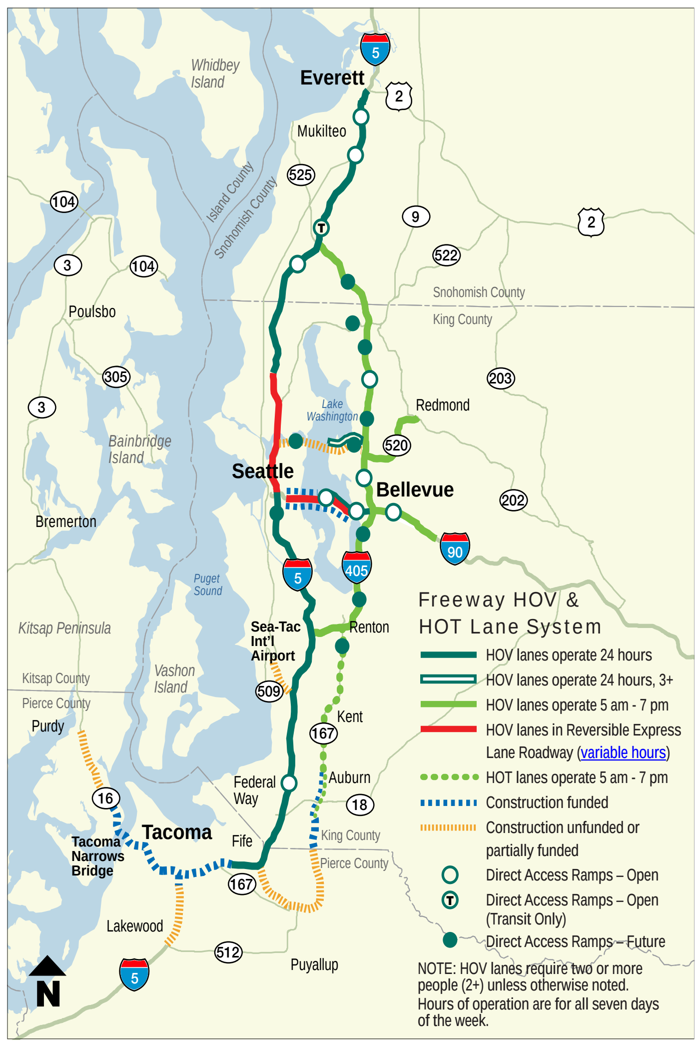
The graph below left provides the results of person throughput estimates for HOV and adjacent SOV lanes performed at specific locations in the central Puget Sound area for the 2013 *Corridor Capacity Report*.

High occupancy vehicle lane performance data

WSDOT uses the same data sources as its commute trip analysis for the HOV performance analyses (see pp. 25-28) and additionally the vehicle occupancy monitoring data.

Background information

WSDOT maintains a 310 lane-mile system of HOV lanes throughout the central Puget Sound area. Details are available here: http://www.wsdot.wa.gov/HOV/. WSDOT also operates high occupancy toll (HOT) lanes or "Express Toll Lanes". For more information on HOT lanes and how they help transportation in Washington go to http://www.wsdot.wa.gov/Tolling/SR167HotLanes/.



Freeway HOV and HOT lane systems in the greater Puget Sound area.

10 Transit Trip Analysis Methodology

Transit trip analysis is part of WSDOT's overall analysis of commutes to provide a multimodal view of regional travel patterns. WSDOT works with transit agencies in major urban areas statewide to align bus, light rail and commuter rail routes with the peak period commute trips (see the 2014 *Corridor Capacity Report* pp. 9-40 and Appendix pp. 13-14, 27-28 and 31-32).

Transit trip analysis measures

WSDOT computes the following average daily transit measures for each commute corridor statewide:

Transit trips

- Transit ridership
- Transit passenger miles traveled
- Vehicle miles avoided by transit use
- Emissions avoided due to transit
- Transit utilization
- Transit travel times

Transit fleet in service during peak

Park and ride lot utilization

Transit trips

Transit ridership is the average maximum load of people using transit services each day during the morning and evening peak periods. WSDOT uses a peak period of 6-9 a.m. for the morning commutes and 3-6 p.m. for evenings based on recommendations from transit agency partners.

Transit ridership is calculated based on data provided by transit service providers in the region. Ridership for individual bus routes that closely follow WSDOT's defined commute routes is assigned to that commute route. The total "ridership" value for each commute corridor is the summation of the average maximum load for all transit trips that are assigned to the specific commute corridor.

$$\text{Transit ridership} = \sum_{\text{Peak period transit trips 1 - n}}^{\text{Commute trip}} \text{Average maximum load}$$

Transit passenger miles traveled is the person miles traveled specifically by transit users (excluding the driver). Transit passenger miles traveled is calculated by multiplying the average maximum load of passengers for each transit trip by the trip distance (see the equation at the top of the next column).

$$\text{Transit passenger miles traveled} = \sum_{\text{Time period}}^{\text{Commute trip}} \left(\text{Average maximum load}_{\text{Transit trip}} \times \text{Distance traveled}_{\text{Transit trip}} \right)$$

WSDOT reports transit passenger miles traveled for major commute corridors in urban areas. Statewide transit passenger miles traveled are pulled from the National Transit Database. The calculation below gives the transit passenger miles traveled on the I-5 Everett to Seattle commute route. For more on miles traveled calculations see the vehicle miles traveled section on p. 11-12.

$$\text{Transit passenger miles traveled}_{\text{2012}} = \sum_{\text{Morning peak period}}^{\text{I-5 Everett to Seattle}} \left(832_{\text{ST 510 @ 4:11 am}} + 1{,}214_{\text{ST 510 @ 4:41 am}} \ldots + 1{,}181_{\text{CT 412@ 10:00 am}} \right)$$

$$= 137{,}646 \text{ transit passenger miles traveled}$$

Vehicle miles avoided by transit use is the approximate number of miles that were not traveled in a single occupant vehicle due to people taking transit instead. King County Metro provided WSDOT with the factor that approximately 62% of transit miles traveled would have been taken as equivalent single occupant vehicle (SOV) trips if transit services were not available. This takes into consideration the average rate of ridesharing in the central Puget Sound area served by Metro's transit services. Multiplying the passenger miles traveled by 0.62 results in the estimated SOV miles avoided due to transit services.

$$\text{Vehicle miles avoided through transit} = \text{Transit passenger miles traveled} \times \text{0.62 SOV miles per transit passenger mile}$$

For example, if we applying King County Metro's conversion factor to the transit passenger miles traveled for the 2012 Everett to Seattle commute we get the SOV miles avoided.

$$\text{Vehicle miles avoided through transit}_{\text{2012; Morning peak I-5 Everett to Seattle}} = \text{137,646 transit passenger miles traveled} \times \text{0.62 SOV miles avoided per transit passenger mile}$$

$$= \text{81,795 SOV miles avoided through transit use}$$

Emissions avoided due to transit is the net pounds of carbon dioxide equivalents (CO_2e) emissions avoided due to transit ridership. This value is the difference between what is not emitted when people take transit instead of driving, and the emissions from transit vehicle operations. See the greenhouse gas emissions chapter on pp. 15-18.

$$\text{Emissions avoided}_{\text{Due to transit use}} = \text{Transit ridership} \times \text{Trip length} \times \text{0.62 SOV miles per transit passenger mile} \times \text{1 lb } CO_2e \text{ per mile traveled}$$

$$- \sum_{\text{All transit trips}} \left(\text{Transit trip length} \times \text{Transit vehicle GHG factor} \right)$$

WSDOT reports emissions avoided at the commute level. The example below gives pounds of CO_2e avoided due to transit ridership during the 6-9 a.m. morning commute peak period in 2012 on the Everett to Seattle commute corridor on service provided by Community Transit:

$$\underset{\text{Due to transit use}}{\textbf{Emissions avoided}} = \underset{\textbf{riders}}{\textbf{4,842}} \times \underset{\textbf{miles}}{\textbf{23.66}} \times \underset{\textbf{transit passenger mile}}{\textbf{0.62 SOV miles per}} \times \underset{\textbf{mile traveled}}{\textbf{1 lb } \boldsymbol{CO_2e} \textbf{ per}}$$

$$-\sum_{\text{All transit trips}} \left(\begin{matrix} 16.18 \times 5.448 + 15.77 \times 5.448 + 21.93 \times 5.448 + \\ 23.66 \times 5.448 + 21.88 \times 5.448 + \ldots \end{matrix} \right)$$

