Developing a System for Computing and Reporting MAP-21 and Other Freight Performance Measures

WA-RD 844.1

Mark E. Hallenbeck
Ed McCormack
Saravanya Sankarakumaraswamy

July 2015

Washington State Department of Transportation
Office of Research & Library Services

WSDOT Research Report

Research Report
WSDOT FPM
Agreement T1461, Task 12

DEVELOPING A SYSTEM FOR COMPUTING AND REPORTING MAP-21 AND OTHER FREIGHT PERFORMANCE MEASURES

by

Mark E. Hallenbeck
TRAC-UW Director

Dr. Ed McCormack
Assistant Research Professor

Saravanya Sankarakumaraswamy
Graduate Research Student

Washington State Transportation Center (TRAC-UW)
University of Washington, Box 354802
University District Building, Suite 535
1107 NE 45th Street
Seattle, Washington 98105-4631

Washington State Department of Transportation
Freight Systems Division

Prepared for

The State of Washington
Department of Transportation
Lynn Peterson, Secretary

July 2015

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 844.1		

4. TITLE AND SUBTITLE	5. REPORT DATE
Developing a System for Computing and Reporting MAP-21 and Other Freight Performance Measures	July 2015
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Mark E. Hallenbeck, Ed McCormack, Saravanya Sankarakumaraswamy	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Washington State Transportation Center (TRAC) University of Washington, Box 354802 University District Building; 1107 NE 45th Street, Suite 535 Seattle, Washington 98105-4631	11. CONTRACT OR GRANT NO. Agreement T1461, Task 12
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Research Office Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Doug Brodin, Project Manager, 360-705-7972	Research Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This report documents the use of the National Performance Monitoring Research Data Set (NPMRDS) for the computation of freight performance measures on Interstate highways in Washington state. The report documents the data availability and specific data quality issues identified with NPMRDS. It then describes a recommended initial set of quality assurance tests that are needed before WSDOT begins producing freight performance measures. The report also documents the initial set of performance measures that can be produced with the NPMRDS and the specific steps required to do so. A subset of those metrics was tested using NPMRDS data, including delay and frequency of congestion to illustrate how WSDOT could use the freight performance measures. Finally, recommendations and the next steps that WSDOT needs to take are discussed.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Performance measures, Roadway performance measures, Freight performance measures	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None		

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

FIGURES AND TABLES

FIGURES

TABLES

EXECUTIVE SUMMARY

INTRODUCTION

This report describes the outcome of the initial exploration of the National Performance Research Monitoring Data Set (NPMRDS), supplied by the Federal Highway Administration (FHWA) to state transportation agencies and metropolitan planning organizations for use in computing roadway performance measures.

The NPMRDS provides roadway performance data for the national highway system (NHS). The intent of the NPMRDS was to provide a travel time estimate for every 5-minute time interval (epoch) of the year for all roadway segments in the NHS. The NPMRDS data are derived from instantaneous vehicle probe speed data supplied by a variety of GPS devices carried by both trucks and cars. The data are supplied on a geographic information system (GIS) roadway network, which divides the NHS into directional road segments based on the Traffic Message Channel (TMC) standard.

The report describes the availability, attributes, quality, and limitations of the NPMRDS data on the Interstates in the state of Washington.

On the basis of the review of the NPMRDS data, this report recommends a set of performance metrics for WSDOT's use that describe the travel conditions that trucks moving freight within the state experience. It describes specific steps for computing those measures. And it uses a subset of those measures produced with the NPMRDS to illustrate how WSDOT can use those measures in its reporting and decision making procedures.

CAPABILITIES AND LIMITATIONS OF THE NPMRDS DATA SET

The NPMRDS is supplied by a combination of HERE (the company that was once Traffic.com and was also known as NAVTEC) and the American Trucking Research Institute (ATRI). HERE supplies the data used to estimate 'car' vehicle travel times, and ATRI provides the data for 'truck' travel time estimates. HERE then combines the data from these two data sets into a single travel time statistic meant to be an estimate of 'average vehicle travel time' for both cars and trucks. The intent of the

NPMRDS data set is to provide one travel time statistic for each 5-minute interval, for each TMC segment (TMC/epoch), for each type of vehicle (truck, car, or combined).

The NPMRDS does provide WSDOT with a considerable amount of roadway performance data on both car and truck speeds that would not otherwise be available. This allows WSDOT to perform a significant number of analyses that would otherwise not be financially possible, given the current WSDOT budget.

