Draft Research Report
Agreement T4118, Task 31
Truck Performance Measure Research Project

GPS TRUCK DATA PERFORMANCE MEASURES PROGRAM IN WASHINGTON STATE

by

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16. ABSTRACT

The Washington State Department of Transportation (WSDOT), Transportation Northwest at the University of Washington (UW), and the Washington Trucking Associations (WTA) have partnered on a research effort to collect and analyze global positioning systems (GPS) truck data from commercial, in-vehicle, truck fleet management systems. This effort was funded by the Washington State Legislature, and its purpose is to develop a statewide freight performance measures program for use by WSDOT. This document reviews the program's previous phases and provides details about the latest phase of the program. The report also provides references to the technical documents that support the program.

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INTRODUCTION

The Washington State Department of Transportation (WSDOT), Transportation Northwest at the University of Washington (UW), and the Washington Trucking Associations (WTA) have partnered on a research effort to collect and analyze global positioning systems (GPS) truck data from commercial, in-vehicle, truck fleet management systems. This effort was funded by the Washington State Legislature, and its purpose is to develop a statewide freight performance measures program for use by WSDOT. The program's specific goals are to the following:

- *Guide federal freight funding requests.* The re-authorization of the Transportation Bill is expected to require performance-based freight project evaluation and performance measures.
- *Increased public accountability to citizens*. Tracking truck freight performance before and after projects are constructed explains the value of their investments.
- *Making the most productive investments of state dollars.* Locating and quantifying delay at truck freight bottlenecks allows the state to identify key problems and prioritize project funding.

This document reviews the program's previous phases and provides details about the latest phase of the program. The report also provides references to the technical documents that support the program.

PROJECT HISTORY

The current Freight Performance Measures Program is the result of three projects.

FMSIB Data Validation

The initial project was a test of the value of the GPS data in tracking and monitoring trucks. This effort, completed in 2004, was supported by Washington State's Freight Mobility Strategic Investment Board (FMSIB) and evaluated the development of data collection methodologies that can be used to cost effectively measure truck movements along specific roadway corridors. The intent of this study was to design and test methodologies that could be used to measure the performance of freight mobility roadway improvement projects against benchmarks, or selected standards, that would be used both as part of the project selection process and to report on speed and volume improvements that resulted from completed infrastructure improvement projects. The effort placed 25 portable global positioning systems (GPS) in volunteer trucks recruited for this project to collect specific truck movement data at 5-second intervals.

The researchers found that with GPS data, analysts can understand when and where monitored trucks experience congestion. By aggregating this information over time, they can generate performance statistics related to the reliability of truck trips, and even examine changes in route choice for trips between high volume origin/destination pairs. The key is whether enough GPS-equipped instrumented vehicles pass over the roadways for which data are required. This basic condition significantly affects whether the transponder and GPS technologies will be effective at collecting the data required for any given benchmark project.

More information about this project can be found in McCormack and Hallenbeck (2004, 2006).

Freight Performance Measures Phase 1

The initial phase of the legislatively funded WSDOT project explored the ability of a truck freight performance measurement program to

- efficiently collect and process truck GPS devices' output
- extract useful truck travel time and speed, roadway location, and stop location information
- protect the identity of the truckers and their travel information so that business sensitive information is not released.

Starting in August of 2009, the research team collected data from 2,000 to 3,000 trucks per day in the central Puget Sound region. One of the most important steps in this phase of the project was to obtain fleet management GPS data from the trucking industry. Trucking companies approached by WSDOT and the UW at the beginning of the study readily agreed to share their GPS data, but a lack of technical support from the firms made data collection difficult. The research team overcame that obstacle by successfully negotiating contracts with GPS and telecom vendors to obtain GPS truck reads in the study region. The next challenge was to gather and format the large quantities of data (millions of points) from different vendors' systems so that they could be manipulated and evaluated by the project team. Handling the large quantity of data meant that data processing steps had to be automated, which required the development and validation of rule-based logic that could be used to develop algorithms.

Because a truck performance measures program will ultimately monitor travel generated by trucks as they respond to shippers' business needs, picking up goods at origins (O) and dropping them off at destinations (D), the team developed algorithms to extract individual truck's O/D information from the GPS data. The researchers mapped (geocoded) each truck's location (as expressed by a GPS latitude and longitude) to its actual location on the Puget Sound region's roadway network and to traffic analysis zones (TAZs) used for transportation modeling and planning.