= 48,413 pounds of CO_2e emissions avoided each weekday during the morning peak period

Transit utilization is the percent of seats occupied on all transit trips during the peak commute periods. This figure is calculated by dividing transit ridership as described earlier by the total number of seats available on transit trips during the peak commute periods. A trip may have a utilization greater than 100% if there is standing room only during the trip.

$$\underset{\textit{Commute ; Peak period}}{\textbf{Transit utlization}} = \frac{\sum \textbf{Transit ridership}}{\sum \textbf{Available seats}}$$

WSDOT reports transit utilization at the commute route level for major urban corridors. For example, the calculation below gives the transit utilization for the I-5 Everett to Seattle morning commute in 2012:

$$\underset{\textit{I-5 Everett to Seattle; Morning peak}}{\textbf{Transit utlization}} = \frac{\sum (50 + 37 + \ldots + 27 + 47 + 68 = 4{,}842)}{\sum (60 + 77 + \ldots + 77 + 60 + 77 = 7{,}718)} = 62.7\%$$

WSDOT also reports the number of transit trips that are above 90% of their capacity to show the load experienced during the peak utilization of transit.

Transit travel times

Transit travel times reported in the *Corridor Capacity Report* are the planned travel time for a selected transit trip. WSDOT selects the transit trip that most closely aligns with commute origins and destinations, and occur closest to the 5-minute peak interval (see the Travel Time Trends chapter on pp. 21-22).

WSDOT compares the travel times on the commute corridors for transit, HOV lane user and those in the single-occupant vehicle lanes. See p. 30 for a sample illustration.

Transit fleet in service during peak

The transit fleet in service during the peak period is the total number of transit vehicles providing rides during the morning and evening peak commute periods. This metric helps give an understanding of the scope of transit service occurring in major urban areas around the state. The measure can also be reported as the percent of a transit agency's fleet in service during the peak.

Transit data

All of the data for the transit trip analysis comes directly from the transit agencies WSDOT works with including Community Transit, C-Tran, Intercity Transit, King County Metro, Sound Transit and Spokane Transit Authority. These partner agencies provide the following data directly to WSDOT:

- Average maximum load by trip. Collection methods vary based on each agency's available resources. For example, some transit agencies have automatic counters at the entrance and exits on their buses. Other agencies take regular sample counts of ridership on their buses.

Transit trip performance by commute corridor

2013 Commute Information			Commute		Origin/Destination		Milepost	Length	Transit travel time at commute peak		
			6-9 a.m.		Everett		189.41	23.61	Peak time	Cars	Transit
			I-5 southbound		Seattle		165.75		7:20 a.m.	50 min.	1 hr 3 min.
Summary Statistics		Transit provider	Number of trips	Boardings	Average max load	Total seats	Percent utilization	# >90% capacity	Passenger miles traveled		Pounds of CO_2e not emitted due to transit
		All	119	4,993	4,842	7,718	62.7%	7	103,178		48,413
Route	Departure time	Arrival time	Planned travel time	Average boardings	Average max load	Seats	Vehicle load	Trip length	Passenger miles traveled	Emission factor	Emissions per trip
CT 402	5:53	6:27	0:34	50	50	60	84%	16.18	812	5.448	88
CT 405	7:45	8:37	0:52	34	37	77	48%	15.77	579	5.448	86
CT 410	8:00	8:58	0:58	29	27	77	35%	21.93	592	5.448	119
CT 412	5:30	6:33	1:03	47	47	60	78%	23.66	1,388	5.448	129
CT 413	5:40	6:24	0:44	61	68	77	88%	21.88	1,483	5.448	119

Data source: WSDOT's Office of Strategic Assessment and Performance Analysis, and central Puget Sound area transit agencies.

Notes: CT = Community Transit, IT = Intercity Transit, KCM = King County Metro, ST = Sound Transit, STA = Spokane Transit Authority. Emission factors in terms of pounds of CO_2e emitted per transit vehicle mile traveled. For passenger vehicle emissions avoided, assume 62% of transit passenger miles traveled would occur by SOV if transit were not available, and passenger vehicle emissions average one pound of CO_2e per mile traveled.

- Transit trip length by trip.
- Transit capacity by trip.
- Planned transit travel times by trip.
- Number of vehicles in service during peak
- Emissions factors by trip. Transit agencies generally track the greenhouse gas emissions for their fleet by vehicle type. This information is provided to WSDOT by transit trip and used to calculate transit greenhouse gas emissions. Emissions factors for private automobiles were estimated as one pound of carbon dioxide per mile.

The following Washington state transit agencies provided transit ridership data after detailed, collaborative discussions with WSDOT:

- C-Tran (Vancouver area), Development and Public Affairs
- Community Transit (central Puget Sound area), Strategic Planning office
- Intercity Transit (south Puget Sound area), Planning Division
- King County Metro (central Puget Sound area), Strategic Planning and Analysis office
- Sound Transit (central Puget Sound area), Service Planning office
- Spokane Transit Authority, Planning Division

http://www.watransit.com/Pages/OurMembers.aspx

Park and ride lot utilization

Park and ride (P&R) lots provide locations for commuters to meet up with a carpool or vanpool, or catch a bus to work if transit does not come close to their home. WSDOT monitors the usage of park and ride lots owned or managed by public agencies, as well as private lots. The utilization rate is calculated by dividing the average maximum weekday occupancy by the number of parking stalls. The final figure is the percent of total capacity used on a typical weekday. A utilization rate of 100% means that there are no available spaces at some point in time on an average weekday.

$$\text{Park and ride lot utlization}_{\text{Lot } n} = \frac{\text{Typical weekday occupancy}}{\text{Available parking stalls}}$$

WSDOT generally reports park and ride utilization by lot individual lot as in the example below. However, when multiple lots are close together such as in the Federal Way area, lot capacity and utilization is aggregated for reporting.

$$\text{Park and ride lot utlization}_{\text{Tacoma Dome}} = \frac{\text{2,169 occupied stalls}}{\text{2,283 available stalls}} = \text{95\% utilization}$$

Park and ride data

WSDOT's Public Transportation Office maintains and publishes information on park and ride lot capacity and utilization rates. The data and more information is available at www.wsdot.wa.gov/Choices/parkride.htm

Incorporating transit use into commute trip performance analysis

WSDOT recognizes that transit agencies in urban areas serve a wide variety of travel needs, and that much of the service may not align with the pre-defined intra-urban highway commute corridors assessed in other portions of the *Corridor Capacity Report*. For example, many bus trips in Seattle begin and end within the city limits and do not use the I-5 corridor, while serving thousands of Seattle commuters, students, and other residents. Some of these riders would drive a personal vehicle on the freeway if bus service were not provided in close proximity to their residence and place of work. Therefore, WSDOT believes that the transit ridership reported for each of the commute corridors under-represents the actual transit use in the area. At the current time, no other ridership statistics are readily available that might help capture this ridership.

Two adjustments have been made in an attempt to capture ridership that does not exactly align with the origins and destinations of WSDOT's commute corridors:

1) Bus trips that travel on the primary highway corridor associated with WSDOT's commute corridors (such as I-5 in Seattle), while not traveling the full distance from or to Everett (or other regional origins/destinations), may be counted in the corridor's transit ridership numbers. The reasoning is that these trips, while going only part of the way on the corridor, take personal vehicle trips off the corridor, thereby improving conditions for other travelers. One example is Metro bus route #41 that travels between Northgate and downtown Seattle along I-5. Ridership will be counted in the I-5 Everett-Seattle commutes, while the passenger miles traveled and greenhouse gas emissions avoided will be prorated based on the relative length of this trip.

2) For bus trips that travel along two or more of WSDOT's commute corridors (such as Issaquah to Bellevue and continuing on to Seattle), the transit agencies perform more detailed stop-level analysis to determine the relative ridership for each segment of this trip, along with ridership that gets on at the first stop, and gets off at the last stop.