Analysis of the data availability for Interstate road segments showed that the availability of data is increasing substantially over time. An analysis of data from October 2013 through February 2014 showed that roughly 47 percent of all I-90 TMC/epochs had data during that time period. A similar analysis for October 2014 showed that 71 percent of all TMC/epochs had a reported travel time. Data availability varies considerably for cars and trucks, as well as for rural versus urban portions of the Interstate highway system. Data availability also varies by time of day. Figure Ex-1 illustrates this variation by presenting the availability of data for four different time periods for weekdays in October 2014.

Table Ex-1: Data Availability on Westbound I-90 for Weekdays in October 2014

Time Period	Cars	Trucks	Combined
WB I-90 AM Peak	60.5%	62.1%	82.6%
WB I-90 Mid-day	63.8%	66.9%	86.6%
WB I-90 PM Peak	56.9%	60.0%	81.6%
WB I-90 Night	28.8%	41.9%	55.9%
WB I-90 all time periods combined	46.1%	53.6%	71.0%

The fact that data availability is much higher for the 'combined' speeds (based on a combination of both car and truck speeds) than for either truck or car speeds, suggests that the number of vehicles supplying data is modest, as data for one vehicle type frequently fills in a hole for the other vehicle type – indicating that there are not many vehicle probes present in each time period when any data actually exists at all. Unfortunately, the NPMRDS data set does not include a statistic describing the number of vehicle probe samples that are used to compute the travel time statistics reported for any given epoch and TMC segment. Therefore, it is not clear whether a reported travel time statistic derives from one vehicle or several hundred.

LIMITATIONS OF THE NPMRDS

In addition to concern about the limited size of the vehicle sample upon which the available roadway performance reports are based, the NPMRDS has several other observed limitations.

- The data collection methodology used by the NPMRDS creates some bias toward reporting slower speeds in the data set.
- The use of instantaneous GPS speeds when there are relatively few data points in a roadway segment makes the reported data more variable than actual roadway performance, as vehicle speed can vary considerably within a roadway segment.
- The use of a limited number of instantaneous speeds is a particularly problematic approach to roadway performance reporting on road segments that contain long steep grades. On those road segments, heavily loaded trucks often drive slowly because of their limited power-to-weight ratio. When those trucks report their speeds, the speed value they report is a function of their power-to-weight ratio, not a function of the road's congestion level. This creates errors in the reported roadway performance and can result in significant under-estimation of actual roadway speed on any road segment that contains a significant grade.

Figure Ex-1 illustrates how the NPMRDS travel time estimates (converted to speed estimates) compare to the speeds reported by WSDOT North West Region loop detectors on I-90 near I-405. The variability in the NPMRDS data is clear to see in comparison to the NW Region speeds—which are capped to report speed no faster than the speed limit.