The researchers reviewed truck freight performance measures that could be extracted from the data and that focused on travel times and speeds, which, analyzed over time, determine a roadway system's reliability. They placed the truck performance measures that were developed into a prototype web-based data analysis and visualization program called Drive-NET (Ma and McCormack 2010).

Because the fleet management GPS data from individual trucks typically consist of infrequent location reads, making any one truck an unreliable probe vehicle, the researchers explored whether data from a larger quantity of trucks could compensate for infrequent location reads. To do this, the project had to evaluate whether the spot (instantaneous) speeds recorded by one truck's GPS device could be used in combination with spot speeds from other trucks on the same portion of the roadway network.

The researchers also explored methods for capturing regional truck travel performance. The approach identified zones that were important in terms of the number of truck trips that were generated. Trucks' travel performance as they traveled between these economic zones could then be monitored over time and across different times of day.

More details about the data collection effort, the GPS data process, and the GPS-based performance measures program can be found in McCormack et al. (2010) and in Ma, McCormack and Wang (2011).

Freight Performance Measures Phase 2 – Statewide Data

This second phase of the WSDOT freight performance measures program is an expansion of the phase one effort and has completed the following steps:

- initiated collection of statewide data
- tested the validity of spot speeds data
- explored the GPS data for use before and after analyses of project
- develop a method to identify and quantify bottlenecks.

This phase is discussed in detail this report.

COLLECTION OF STATEWIDE GPS DATA

As was the original intent of the program, the project team expanded the data collection process from just the Puget Sound region to statewide. In this phase of program, the team currently receives daily GPS data from about 6,000 trucks traveling on roads throughout Washington state. As in the first phase, a contract negotiated with a large GPS vendor has resulted in a near real-time raw data feed for all its client trucks when they travel in the state. The commercial in-vehicle GPS devices report, via cellular technology, both at preset intervals (every 10 to 15 minutes) and when the trucks stop. The resulting GPS data set includes reads for individual truck's longitude and latitude, the truck's ID (scrambled for privacy), spot (instantaneous) speeds, and a date and time stamp. Other variables in the data set include GPS signal strength, travel heading, and the status of a truck's stop (parked with engine on or engine off).

Figure 1 shows typical daily coverage for the state. The collected data include GPS reads 100 miles outside of Washington's borders (in British Columbia, Idaho, and Oregon). This information allows analysis of truck movements into and out the state.

TESTING THE VALIDITY OF SPOT SPEED DATA

Many of the performance measures use speeds reported by the GPS devices in the trucks known as spot speeds. A spot speed is the instantaneous speed measured at a particular moment in time and then reported by the GPS unit. Spot speeds collected by GPS devices have advantages over time- and distance-based speed calculations (known as space mean speed) in that they can be directly obtained from GPS devices and require minimal data processing. GPS spot speeds raise minimal privacy concerns because they do not require tracking individual vehicles or using vehicle IDs to calculate speeds.