Accessibility Evaluation Methodology

11

Accessibility is the ease of reaching valued destinations. There are multiple ways to quantify accessibility in terms of to what, for whom, and the value of destinations. WSDOT uses a cumulative opportunities measure of accessibility for peak period commuters to jobs. Essentially, it is a count of jobs reachable from each census tract in a study area, during the morning commuter rush and within a certain travel time. For further discussion on accessibility as a concept, see the background section on p. 36 at the end of this chapter.

Accessibility measures

WSDOT uses the following measures to evaluate peak commute period accessibility to jobs on major commute corridors in the state's urban areas:

Jobs accessible in average commute time

- Accessibility by automobile
- Accessibility by transit
- Transit/Automobile accessibility ratio

Jobs accessible in average commute

WSDOT measures accessibility in terms of the total number of jobs a person could reach within an average commute time (The average commute time for the Seattle-Tacoma metropolitan statistical area in 2012 was 28.5 minutes). This is accomplished by counting the number of jobs reachable from a given location within the given time and repeating this for all locations in the area. The accessibility evaluation follows several steps to prepare for actually measuring system performance.

- **Assign jobs to locations** - Using covered employment estimates from the Puget Sound Regional Council (PSRC) and Geographic Information Systems (GIS) software, WSDOT is able to assign jobs to appropriate locations. The data from PSRC aggregates jobs to census tracts (see map below). WSDOT uses the geographic center of each census tract — called the 'centroid' — as the origin/destination for measuring travel times. This creates an average travel distance to jobs assuming they are evenly distributed in each tract.
- **Assign travel times to the transportation network** - In order to calculate the travel time between locations, WSDOT assigns annual average peak period travel speeds to segments of highway based on data gathered from in-pavement loop detectors. Local streets utilize speed data from GPS and Bluetooth pings gathered by private vendors. Each segment's speed is then divided by its length to give an average peak period travel time for private automobiles.

  To calculate transit travel times, WSDOT uses detailed information about transit stop locations and transit service published by transit agencies along with an average walking speed to calculate transit travel times between locations. This approach allows a low level of accessibility even for areas without transit service. However it does not allow for driving to a park and ride in order to take transit.

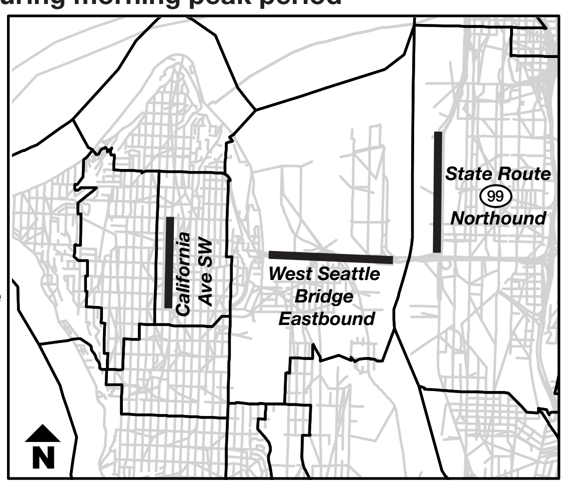
Accessibility to jobs during morning peak period

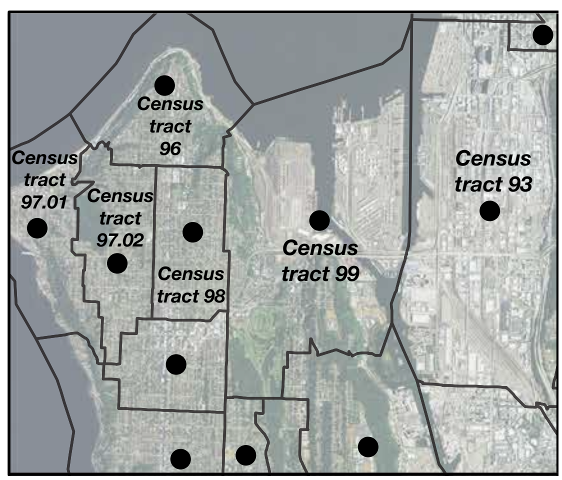
Jobs by census tract

Tract number	Jobs[1]
93	39,552
96	1,145
97.01	480
97.02	495
98	1,480
99	5,219

Road segment average AM peak period speed

Example[2]	Speed[3]
SR 99 NB	40
W Seattle Bdge EB	35
California Ave SW	20





To analyze regional accessibility, WSDOT assigns jobs data to census tracts which gives them a location, and speed data to road segments on the transportation network. Travel times are then calculated from each census tract's geographic center to all other census tracts in the region. A count of job opportunities reachable within a certain travel time can be calculated for each census tract. 1 Jobs data is from the Puget Sound Regional Council's covered employment estimates. 2 Examples are of highway, arterial and local road types. 3 Speed data comes from a variety of sources based on the roadway type. The numbers presented here are meant to serve as an example and are not actual speed data.

- **Measure accessibility for each location** - After the jobs locations and travel times have been assigned, the cumulative number of jobs accessible within the threshold time is measured from each census tract by personal automobile and public transit. As stated earlier WSDOT uses the average commute time for the metropolitan area being analyzed as the threshold. This count is conducted using a GIS tool developed by the University of Minnesota's Center for Transportation Studies called the Cumulative Opportunities Accessibility Tool for their Access to Destinations study.
- **Calculate transit/automobile accessibility ratio** - The transit/automobile accessibility ratio is the number of jobs accessible by transit divided by the number accessible by private automobile. A value of 1.0 means you can reach just as many jobs by transit as by personal automobile within the given time frame.

For a detailed description of accessibility evaluation steps, see the Access to Destinations study at www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=2318.

Accessibility data

- Transportation network map - As accessibility is a location-based measure, a detailed model of a region's transportation network is needed, including local and arterial streets and transit networks in addition to highways. WSDOT used the Puget Sound Regional Council's transportation network model for the Seattle area. The model is available by request at www.psrc.org/data/gis.
- Highway automobile speeds - WSDOT uses data from in-pavement loop detectors on highways in the Puget Sound area to determine highway automobile speeds and travel times. See p. 25 for more information on this data.
- Arterial and local street automobile speeds - WSDOT uses private sector speed data to determine travel times on arterial streets. When data is unavailable, a generalized speed was applied to local streets.
- Average commute time - Data on average commute times is published annually by the U.S. Census Bureau as part of the American Community Survey. The data is available at factfinder2.census.gov.
- Job locations - The Puget Sound Regional Council publishes "covered employment" estimates annually that provide locations of jobs covered under the State Employment Security Act by census tract. The data is available at http://www.psrc.org/data/employment.
- Transit service - Public transit agencies in the Puget Sound area all publish detailed service schedules through Google's General Transit Feed Specification (GTFS) system which provides information for the company's transit trip planner. This information can be used to efficiently calculate planned transit travel times from one location to another.

Accessibility evaluation incorporates land use, behavior and mobility

Accessibility as a concept has been present in transportation planning literature for more than 40 years, and methods for quantifying accessibility are becoming more sophisticated. WSDOT is interested in accessibility as a performance measure because it takes into account the purpose of travel: to fulfill life's daily needs.

Traditionally, many departments of transportation have used mobility-based metrics to measure system performance. Mobility is the ease of moving through the transportation system regardless of destination. Mobility measures generally look at travel speeds and include metrics such as congestion or travel delay. However, these mobility-based metrics can provide a picture of system performance that is skewed towards the costs of travel (time or delay) while ignoring the benefits (valued destinations). As such, roads in areas with low densities of destinations which tend to operate near posted travel speeds appear to be performing well. On the other hand, areas with high destination density that experience congestion appear to be performing poorly even though they are facilitating significant activity.

A classic example to illustrate this bias in mobility-based metrics is comparing Manitoba and Manhattan. Downtown Manhattan experiences speeds much slower than the posted speed limit so it would perform poorly according to mobility-based performance measures. However, people are able to reach many destinations even by walking due to the density. Highways in rural Manitoba, on the other hand, rarely experience delay compared to posted speeds and so would appear to be high-performing in terms of mobility. However, the number and density of destinations in rural Manitoba is much lower than in Manhattan. As a result, the accessibility is lower.