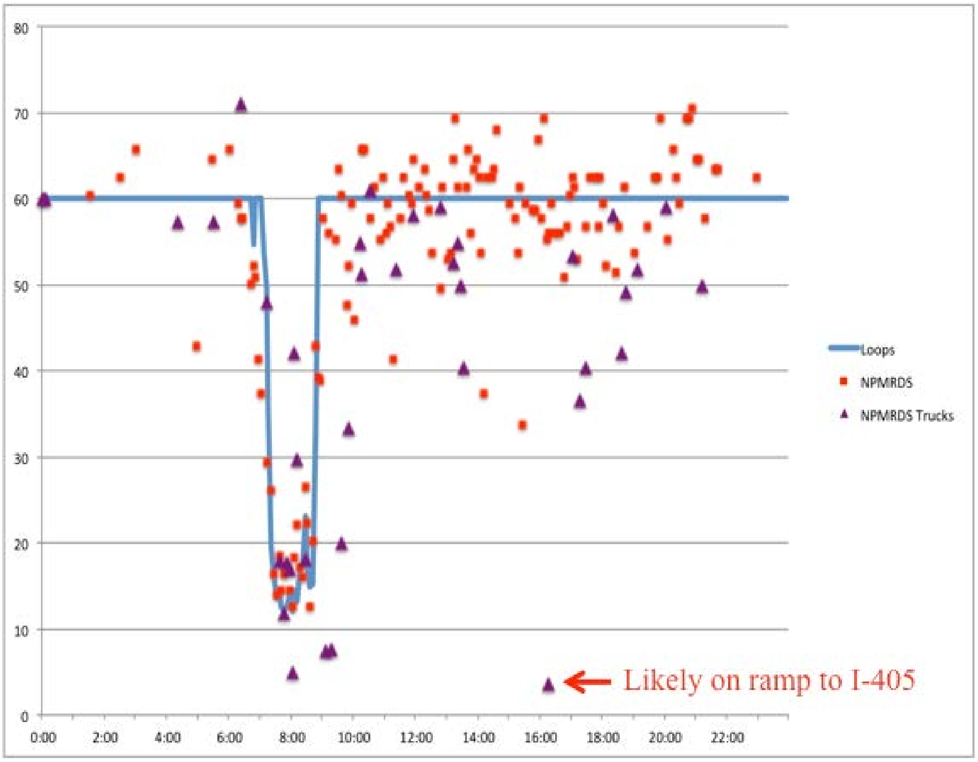

Figure Ex-1: Comparison of NPMRDS Speeds and NW Region Traffic Sensor Data

QUALITY ASSURANCE TESTS

While HERE and ATRI perform their own quality assurance reviews of data before producing the NPMRDS data set they send to FHWA, a review of the NPMRDS data indicated that a number of additional data points should be removed from the NPMRDS data set before those data are used for performance measurement calculations. The quality assurance tests described in the report are the first cut at these tests. The data points removed are for vehicle speed reports that are unreasonably slow. The project team suspects that many of these data points are for vehicles that are not actually located on the Interstate mainline roadways but are instead on ramps leading to/from the mainline, or are for vehicles on roads closely parallel to the Interstate mainline.

The quality assurance tests that identify these data points are based on simple rules. The rules consist of simple thresholds (e.g., no average speeds on segments are allowed below 2 mph), comparisons between reported car and truck travel times, and the fact that vehicles arriving later in the day at the start of a TMC segment cannot travel the length of that segment and arrive at its end before vehicles that started their trip on that segment earlier in the day. After adjustments are made to the database to account for these data errors, the NPMRDS data can be used for roadway performance reporting for freight vehicles.

PERFORMANCE METRICS THAT CAN BE COMPUTED FROM THE NPMRDS

Mathematically, the NPMRDS can be used to compute a wide range of roadway performance metrics. However, the data limitations described above (e.g., the holes in the data set, the presence of bias in some of the reported speeds, and issues with trucks on steep grades producing heavy bias in some speed reports) do limit the accuracy of the roadway performance statistics that can be reported. Despite these limitations, the project team believes that WSDOT can gain considerable benefit in the computation and use of freight-oriented, roadway performance metrics.

It is possible to compute delay statistics (veh-hrs of delay) by TMC segment. While the limitations in the NPMRDS result in bias in these computations, the results of these computations can nevertheless be used to examine the relative size and timing of delays occurring on the roadway system. This will allow WSDOT to identify and understand the relative importance of different delay causing factors (e.g., total traffic volume versus vehicle crashes versus construction traffic closures versus bad weather).

It is also possible to compute frequency of congestion statistics with the NPMRDS data. This measure is particularly good at describing the reliability of travel through specific road sections. (That is, how often do trucks experience congestion at specific locations?) The frequency of congestion computation has two limitations. The first is the accuracy of the NPMRDS speed values already discussed above. The second is the effect that TMC segment length has on the average speed being reported on a segment. Essentially, when TMC segments are long (more than 1 mile), it becomes difficult to identify the occurrence of congestion because while congestion is occurring on a subsection of the roadway segment, other portion(s) of the segment can be free flowing. The fact that the NPMRDS mixes the GPS speeds from vehicles in these two very different operating conditions means that the reported average speeds for that segment do not effectively identify the congested subsection of the roadway. As a result, the project team recommends that frequency of congestion be reported only for TMC segments of 1 mile or shorter.

The NPMRDS can also be used to compute travel time and travel time reliability statistics. However, additional work is needed before this capability is available to WSDOT staff. Two key issues need to be resolved. The first is the fact that even with the substantial increase in the amount of data present in the database in the latter half of 2014, there are still large holes in the database. This means that computing travel times at the 5-minute interval level will be somewhat problematic, because a large portion of the travel times will be as much a result of the assumptions used to fill in the missing data as they will be about the actual roadway performance. We recommend that travel times be computed on a 15-minute interval in the near term, to increase the number of travel time computations that can be made without relying on the replacement of a large number of missing data points.

The second issue is that the reported travel times for trucks include speeds reported when heavily loaded trucks are traveling slowly because they are heavily loaded, and not because road conditions (e.g., congestion) are slowing those vehicles. A fraction of trucks on road segments with hills move slowly simply because they do not have sufficient engine power to travel the speed limit. While these are valid speed reports, they represent the performance of the truck, not the performance of the roadway. Therefore, for WSDOT's freight performance reporting efforts, travel time needs to be reported twice: once in a manner that describes the road condition, and once in a manner that reflects the travel times required when trucks haul heavy loads.

In the main body of this report, the project team recommends a process by which both of these truck travel times can be computed from the NPMRDS. However, additional coding and testing are needed before these travel time metrics can be computed. This coding must take place within the Digital Roadway Interactive Visualization and Evaluation Network (DRIVENet)[1] software system.