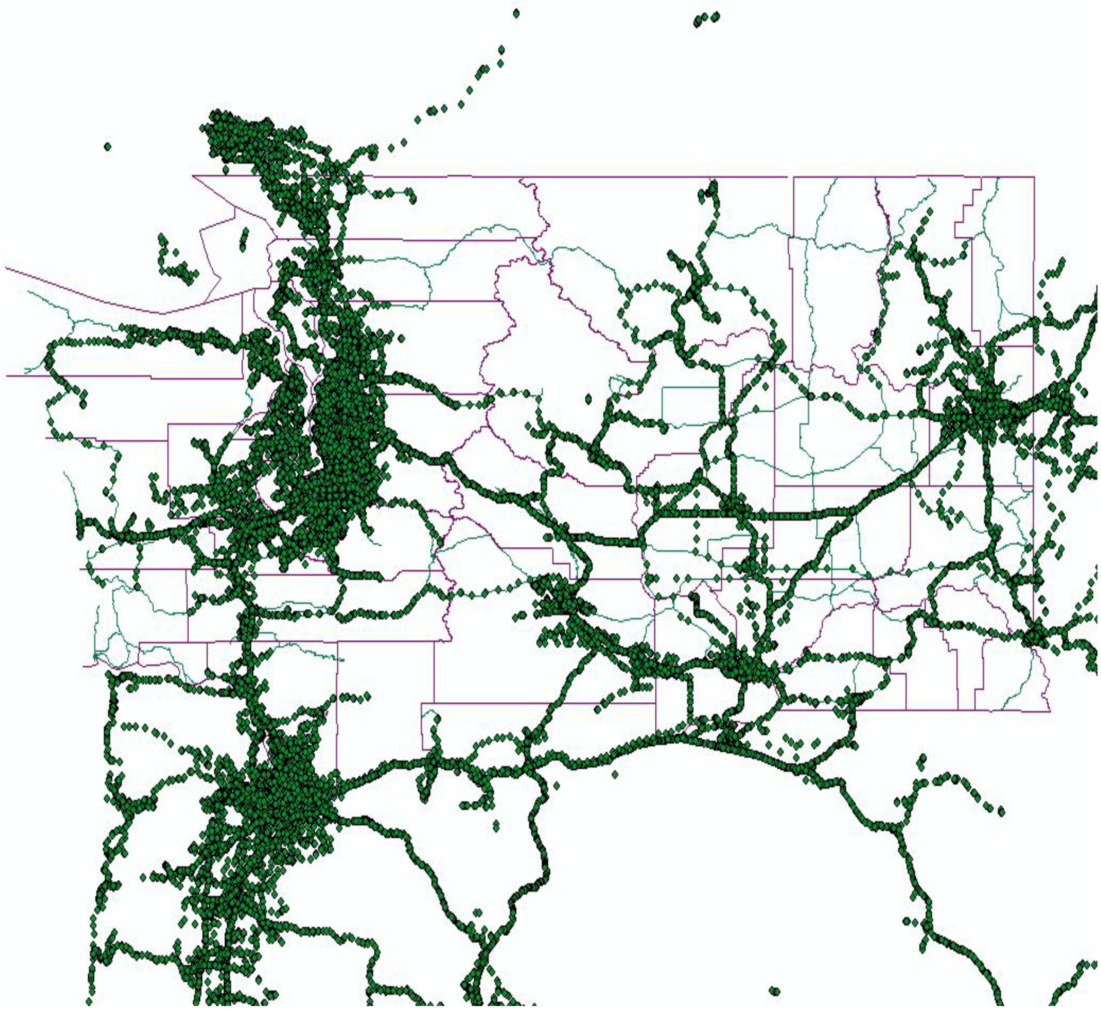

Figure 1: Statewide GPS Coverage

In addition, because the GPS data collected for this effort typically have read rates of about every 15 minutes, it can be difficult to use these data to estimate the space mean speed for a particular link. This problem may occur if no reads have been taken on the link or if reads have not taken near the beginning and end of the link. However, spot speed availability is not restricted by data read frequency, and spot speeds can be useful for any link if a significantly large number of vehicles report them.

While these benefits exist, there are some concerns regarding the accuracy of truck GPS spot speed measurements. To address these concerns, the research team investigated whether GPS spot speed data are sufficiently accurate for estimating truck travel speed. To answer this question, the team conducted two analyses.

First, the team compared GPS spot speeds with speeds estimated from dual loop vehicle detectors on State Route 167. They selected this route because it is a restricted access freeway where no vehicle delays are caused by traffic signals or intersections.

Second, the team developed a simple speed estimation method based on GPS spot speeds to estimate link travel speed and compared that method to space mean speed estimation based on GPS vehicle location and time data. The analysis demonstrated that aggregated GPS spot speeds generally matched loop detector speeds and captured travel conditions over time and space. Speed estimation based on GPS spot speeds was sufficiently accurate in comparison to space mean speeds, with a mean absolute difference of less than 6 percent. The team concluded that GPS spot speed data provide a reasonable approach for measuring freight corridor and segment performance, and truck travel characteristics.

Technical documentation of this task is found in Zhao, Goodchild, and McCormack (2011).

BEFORE AND AFTER ANALYSIS

In an effort to explore the usability of the GPS data for analyzing the impacts of infrastructure improvements, the research team evaluated the impacts of the second phase of construction on State Route (SR) 519 (the off-ramps) in downtown Seattle for trucks. This analysis looked at truck travel on SR 519 and compared travel volumes and speeds between SR 519 and Royal Brougham Way immediately to the north. Royal Brougham Way was included in the analysis because it serves as an alternative route both for east-west truck travel and for access to the interstate system. The data were collected between 2008 and 2010 and included truck travel information from both before and after the phase 2 construction project which added access ramps to the nearby Interstate-90. These GPS data came from a subset of the trucking population that comprised trucks used as probe vehicles.