Given that most travel occurs to facilitate fulfillment of other needs such as reaching jobs or getting groceries, accessibility-based measures are important to incorporate into analysis of transportation system performance.

Marine Highways (Ferries) Capacity and Trip Analysis Methodology

12

Ferry system performance tracks measures such as the annual ridership, trip reliability and utilization of Washington state's ferry system. Ferries operate on service routes defined as marine highways: they are integral links across the Puget Sound, connecting island and peninsula communities with the major employment centers on the mainland. WSDOT owns and operates 22 ferry vessels, serving nine routes, with stops at 19 ferry terminals in Washington, and one in Sydney, B.C. Seven of the nine ferry routes are served by at least two vessels - typically operating simultaneously in order to minimize terminal wait times.

Ferry performance measures

WSDOT uses the following metrics to analyze and communicate ferry system performance in the *Corridor Capacity Report:*

Ferry route metrics

- Ferry ridership
- Ferry on-time performance
- Ferry trip reliability
- Ferry route capacity utilization
- Ferry trip travel times
- Ferry vessel fuel usage - fuel use per service mile.
- Ferry vessel emissions

Savings realized by ferry users

- Time savings by ferry users
- Cost savings by ferry users
- Vehicle miles avoided by ferry trips
- Emissions avoided by ferry trips

Ferry route metrics:

Ferry ridership is the number of passenger and vehicle trips taken on ferries within a defined timeframe (quarterly, annually, etc.), reported system-wide or for specific ferry routes.

WSDOT's Ferries Division tracks the number of people and vehicles that travel on ferry vessels. The ferry vessel ridership is divided into two categories: 1) passengers (walk-ons, drivers and vehicle passengers) and 2) vehicles.

The ridership is tracked for each ferry route (origin to destination), and summed over a quarter or a year.

Quarterly or annual ridership should be described as the number of trips taken, instead of the number of people served, because many customers onboard ferry vessels are frequent users and are counted for each of the many trips they take in the defined timeframe.

In addition to tracking ridership, WSDOT conducts user surveys to identify the types of users of the system. The most recent survey indicated that about 33% of the users take the ferries to commute to and from work regularly. The other 67% use it for a variety of reasons, such as personal errands or reaching recreational destinations.

Ferry on-time performance is the percent of trips on each ferry route that depart within 10 minutes of their scheduled departure time within a defined timeframe (quarterly, annually, etc.). It may be reported system-wide, or for specific ferry routes. WSDOT strives to keep vessels sailing on time, with an annual goal of at least 95% of all sailings departing within 10 minutes of their scheduled departure.

$$\text{Ferry on-time performance} = \frac{\text{Number of trips that departed within 10 minutes of scheduled departure}}{\text{Number of trips taken}}$$

Ferry trip reliability is the percent of sailings that sailed within a defined timeframe (quarterly, annually, etc.) compared to scheduled trips. It can be reported system-wide, or for specific ferry routes. Some scheduled sailings are delayed or canceled due to extenuating circumstances such as tidal issues, mechanical issues onboard or at the terminal, or security concerns. WSDOT replaces canceled trips when possible, and strives to maintain at least 99% annual trip reliability.

$$\text{Ferry trip reliability} = \frac{\text{Planned trips} - \text{Canceled trips} + \text{Replacement trips}}{\text{Planned trips}}$$

Ferry capacity utilization is calculated as the percent of available vehicle (or passenger) capacity that is used for each trip, over all trips on that route for a defined timeframe (quarterly, annually, etc.). This information is collected at the ticket booth, and compared to the vessel capacity.

$$\text{Ferry capacity utilization}^{\text{Vehicle or passengers}}_{\text{Averaged for each ferry route}} = \frac{\text{Vehicles (or passengers) onbard}}{\text{Allowed number of vehicles (or passengers)}}$$

Marine Highways (Ferries) Capacity and Trip Analysis

During the peak summer season, three vessels serve as maintenance spares, ready to replace a vessel that is taken out of service for planned or emergency maintenance. The replacement vessels may have a reduced capacity compared to the vessel typically serving a route. Another variable that affects capacity relates to staffing. The U.S. Coast Guard sets the number of crew required onboard for each vessel in order to sail. Some of the larger vessels could operate with fewer crew members during off-peak sailings on some routes, by closing the upper level passenger decks to reduce passenger capacity. Staffing level reductions are not used on routes that typically have high passenger loads. These scenarios illustrate that the capacity on a route may fluctuate.

Ferry trip travel times are the scheduled sailing time between origin and destination terminals, not including waiting at the terminal, loading and unloading.

Ferry vessel fuel usage is the gallons of fuel used by ferry vessel operations during a defined timeframe (quarterly, annually, etc.). A related metric is the **fuel use per service mile**, although this is not yet reported regularly.

Ferry operations data sources

- The following Ferries Division offices provide this data: Planning Office, Environmental Office and Budget Office.
- The number of vessel trips and related numbers come from the Automated Operating and Support System (AOSS).

Savings realized by ferry users:

WSDOT examined the six busiest commuter routes in the ferry system (representing 71% of all ferry commuters) to compare the time, cost and emissions of a commuter driving around the Puget Sound versus taking a ferry.

Commuting by ferry saves time, costs and emissions
Time in minutes; Greenhouse gas emissions (GHG) saved compared to driving around the Puget Sound

Highest volume commute routes in the Puget Sound[1]	Daily round trip savings		
	Time	Cost	GHG[2]
Bainbridge - Seattle	119	$32	66
Bremerton - Seattle	39	$21	40
Poulsbo - Seattle	87	$23	51
Port Townsend - Seattle	75	$21	41
Langley - Everett	219	$19	67
Hansville - Everett	194	$14	72

Data source: WSDOT Washington State Ferries Division.
Notes: 1 Trips to Seattle assume ferry commuters are walk-on passengers and some routes involve driving to the ferry terminal. Trips to Everett assume commuters drive a vehicle onto the ferries. 2 Greenhouse gas emissions are shown in kilograms of carbon dioxide equivalents.

Time savings by ferry users is the travel time saved by ferry passengers, compared to if they had decided to drive between their origin and destination. This would exclude any trips beginning or ending on an island that is not connected to the mainland by a bridge.

$$\underset{\text{Round-trip}}{\textbf{Ferry trip time savings}} = \left(\underset{\text{One-way around Puget Sound}}{\textbf{Drive time}} - \left(\underset{\text{One-way}}{\textbf{Ferry trip travel time}} + \underset{\text{One-way}}{\textbf{Walk or drive to/from ferry}}\right)\right) \times 2$$

The time saved on a round-trip between Bainbridge Town Center and Seattle Westlake is almost 2 hours daily, assuming a 0.5-mile walk from Bainbridge Town Center to the Bainbridge ferry terminal, and a 0.9-mile walk from the Seattle ferry terminal to Westlake Center. This does not account for wait time at the ferry terminals.

$$\underset{\text{Round-trip between Bainbridge and Seattle}}{\textbf{Ferry trip time savings}} = \left(\underset{\text{One-way drive Bainbridge-Seattle}}{\textbf{114 minutes}} - \left(\underset{\text{Onboard ferry}}{\textbf{35 minutes}} + \underset{\text{Walk to/from ferry}}{\textbf{20 minutes}}\right)\right) \times 2$$

$$= \textbf{119 minutes saved per round trip}$$

Cost savings by ferry users is the money saved by ferry passengers, compared to if they had decided to drive between their origin and destination. This would exclude any trips beginning or ending on an island that is not connected to the mainland by a bridge.

$$\underset{\text{Round-trip}}{\textbf{Ferry trip cost savings}} = \left(\frac{\textbf{Gas price per gallon}}{\textbf{Fuel efficiency}}\right) \times \textbf{Driving distance} + \textbf{Bridge toll} - \textbf{Round trip ferry cost}$$

Driving costs include gas ($4.00 per gallon) and toll charges on the Tacoma Narrows Bridge ($4.00 with *Good to Go!* pass). Parking and vehicle maintenance costs were not included. (Vehicle fuel consumption was based on the model year 2000 average of 20.3 miles per gallon.) Ferry fares were for non-peak travel published in the May 1, 2012, schedule, assuming walk-on passengers traveling to Seattle ($7.70 - free passage on return trip), and round-trip, single occupant vehicle fares to other destinations ($15.70-$26.30).