The analyses demonstrated that trucks did divert from Royal Brougham Way to SR 519 after phase 2 construction, suggesting that the completed project provides benefits to truckers. Spot speeds showed small and insignificant changes in travel speed. However, because the route was only one-quarter mile long, any construction-based speed increase would be hard to capture. An evaluation of the travel range of the trucks using SR 519 was also inconclusive, probably because the 15-minute GPS read rate was simply too coarse to effectively capture truck routes that included SR 519.

On the basis of this study, the research team determined that an ideal before-and-after study would have the following:

- a long roadway (which captures more GPS reads)
- more data points (either by having more GPS-equipped trucks or more data collected over more time)
- more frequent location reads
- ideally, truck volume data both before and after construction.

The feasibility of other before-and-after studies will depend on the correct mix of the above factors. The technical report for this study is by Scharnhorst and McCormack (2011).

THE BOTTLENECK IDENTIFICATION PROCESS

The bottleneck identification process developed for Washington state is designed to find sections of Washington’s roadways that perform poorly for trucks and then to develop quantitative measures that allow these bottlenecks to be ranked and compared. The process is designed to be repeatable and statistically valid while also producing results that are usable and that transportation professionals and decision makers can readily comprehend. Because the results are oriented toward WSDOT’s mission, the measures also have to reasonably mesh with measures that WSDOT has already developed for evaluating congestion and roadway performance for all types of vehicles.

The bottleneck process must also account for network reliability, since travel reliability (travel time consistency) is as important as travel speed to the trucking community. For example, the USDOT’s office of operation noted, “Shippers and freight carriers require predictable travel times to remain competitive” (U.S. Department of Transportation 2011). This view is supported by input from local truckers’ focus groups, as well as by input from WSDOT’s Freight Systems Division staff.

The bottleneck identification and ranking process developed by the research team for Washington state involves the following tasks.

Task 1. Segment the State Roadway Network

The research team divided WSDOT's entire road network into analysis segments by using geographic information systems (GIS) software. The analysis segments were divided according to the locations of junctions, ramps, or signalized intersections. They further divided any segment longer than 3 miles into shorter segments. On interstate with ramps, they calculated the midpoint between ramps and used it as the splitting point. This task resulted in 11,000 roadway segments.

Task 2. Add Attribute Information to the Segments

The researchers assigned the appropriate roadway attributes to each segment. These attributes included road route number, mileposts, speed limits, and Washington State Freight and Goods Transportation System (FGTS) category. FGTS is a WSDOT classification of state highways, county roads, and city streets based on the average annual gross truck tonnage they carry (Washington State Department of Transportation, 2011).

Task 3. Geo-Locate the Trucks

On a daily basis, 24 hours of new truck GPS location reads enter the project's database. On a typical day, this data stream includes about 250,000 GPS location records. Each of these location reads needs to be assigned or geocoded by latitude and longitude to a point on the map with a GIS based-process. Next, the process compares the location and heading of each point to the segmented road network from Task 2, and any GPS reads taken from trucks that were not traveling along a WSDOT route are filtered out. The process eliminates points that fall outside of a buffer created around each roadway segment (roughly 50 feet from the roadway's center). Next, the process compares the heading of each point to the closest heading of a short section of the analysis segment. Points with a difference in heading of greater than 15 degrees are eliminated. After this process, about 10 percent of all statewide GPS reads remain.

Task 4. Locate Roadway Bottlenecks

For segments with enough truck data, the GPS trucks' spot travel speeds are averaged over time to quantify the reliability and overall performance of each segment and to identify as bottlenecks locations where trucks are performing unreliably or slowly. This process is only completed if enough GPS truck data reads are on a segment for a valid analysis—a minimum of a 100 trucks per segment. Fortunately, important truck corridors, by definition, have higher truck volumes and are therefore more likely to be used by more GPS probe trucks and included in the bottleneck analysis.

After the roadway segments with enough reads have been identified, the bottleneck identification process determines the travel reliability of that segment. Because each GPS report by a device in a truck includes a spot or instantaneous speed, the distribution of speeds for the different trucks that travel on that segment can be calculated and plotted (Figure 2). On the basis of this speed distribution, the reliability of each roadway segment can be placed into one of three categories: reliably slow, reliably fast, and unreliable.

Each roadway segment is fit with a statistical distribution based on the trucks' spot speed data. For the urban areas in the central Puget Sound region, the researchers analyze the truck speed data by determining speed distributions during different time periods:

- AM 6:00 AM to 9:00 AM
- Midday 9:00 AM to 3:00 PM
- PM 3:00 PM to 7:00 PM
- Night 12:00 AM to 6:00 AM and 7:00 PM to 12:00 AM

Because the other areas of the state have fewer data points and less time-related congestion, their analysis period is a full day.

The reliability evaluation criteria examine whether the travel conditions during a given time period (in the central Puget Sound region) or a given day (in the non-Puget Sound areas of the state) are reliable, given the speed distribution and a statistical fitting process. Generally speaking, if the speed distribution has two speed "humps" and is bimodal (such as in Figure 2a),

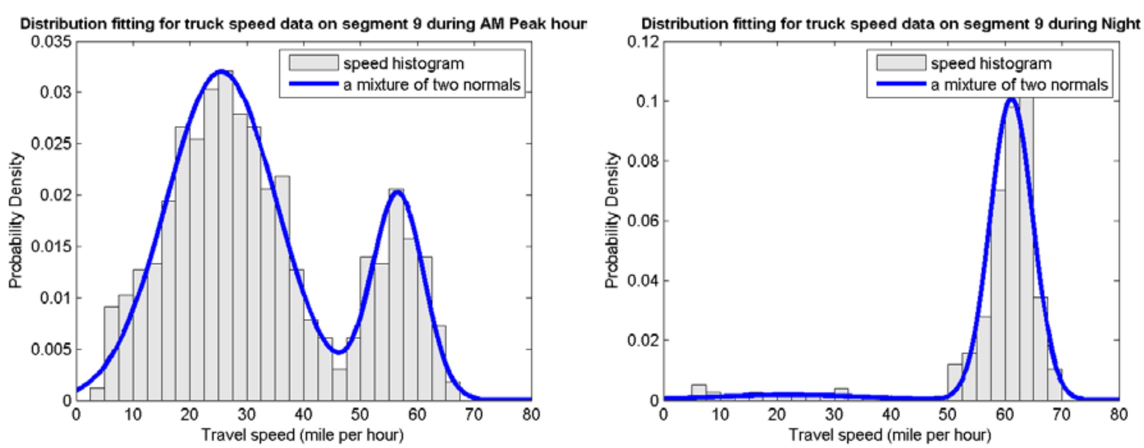

Figure 2: Speed Distribution: (a) speed distribution with a bimodal feature (b) speed distribution with a unimodal feature.

then the travel condition is considered unreliable. Otherwise, the travel condition is unimodal and is considered reliable with one average speed (as in Figure 2b), and further evaluation determines whether the travel speed is reliably slow or reliably fast. For the Puget Sound roadways, this measure can identify how the reliability condition changes over different times of the day.

Task 5. Rank the Bottlenecks

Once the bottlenecks have been identified on the basis of their level of (un)reliability, WSDOT staff may use, at their discretion, different measures to further rank and sort the truck bottlenecks' severity. Ranking metrics can include the following.

Average Speed

For the areas with enough data for the four different time periods (in the central Puget Sound region), this method first calculates the mean speed for each freeway segment during the time periods. The four mean values are combined to get an average speed measurement. This measure weighs different time periods equally and reflects the overall performance of the freeway segment. For areas without enough time period data (typically the non-Puget Sound roadways), the ranking of average speed for the entire day is used.

Frequency of Truck Speed Falling below 60 Percent of the Posted Speed Limit

WSDOT developed this measure to reflect the severity of congestion on the freeway segments. For the central Puget Sound region, this method calculates the percentage of truck speeds falling below 60 percent of the posted speed limit during the different time periods and then averages those four percentage values to evaluate the frequency of truck speeds falling below 60 percent. For most urban freeways, 35 mph is the threshold because this is 60 percent of the posted speed of 60 mph. WSDOT uses the 60 percent value as the speed threshold for evaluating whether the freeways are experiencing severe congestion (WSDOT 2010, p.11). This threshold is adjusted for roadways with different posted speed limits.