For example, someone choosing to take the ferry between Bainbridge Town Center and Seattle's Westlake Center would save about $32 for each round trip, assuming a 0.5-mile walk between Bainbridge Town Center and the Bainbridge ferry terminal, and a 0.9-mile walk between the Seattle ferry terminal and Westlake Center.

$$\underset{\text{Round-trip between Bainbridge and Seattle}}{\textbf{Ferry trip cost savings}} = \frac{\textbf{\$4.00/gallon}}{\textbf{20.3 miles/gallon}} \times \textbf{181 miles} + \textbf{\$4.00 toll} - \textbf{\$7.70 ferry passenger cost}$$

$$= \textbf{\$32 saved per round trip}$$

Vehicle miles avoided by ferry trips is the number of miles that ferry passengers would have to drive between their origin and destination if they did not take a ferry. This would exclude any trips beginning or ending on an island that is not connected to the mainland by a bridge.

$$\text{Miles avoided by ferry trip} = \text{Round-trip driving distance for trip around the Puget Sound} \times \text{Average number of ferry passengers}$$

Emissions avoided by ferry trips is the difference in greenhouse gas emissions per trip when comparing the drive-alone trip between their origin and destination and the ferry passengers based on a per-person emissions. This would exclude any trips beginning or ending on an island that is not connected to the mainland by a bridge.

$$\text{Emissions avoided by ferry use} = \left(\frac{\text{Driving distance}}{\text{Fuel miles/gallon}} \times \frac{7.97\ \text{kg } CO_2e}{\text{gallon of gas}}\right) - \left(\frac{\text{Ferry fuel use/trip}}{\text{Ferry riders/trip}} \times \frac{9.70\ \text{kg } CO_2e}{\text{gallon of diesel}}\right)$$

The kilograms of CO_2e avoided or "saved" per round-trip passenger trip on the ferry between Bainbridge Town Center and Seattle's Westlake Center is calculated as follows, compared to driving around the Puget Sound:

$$\underset{\text{Round-trip between Bainbridge and Seattle}}{\text{Emissions avoided by ferry use}} = \left(\frac{181\ \text{miles}}{20.3\ \text{miles/gallon}} \times \frac{7.97\ \text{kg } CO_2e}{\text{gallon of gas}}\right) - \left(\frac{0.488\ \text{gallons}}{\text{Ferry rider}} \times \frac{9.70\ \text{kg } CO_2e}{\text{gallon of diesel}}\right)$$

$$= 66\ \text{kg of } CO_2e \text{ avoided per person per trip}$$

The evaluation of emissions avoided, ferry trip time and cost saved by riding the ferry instead of driving around the Puget Sound does not apply to all ferry routes. Specifically, riders served by ferry routes to and from Vashon and the San Juan Islands do not have an alternative to drive as these islands are not connected to the mainland by bridges.

This analysis does not take into consideration that some ferry passengers might not take the trip if they had to drive instead of sail on the ferry vessel due to the impacts of cost and travel time.

Data for savings realized by ferry users

- The "Drive or Sail" folio can be found online at http://www.wsdot.wa.gov/Ferries/Environment/default.htm.
- Ferry fares and Tacoma Narrows Bridge tolls used were from May 1, 2012. Updated values from current fare and toll schedules should be used for future analyses, available at http://www.wsdot.wa.gov/ferries/fares/ and http://www.wsdot.wa.gov/Tolling/TollRates.htm.
- Fuel efficiency is calculated for various vehicle models every year. The analysis used 20.3 miles per gallon for a 2000 model year vehicle from the U.S. Energy Information Administration, available here: http://www.eia.gov/consumption/archive/rtecs/nhts_survey/2001/tablefiles/page_a05.html.
- The price for gasoline used was $4.00 per gallon for 2012. The average price was more than $4.00 per gallon for six months that year (the annual average was $3.85 according to the U.S. Energy Information Administration). Gasoline prices should reflect annual average regional prices for future analyses. Average gasoline prices are available online in weekly, monthly and annual formats at: http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_Y48SE_w.htm.
- The following emission factors were applied to fuel consumption by mode: Driving: 7.97 kg carbon dioxide equivalents (CO_2e) per gallon of gasoline, and Ferries: 9.70 kg CO_2e per gallon of B5 diesel. These values were updated after WSDOT published the "Drive or Sail folio" in 2012, noted above.
- The Puget Sound Air Emissions Inventory is a collaborative study of trends in Puget Sound maritime air emissions between 2005 and 2011. WSDOT's Ferries Division participated in the study, which can be found in its entirety at: http://www.pugetsoundmaritimeairforum.org/.

13 Incident Response Analysis Methodology

Incident Response (IR) is WSDOT's traffic incident management program with a mission to clear roads and help drivers. The program works in partnership with other agencies such as the Washington State Patrol (WSP) to achieve this goal. IR is instrumental in operating the transportation system efficiently .

Incident Response measures

WSDOT uses the following metrics to analyze and communicate the performance and benefits of the Incident Response program in the *Corridor Capacity Report*:

Clearance Time

- Incident clearance time
  - Extraordinary incidents
- Roadway clearance time
  - Over-90-minute incident clearance time
  - Successful Major Incident Towing activations
- Response time
- Cost of Incident-induced delay

Statewide incident responses

- Blocking and non-blocking incidents
- Secondary incidents avoided

Incident Response economic benefits

- Incident Responde cost/benefit ratio

Clearance time

Incident clearance time is the average time between the first recordable awareness of the incident (detection, notification, or verification) and the time the last responder has left the scene. These times are recorded in the field by IR teams. WSDOT reports statewide incident clearance time on a quarterly basis and annually.

$$\text{Incident clearance time} = \frac{\sum\left(\text{Time last responder left the scene} - \text{Time of first recorded awareness}\right)}{\text{Number of incidents responded to}}$$

WSDOT also reports the **clearance time for extraordinary incidents** that took 6 hours or more to clear. WSDOT typically describes the primary factors contributing to the extraordinary duration, such as hazardous chemical spills, multiple fatalities or semitruck load spills requiring special equipment to move. These metrics allow WSDOT to see the relative impact of more severe incidents on system performance.

Roadway clearance time is the average time between the first recordable awareness of an incident by a responding agency and first confirmation that all lanes are available for traffic. WSDOT calculates this metric by subtracting the roadway clear time from the incident notification time collected by IR teams.

$$\text{Roadway clearance time} = \frac{\sum\left(\text{Time all lanes are clear for travel} - \text{Time of first recorded awareness}\right)}{\text{Number of incidents responded to}}$$

As a subset of roadway clearance time, WSDOT reports the **over-90-minute roadway clearance time** for incidents that last more than 90 minutes. WSDOT tracks this metric because blocking incidents that last this long have a disproportionate impact on non-recurrent congestion.

Additionally, WSDOT reports the number of **successful Major Incident Towing (MIT) activations**. The MIT program clears heavy vehicles blocking the roadway. A successful activation means the roadway is cleared within 90 minutes of a "notice to proceed."

2012 Incident Response clearance times
2012; Clearance times in minutes by incident duration category

Incident type	Number of incidents	Average IR response time	Average *roadway* clearance time	Average *incident* clearance time
Incident duration less than 15 minutes				
Blocking	5,076	2.0	4.9	6.8
Non-blocking	29,343	0.4	-	5.1
Total	**34,419**	**0.6**	**4.9**	**5.3**
Incident duration 15 to 90 minutes				
Blocking	4,139	8.8	25.5	33.3
Non-blocking	5,980	6.7	-	27.1
Total	**10,119**	**7.6**	**25.5**	**29.6**
Incident duration longer than 90 minutes				
Blocking	384	20.8	167.3	184.4
Non-blocking	115	21.7	-	164.7
Total	**449**	**21.0**	**167.3**	**179.9**
Grand total	**45,037**	**2.4**	**21.1**	**12.7**

Data source: Washington Incident Tracking System (WITS), WSDOT Traffic Office, Washington State Patrol and Washington State Transportation Center (TRAC) at the University of Washington.