For non-Puget Sound regions this process is completed for a full day.

Geographic Areas and Freight and Goods Transportation Systems (FGTS) Categories

This type of ranking reflects policy decisions WSDOT has made.

The bottleneck process as currently developed separates the state into the central Puget Sound area and the rest of the state. This step acknowledges that the Puget Sound area's freight issues and truck volumes are notably different than those in other areas of the state.

Additional sorting of the bottlenecks based on the FGTS is possible. Use of FGTS categories allows freight routes with inherently more importance (a higher FGTS rating) to be given greater weight. This measure captures a segment's strategic importance to freight mobility.

Bottleneck Analysis Reports

The results of this bottleneck process are placed in tables sorted by a range of measures, as identified in Task 5. However, for easier use by transportation professionals and decision makers, the results can also be summarized into a one-page-per-bottleneck report. An example for a Puget Sound area bottleneck report is shown in Figure 3. A non-Puget Sound bottleneck report is shown in Figure 4. The bottleneck report includes a map and description of the bottleneck location, daily truck volume if available, and other relevant information.

The bottleneck data re also formatted so that they can transferred to WSDOT for use in internal GIS and Web tools designed for capital programming and policy evaluation.

Technical details about the bottleneck identification and ranking process can be found in McCormack, Scharnhorst, and Zhao (2011).

NEXT STEPS

New biennium funding (2011-2013) from the Washington State Legislature will support maintenance of the existing truck database and continue the acquisition of statewide GPS truck data from a GPS vendor. This funding will also support data analysis requests by public agencies, continue the analysis of truck performance on most statewide freight corridors, and develop new truck performance evaluation tools.

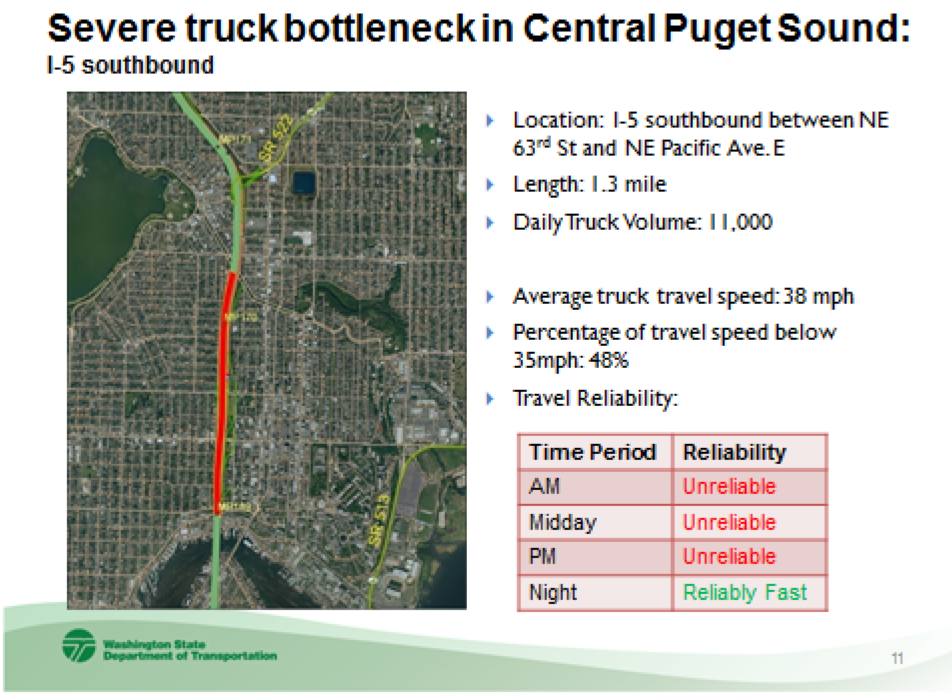

Figure 3: Example of a Bottleneck Report in the Central Puget Sound Region.