Response time is the average time between the first recordable awareness of an incident and when an IR team arrives on scene. The metric allows WSDOT to track how quickly IR crews are able to react to incidents.

Cost of Incident-induced delay is the economic impacts of delay that occurred due to incidents to which WSDOT IR crews responded (see p. 8 for a definition of what constitutes "delay"). WSDOT estimates the cost of delay at $244 per minute of incident duration for non-blocking incidents and $345 per minute of blocking incidents based on research from the University of Washington's Transportation Center (TRAC).

$$\text{Cost of incident induced delay} = \sum_{n=1}^{\text{Number of incidents}} \left(\text{Incident clearance time} \times \text{Cost of delay per minute of incident}_{\text{Incident type}} \right)$$

This allows WSDOT to evaluate the relative impacts of blocking and non-blocking incidents and estimate the monetary impacts to society at large. The complete research report can be found on WSDOT website at: www.wsdot.wa.gov/Research/Reports/700/761.1.htm

Statewide incident responses

Incident Response teams record information about each incident at which they attempt to provide assistance. This data is used to create a count of the total number of incidents to which a WSDOT team responded.

Blocking incidents are incidents that obstruct at least one lane of travel. WSDOT tracks these incidents as they have a greater impact on incident-induced delay. **Non-blocking incidents** occur on the shoulder or off the roadway altogether. They have less effect on traffic, but frequently result in traffic delay due to distraction of drivers passing the scene. Some incidents clear on their own while an IR team is on the way. These incidents are called "**unable to locate"** and are included in the count of total incidents but not in the calculations of clearance times or program benefits.

Secondary incidents avoided is the estimated number of incidents that did not occur as a result of a prior incident due to the quick work of IR teams. Secondary incidents are unplanned incidents that can occur either within the scene of the original incident or within the resulting back-up in either direction on the highway.

The Federal Highway Administration (FHWA) acknowledges that on average there are 20% or more secondary incidents occurring on the system due to the primary incidents. WSDOT uses this figure to calculate the number of secondary incidents avoided by applying it to the number of incidents to which a WSDOT team responded.

$$\text{Secondary incidents avoided} = \text{Number of incidents} \times 0.2_{\text{FHWA incident prevention rate}}$$

WSDOT reports secondary incidents avoided on a statewide basis for the IR program. For example, the calculation below gives the number of secondary incidents avoided statewide in 2012:

$$\text{Secondary incidents avoided}_{2012} = 43{,}051 \text{ incidents} \times 0.2 = 8{,}610 \text{ secondary incidents avoided}$$

Incident Response economic benefits

WSDOT estimates the economic benefit of the IR program based on the amount of incident-induced delay and secondary incidents prevented through the intervention of IR teams at assisting at incident scenes.

$$\text{Economic benefits of IR program} = \text{Economic benefits of reduced traffic delay} + \text{Economic benefits of secondary incidents avoided}$$

WSDOT's method for calculating the amount of incident-induced delay avoided is based on two case studies conducted by the University of Maryland and Rice University in cooperation with the Texas Transportation Institute. The case studies are titled "A case study of Maryland CHART Operations," and "Safe-Clear Performance Report 2008," respectively. These reports found that incident-induced delay was reduced by about 25% on average when comparing the duration of incidents where response personnel assisted compared to when they were not present.

WSDOT applies this figure to the estimated incident-induced delay experienced at each incident resulting in a conservative estimate of delay avoided. This method will over-estimate the actual benefits for some incidents and under-estimate it for others but, on the whole should create a reliable estimate of delay avoided through the IR program according to research.

$$\text{Economic benefits of reduced traffic delay} = \sum_{n=1}^{\text{Number of incidents}} \left(\text{Cost of Incident induced delay} \times 0.25_{\text{Rate of incident delay prevented}} \right)$$

Incident Response Analysis

To calculate the economic benefits of avoided secondary incidents, WSDOT applies an average cost per minute to the estimated secondary incident. WSDOT calculates the minutes of secondary incident avoided by applying the FHWA-derived 20% reduction in secondary incidents to the incident clearance time of each incident. An average cost of \$286 per minute of crash scene duration is applied to calculate the final cost which comes from the WSDOT Incident Response Phase 3 research mentioned on p. 41.

$$\text{Economic benefits of secondary incidents avoided} = \sum_{n=1}^{\text{Number of incidents}} \left(\text{Incident clearance time} \times \underbrace{0.2}_{\text{FHWA incident prevention rate}} \times \text{\$286 per minute of secondary incident} \right)$$

The example calculations below show how these equations were applied to derive the economic benefit from the Incident Response program for 2012.

$$\text{Economic benefits of reduced traffic delay}_{2012} = \sum \left(\$3{,}450 \times 0.25 \right) + \ldots + \left(\$732 \times 0.25 \right)$$

$$= \text{\$39.3 million in economic benefits from reduced traffic delay}$$

$$\text{Economic benefits of secondary incidents avoided}_{2012} = \sum \left(10 \times 0.2 \times \$286 \right) + \ldots + \left(10 \times 0.2 \times \$286 \right)$$

$$= \text{\$31.4 million in economic benefits from secondary incidents avoided in 2012}$$

$$\text{Incident Repsonse economic benefits}_{2012} = \text{\$39.3 million} + \text{\$31.4 million}$$

$$= \text{\$70.7 million in total economic benefits from Incident Response program}$$

Incident Response data

WSDOT tabulates data for all incidents to which an IR team responds in the Washington Incident Tracking System (WITS). Incident Response crews record data about each incident in the field. Data they collect includes times of first awareness, arrival on scene, roadway clearance, and incident clearance which allows WSDOT to analyze various aspects of incident duration. IR teams also record other data such as how they were notified of the incident, incident cause and how many lanes of travel were blocked.

Incident Response performance also a proxy for non-recurrent congestion

WSDOT's Incident Response program works to clear traffic incidents safely and quickly, to minimize congestion, restore traffic flow, and reduce the risk of secondary collisions. The program is an important operational strategy because incidents account for nearly half of non-recurring traffic congestion. Non-reccurrent congestion is caused by one-time events such as collisions, severe weather, or major traffic events such as the Seahawks Superbowl parade where an estimated 700,000 people descended on downtown Seattle.

IR teams are trained and equipped to assist motorists and the WSP during traffic-related emergencies. In addition to responding to emergencies, IR teams provide a variety of services to motorists such as jump-starts or changing flat tires. These services keep traffic moving and reduce the risk of collisions from distracted driving.

WSDOT, WSP and the Washington Fire Chief recognize their joint responsibilities for enhancing the safety and security of the transportation system. The agencies developed the Joint Operations Policy Statement to delineate responsibilities and state policy as guidance for future collaboration. WSP's Field Operations Division is responsible for traffic law enforcement, collision investigation, commercial vehicle regulations and motorist assistance on the state's highways. WSDOT supports WSP with these operations through a wide range of activities and facilities varying from Incident Response to disaster response, winter operations and transportation security.

The IR program is active in all six WSDOT regions, patrolling 493 centerline miles statewide on major traffic corridors during peak commute hours. WSDOT has about 47 full-time equivalent positions in the IR program and 62 dedicated IR-related vehicles, operating with a \$4.5 million annual budget. The IR program delivered services that resulted in an estimated annual benefit to cost ratio of approximately 16:1 for 2012.

An Incident Response unit in action at the scene of a semitruck rollover. The IR technician pictured is applying absorbent material to clean up diesel fuel leaking from the truck's tank.