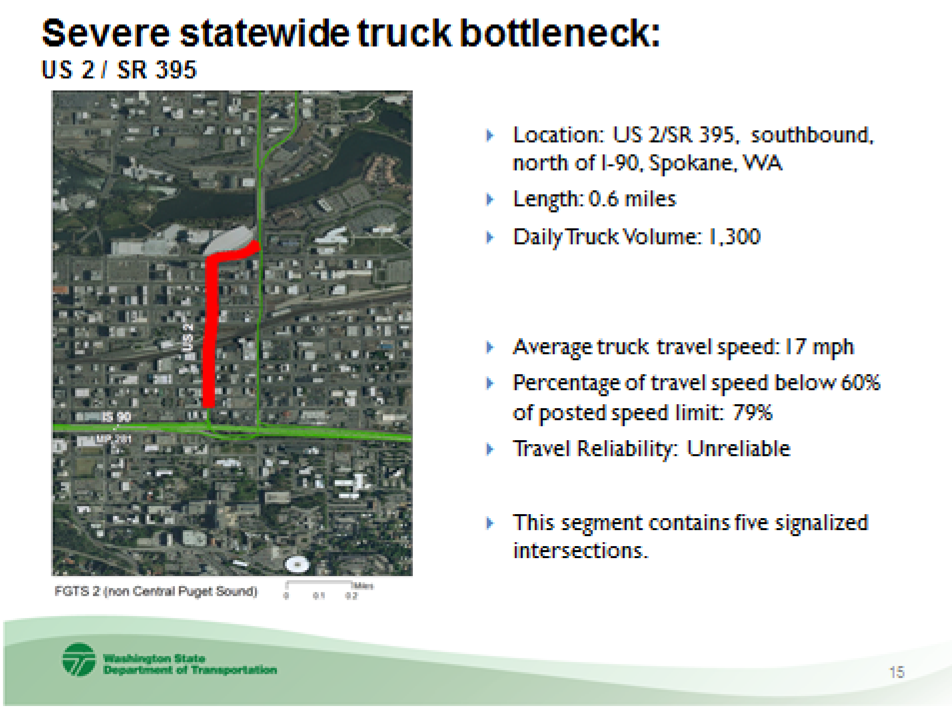

Figure 4: Example of a Statewide Bottleneck Report.

REFERENCES

Ma, X., E. D. McCormack, and Y. Wang (2011) Processing Commercial GPS Data to Develop Web-Based Truck Performance Measure Program, *Transportation Research Record*, in press.

Ma, X., E. D. McCormack, "Using Truck Fleet Management GPS Data to Develop the Foundation for a Performance Measures Program", Presented at 89th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 2010.

McCormack, E. D., and M. E. Hallenbeck (2004) Options for Benchmarking Performance Improvements Achieved from Construction of Freight Mobility Strategic Investment Board (FMSIB) Projects. TRAC/University of Washington report for the Washington State Freight Mobility Strategic Investment Board. http://depts.washington.edu/trac/bulkdisk/pdf/FMSIB_Final.pdf

McCormack, E. D., and M. E. Hallenbeck (2006) ITS Devices Used to Collect Truck Data for Performance Benchmarks. Transportation Research Record 1957, 43-50.

McCormack, E., E Scharnhorst, and W. Zhao, (2011) Using GPS Devices to Identify and Rank Bottlenecks in Washington State, Research Report Prepared for the Washington State Department of Transportation.

McCormack, E., X. Ma, C. Klocow, A. Currarei, and D. Wright (2010) Developing a GPS based-Truck Freight Performance Measures Platform, WA-RD 748.1, April http://www.wsdot.wa.gov/research/reports/fullreports/748.1.pdf.

Scharnhorst E., and E. McCormack, (2011) GPS Truck Data: Before and After Analysis of State Route 519, Research Report Prepared for the Washington State Department of Transportation. November 29.

The Washington State Department of Transportation (2010) The 2010 Congestion Report Gray Notebook Special Edition, WSDOT's comprehensive analysis of system performance on state highways, 19 November, http://www.wsdot.wa.gov/NR/rdonlyres/65FC8A99-8C74-4807-9147-2A27057963D0/0/2010_Congestion_Report.pdf.

The Washington State Department of Transportation (2011) Freight and Goods Transportation GTS classification table, http://www.wsdot.wa.gov/Freight/FGTS/default.htm

U.S. Department of Transportation (2011) Travel Time Reliability Measures, Website: http://ops.fhwa.dot.gov/perf_measurement/reliability_measures/index.htm.

Zhao, W., A. Goodchild, and E. D. McCormack, (2011) Evaluating the Accuracy of GPS Spot Speeds for Estimating Truck Travel Speed, *Transportation Research Record*, in press.