Before and After Project Analysis Methodology

14

Before and after project analyses

capture the effects of projects designed to address mobility issues on Washington's state highways. WSDOT's approach called "Moving Washington" reflects the state's goals and objectives for planning, operating, and investing in the transportation system, and it relies on partnerships with local and regional transportation providers and organizations. *Moving Washington* combines three essential transportation strategies to achieve and align our objectives with those of our partners:

- **Operate efficiently** – This approach gets the most out of existing highways by using traffic-management tools to optimize the flow of traffic and maximize available capacity. Strategies include utilizing traffic technologies such as ramp meters and other control strategies to improve traffic flow and reduce collisions, deploying Incident Response to quickly clear collisions, optimizing traffic signal timing to reduce delay, and implementing low-cost/high-value enhancements to address immediate needs.
- **Manage demand** – Whether shifting travel options, using public transportation or reducing the need to travel altogether, managing demand on overburdened routes allows our entire system to function better. Strategies include using variable-rate tolling in ways that reduce traffic during the most congested times and balance capacity between express and regular lanes, improving the viability of alternate modes, and providing traveler information to allow users to move efficiently through the system.
- **Add capacity strategically** – Targeting our worst traffic hotspots or filling critical system gaps to best serve an entire corridor, community or region means fixing bottlenecks that constrain the flow. Upgrading a failing on-ramp merge or hard-shoulder running during peak periods can free up the flow of traffic through a busy corridor. From improving rail crossings and ferry service to working with transit agencies to connect communities, from building direct-access ramps for carpools and transit to including paths for pedestrians and bicyclists, capacity improvements require strong partnerships with a shared vision for the corridor.

Mobility project prioritization

WSDOT assesses potential mobility-related transportation projects based on the maximum throughput threshold in order to prioritize projects using a benefit to cost evaluation. For more information on the mobility project prioritization, see: http://www.wsdot.wa.gov/mapsdata/travel/pdf/Mobility_Users_Guide_2001.PDF

There is no single solution for traffic congestion, which is why WSDOT reduces congestion by focusing on the three key balanced strategies. Example projects for each of these strategies include:

Types of mobility projects evaluated by WSDOT using "before and after" type methodologies
List of project types is not intended to be exhaustive

Operate Efficiently
Ramp metering
HOV, HOT lanes
Intersection modifications
Coordinate signal timing
Open shoulder for peak period use
Use active traffic management (ATM gantries, variable message signs and dynamic speed limits)
Implement electronic variable tolling
Deploy Incident Response
Prioritize transit at signals
Manage access to highway (consolidate driveways, add median barrier, etc.)
Facilitate multi-modal connections (transit, ferry terminals, park and rides)
Manage Demand
Increase transit services
Increase park and ride lot access and capacity
Encourage, incentivize commute trip reduction (use transit, vanpool, carpool, walk or bike, telecommute, compress workweek)
Enhancing alternate routes (opening new JBLM gates, etc.)
Add Capacity Strategically
Realign interchange ramps
Add new lanes (GP or HOV)
Add new interchange or new ramp(s)
Add turn lanes or exit-only lanes
Add bike lanes

Data source: WSDOT's Highway System Plan and other online sources http://www.wsdot.wa.gov/planning/HSP and http://www.wsdot.wa.gov/movingWashington/.

Project analysis measures

When a project has been selected, funded and designed, WSDOT collects data to document the existing operating conditions before starting construction. This data is used as the "before" condition to evaluate the effectiveness of the project.

WSDOT uses a combination of the following metrics to analyze and communicate the effects of mobility-related transportation projects in the *Corridor Capacity Report:*

Mobility metrics

- Change in travel time
- Change in travel speed
- Change in travel volume / demand
- Change in delay
- Change in duration of congestion
- Change in travel reliability

Safety metrics

- Change in collisions (fatalities, etc.)

Mobility metrics

The table on this page illustrates the types of data and metrics evaluated before and after construction of a project. Details regarding each metric are described below.

Change in travel time is expressed in minutes for a defined trip through the area affected by the project. It is typically based on the average travel time. See pp. 21-28 for more information on calculating travel time metrics.

Change in travel speed is expressed in miles per hour (mph) along a defined trip through the area affected by the project. It is typically based on the average speed or the maximum throughput speed. Comparison to the posted speed is particularly important if there is any change in posted speed after project completion.

Change in travel volume is expressed in the number of vehicles passing a point along the defined trip affected by the project. It can be evaluated on the mainline or on alternate routes, as well as on ramps or auxiliary facilities. Analysts should take into consideration holidays, school schedules, and other factors that are likely to impact travel demand. See pp. 11-12 for more information on calculating the traffic volume or demand.

Change in delay is expressed in hours of travel delay, typically for vehicles or for people, for all trips through the area affected by the project. See pp. 8-10 for more information on calculating delay.

Change in duration of congestion is expressed in minutes, and illustrates if the project has had an effect on how long congested conditions typically last. See p. 23 for more information on calculating the duration of congestion.

Change in travel reliability is expressed as travel time in minutes that allows travelers to expect to arrive on-time or early x% of the time. Changes in travel reliability can show if the travel experience is more or less predictable (see p. 23).

WSDOT evaluates travel times and speeds prior to and after a project is constructed. Typically, measuring speed and travel time for a few mid-week days (Tuesday through Thursday) is sufficient to show the typical travel conditions. In some cases where there are unique circumstances, other timeframes are required. For example one highway typically experienced weekend congestion because it served as a link to popular recreational areas. In that case, weekend data was more useful.

Safety metrics

Change in collisions is the difference in the number of collisions along the defined trip through the area affected by the project. Collisions are evaluated typically for three years prior to the start of construction, and then again for three years following the end of construction. Different factors of particular significance to a particular project area can be evaluated: collision severity, collision frequency, pedestrian/bicyclist collisions, drowsy driving collisions, time of day, and many other factors. Collisions are evaluated for some mobility projects on a case-by-case basis.

I-5/SR 502 interchange project travel time and volume changes

2007 and 2008; I-5 milepost 7 at the junction with I-205 to milepost 11 at the junction with SR 502 near NE 10th Avenue; Commute length in miles; Travel time in minutes; Volume in number of vehicles; Speed in miles per hour

	Commute length		Travel time		Volume[1]		Average speed	
	Before	After	Before	After	Before	After	Before	After
Southbound morning commute 6-10 a.m.	3.92	5.00	12.00	5.00	1,650	2,460	19.60	60.00
Northbound evening commute 2-6 p.m.	3.81	4.20	7.00	5.00	1,700	2,790	32.60	50.00

Data source: WSDOT Transportation Data and GIS Office.
Note: 1 Volume is measured on SR 502 east of NE 10th Avenue.

Mobility data

Mobility data is available through a variety of technologies. Some sources are more applicable to the urban highway segments, such as the permanent traffic recorders.

- Permanent traffic recorders are primarily in-pavement loops that detect vehicle presence and speed, yielding both volume and travel speed data. In the urban areas of the state, these loops are placed about every 0.5 mile on the primary highway corridors. Elsewhere in the state, loops are more spaced out and the data density is insufficient for certain types of analysis. See p. 25 in the Travel Time Trends chapter for more details about access to this data.
- Short counts are temporary data collection sites using movable technologies such as pneumatic rubber tubes that lie across the road and count the number of vehicles crossing them. Depending on how they are installed, these tubes can also yield vehicle speed data.
- Automated license plate readers identify matching license plates at the beginning and end of the project segment to identify vehicle speed and trip travel time. If there is a high rate of matched license plates, this approach can yield approximate traffic volumes as well.
- Test vehicles can be used to drive the project area during peak periods in order to capture the actual drive time for the project segment. Typically one or more test vehicle drives the segment several times to develop an average travel time.
- Private sector speed data procured by WSDOT may be available to assess travel speeds and segment travel times for current and historic data.

Collision data

WSDOT's Transportation Data and GIS Office maintains collision records for all public roads. Staff can request data for the area relating to their project through this website: http://www.wsdot.wa.gov/mapsdata/tdgo_home.htm

Before and after analysis background

For most projects, WSDOT will collect a minimum of two days' worth of data within one year of project start for the "before" data, focused on the congested peak period(s). "After" data is collected about 4-12 months following project completion. If the "before" data is of questionable quality, WSDOT may opt to collect an additional day's worth of "after" data. On some projects it may be necessary to collect data during a longer timeframe to capture the effects of induced growth. WSDOT tries to collect "after" data at approximately the same time of the year as the "before" data to avoid seasonal variations; for example, a national holiday or school being in or out of session can significantly affect travel patterns. WSDOT assumes that data outside of congested times is not necessary since it is unlikely to experience any improvements in travel time or volume during those periods.

For projects that have permanent traffic recorders WSDOT typically analyzes a longer timeframe of data because it requires no additional data collection effort to do so, while increasing the reliability of the data analysis.

On certain high-profile projects there may be a need to collect data immediately (within a couple of weeks) after the completion of a project to address questions from the media and public. Although immediate data will be collected and analyzed for media and outreach purposes, the final reported performance data for these high-profile projects will come from the normal 4-12 month "after" data collection period. Typically, it takes drivers a few months to grow accustomed to a new roadway configuration or technological installation (variable message signs, signal timing, etc.), and therefore collecting data 4-12 months after project completion is more likely to illustrate a steady state for the highway's operation.

Collecting "before" data for multi-stage projects should be a point of discussion between the data collection group and analysts, and is addressed on a case-by-case basis. Often the completion of an initial stage and its effect on traffic will determine whether a "before" study is viable at an interim point, or should precede the initial stage.

15 MAP-21 Related Metrics Proposed Methodology

MAP-21 performance metrics

are established within the federal transportation funding legislation and related rule-making. WSDOT is reviewing and providing feedback on the proposed rules, and will update this chapter as more details are set forth. The U.S. Department of Transportation) and Federal Highways Administration (FHWA) websites have more information: http://www.dot.gov/map21, and https://www.fhwa.dot.gov/map21/.

MAP-21 performance metrics

WSDOT computes the following metrics to report to the Federal Highway Administration (FHWA) on the MAP-21 related performance metrics:

Expanded National Highway System (NHS)

- Washington state highways in the NHS
- Local, county, and rural roads included in the NHS

System performance

- Travel time reliability
- Travel delay

Freight performance

- Freight network
- Freight travel time reliability
- Freight travel delay

Target setting considerations

The target would be set by individual state DOTs and MPOs. Targets may vary by facility, by corridor, by region, by rural or urban, by freight versus commute route or other factors such as investment levels, available transit options, remaining capacity and levels of recurrent versus non recurrent congestion levels.

Targets could have a negative or positive direction. For example “annual delay should not increase more than 5% per year”. Another example of a target could be a comparison of the growth in the delay to the growth in the regional economy. The economic recession has played a major role in reducing congestion in recent years, but population and job growth have had a significant role in system performance in many regions over the past several decades. Measuring the percent change in delay compared to percent change in gross metropolitan product could provide a more relevant comparison of the role of transportation and land use decisions during periods of rapid growth with periods of slow or no growth. An example target for this measure may state that the percent increase in delay should be no more than the percent increase of the gross metropolitan product.

AASHTO performance measure recommendations

The following performance measures were recommended by the American Associate of State Transportation Officials (AASHTO), and supported by WSDOT. AASHTO also provided recommendations for safety, bridges and pavement condition metrics.

Freight metrics

- Annual hours of truck delay (AHTD)—Travel time above the congestion threshold in units of vehicle-hours for Trucks on the Interstate Highway System.
- Truck reliability index (RI)—The RI is defined as the ratio of the total truck travel time needed to ensure on-time arrival to the agency-determined threshold travel time (e.g., observed travel time or preferred travel time).

System performance (under the National Highway Performance Program)

- Annual hours of delay (AHD)—Travel time above a congestion threshold (defined by State DOTs and MPOs) in units of vehicle hours of delay on Interstate and National Highway System (NHS) corridors.
- Reliability index (RI80)—The reliability index is defined as the ratio of the 80th percentile travel time to the agency-determined threshold travel time.

Congestion Mitigation and Air Quality (CMAQ)

- Annual hours of delay (AHD)—Travel time above a congestion threshold (defined by State DOTs and MPOs) in units of vehicle hours of delay reduced by the latest annual program of CMAQ projects.
- Criteria pollutant emissions—Daily kilograms of on-road, mobile source criteria air pollutants (VOC, NOx, PM, CO) reduced by the latest annual program of CMAQ projects.

MAP-21 measurement areas and current WSDOT reporting

MAP-21 goals by program area	Federal threshold/ benchmark[1]	MAP-21 target[2]	Penalty[3] Y/N	Date draft rule was released	Existing WSDOT performance measures for this program area
Highway Safety Improvement Program					
Rate of **traffic fatalities** per 100 million vehicle miles traveled (VMT) on all public roads	No	TBD[4]	Yes	3/11/14	Traffic fatality rates using the NHTSA[5] methodology, see Gray Notebook 54, p. 1
Rate of **serious traffic injuries** per 100 million vehicle miles traveled (VMT) on all public roads	No	TBD	Yes	3/11/14	Serious injury rates using the NHTSA[5] methodology, see Gray Notebook 54, p. 1
Number of **traffic fatalities** on all public roads	No	TBD	Yes	3/11/14	Traffic fatalities using the NHTSA[5] methodology, see Gray Notebook 54, p. 1
Number of **serious traffic injuries** on all public roads	No	TBD	Yes	3/11/14	Serious injuries using the NHTSA[5] methodology, see Gray Notebook 54, p. 1
Rate of per capita **traffic fatalities** for drivers and pedestrians 65 years of age or older	No	TBD	No	Guidance provided 10/1/2012	Traffic fatalities for pedestrians 65 years of age or older. See Gray Notebook 48, p. 8, for review of MAP-21 implications. The rate of traffic fatalities for older pedestrians is part of Washington state's *Target Zero*[6] campaign
Rate of fatalities on high-risk rural roads	No	TBD	Yes	Guidance provided 10/1/2012	Traffic fatality rates on high-risk rural roads as part of Washington state's *Target Zero* campaign
Highway-railway crossing fatalities	No	TBD	No	Guidance provided 2/22/2013	Fatalities at highway-railway crossings
National Highway Performance Program					
National Highway System and Interstate **pavement condition**	TBD	TBD	Yes		Pavement structural and functional condition. See Gray Notebook 52, p. 6, for an update on MAP-21 implications for pavement
Condition of bridges on the National Highway System	<10% of deck area on SD[7] bridges	TBD	Yes		Several measures of bridge condition including good/fair/poor condition rating and structural deficiency (SD) rating, see Gray Notebook 54, p. 4
Measures to be determined through federal rule-making	No	TBD	No		The *2014 Corridor Capacity Report* details highway travel time and reliability trends in Washington state
National Freight Movement Program					
Measures to be determined through federal rule-making	No	TBD	No		WSDOT's freight mobility plan will address trucking, rail and marine freight. See Gray Notebook 49, p. 41, for review of MAP-21 freight implications
Congestion Mitigation and Air Quality (CMAQ) Program					
Measures to be determined through federal rule-making	No	TBD	No		The *2014 Corridor Capacity Report* details the highway travel time and congestion trends in Washington state
Measures for on-road mobile source emissions to be determined through federal rule-making	No	TBD	No		No existing performance measure
Project Delivery					
Duration of NEPA[8] documentation preparation	No	TBD	No		Percent of projects completed early or on time, percent completed on or under budget, and duration of NEPA[7] document preparation

Data source: WSDOT Office of Strategic Assessment and Performance Analysis.

Notes: 1 Minimum threshold or benchmark to be established by the U.S. Department of Transportation, Secretary of Transportation. 2 Performance targets to be set for each performance measure by WSDOT in coordination with metropolitan planning organizations (MPOs) statewide. 3 Penalties apply for some measures if the DOT or MPO does not attain the target within a given time frame. Penalties include minimum allocations of federal funding toward programs to progress toward the desired target. 4 TBD = To be determined. 5 NHTSA = National Highway Traffic Safety Administration. 6 State strategic highway safety plan. 7 SD = structurally deficient. 8 NEPA= National Environmental Policy Act.

Table of Tables and Graphs

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It is the Washington State Department of Transportation's policy to assure that no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated, may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For additional information regarding Title VI complaint procedures and/or information regarding our non-discrimination obligations, contact OEO's Title VI Coordinators, George Laué at (509) 324-6018 or Jonté Sulton at (360) 705-7082.Get WSDOT's mobile application

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Scan the image on the left to download WSDOT's Android application. Scan the image on the right to download the iPhone application.

Android **iPhone**

The mobile phone apps can also be downloaded for free through Android's Google Play or the iPhone App Store, or by navigating to the following website: http://www.wsdot.wa.gov/traffic/seattle/products/

WSDOT's *Handbook for Corridor Capacity Evaluation* is prepared by the

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