[1] Funded by WSDOT, DRIVENet is an on-line transportation platform aimed at data sharing, integration, visualization, and analysis: http://wsdot.uwdrive.net/drivenet.html

THRESHOLDS FOR REPORTING PERFORMANCE

The NCHRP 08-98 project recommends that four different delay computations be performed and reported using different threshold values. Each delay computation describes delay from the perspective of a different road user or operator. Three of those thresholds are applicable to WSDOT: 1) delay based on the speed limit (any travel slower than the speed limit is considered delayed), 2) delay based on 70 percent of the posted speed (roughly equivalent to the speed at maximum throughput), and 3) delay based on a locally set target value.

The NPMRDS data were used to compute these values, and the results of those computations were then compared with each other and with similar delay values computed for the urban area from data obtained from the NW Region's loop detectors. The results presented in the main body of this report describe the accuracy and reliability of the NPMRDS-based computations.

The threshold tests showed that the NPMRDS data significantly over-estimate the amount of delay occurring on the roadway system. When examined as a percentage, the biggest percentage errors occur in rural portions of the state. Errors in the NPMRDS are much smaller on road segments that are heavily congested. The size of the NPMRDS reporting error decreases substantially when lower speed thresholds are used. That is, the NPMRDS does a better job of estimating delay below 70 percent of the posted speed than it does at measuring delay based on using the speed limit as the threshold. This is because the use of the lower speed threshold limits the effects of the high level of variability in the NPMRDS data. Nevertheless, even in using the lower threshold to limit the impact of NPMRDS data variability, the NPMRDS over-estimates delay by a large amount.

Consequently, the project team recommends that

1) the delay computations made with the NPMRDS be used primarily to compare the size and timing of delay within the system, but not be used at this time for reporting total delay for federal reporting requirements, and
2) delay be computed using the 70 percent of posted speed limit threshold.

The NPMRDS is not currently recommended for use in computing delay for federal reporting requirements because the NPMRDS is still evolving, and if it is used for reporting to the FHWA, trends observed in the data over time will more likely be the result of changes in the data set than a result of actual trends in roadway performance. The recommendation to use the 70 percent of posted speed threshold is based on the fact that the lower threshold removes a large fraction of the error caused by the added variability in travel speeds that result from the combination of using instantaneous GPS speeds to compute reported travel times, and from what appears to be lower sample sizes for many 5-minute travel time data values. It therefore provides a better, more stable comparison value.

NEXT STEPS

This project completed the design and testing of the basic process for measuring truck performance on Interstates in the state of Washington. A number of additional steps must be taken before WSDOT can create performance measures for the entire state. The first of these improvements will be to code the algorithms developed into the DriveNet software system, which must also routinely download and make available the NPMRDS and traffic volume data that drive the system. In addition to the work described above, the following tasks need to be completed before WSDOT can produce these measures statewide:

1) Work with FHWA to obtain a significantly improved version of the NPMRDS.
2) Determine the average travel time of heavily loaded trucks on segments where trucks have slow travel times because of power-to-weight ratio limits.
3) Code the travel time algorithms described in this report.
4) Test and refine the travel time algorithms, with specific attention paid to the ability to compute travel times for heavily loaded vehicles.
5) Determine the accuracy of arterial travel times from the NPMRDS data.
6) Determine the availability of NPMRDS data on last mile segments of importance to the Freight Systems Division.
7) Determine how to extend the volume count estimation process to state routes that are not monitored by a specific Permanent Traffic Recorder (PTR) that

can be used to estimate changing traffic volumes by day of week and time of day.

8) Extend the refined volume count process into DriveNet.

Each of these tasks is discussed in the main body of the report.

CHAPTER 1: CAPABILITIES AND LIMITATIONS OF THE NPMRDS VEHICLE PROBE DATA SET

This chapter describes the findings of a review of the use of data from the National Performance Monitoring Research Data Set (NPMRDS) to compute freight performance measures. This chapter

- introduces the NPMRDS data set
- discusses specific limitations in the data set that affect the ability to compute performance measures
- describes quality assurance tests that should be applied to the data set before it is used.

INTRODUCTION TO THE NPMRDS

The NPMRDS is supplied by a combination of HERE (the company that was once Traffic.com and also known as NAVTEC) and the American Trucking Research Institute (ATRI). The data set contains vehicle probe-based travel time estimates for the National Highway System (NHS). The data set is intended to produce a travel time estimate for every 5-minute time interval (epoch) of the year for all roadway segments in the NHS. The data are supplied on a geographic information system (GIS) roadway network, which divides the NHS into directional road segments based on the Traffic Message Channel (TMC) standard.

The Reported Travel Time Estimates

HERE supplies the data used to estimate car vehicle travel times, and ATRI provides the data for truck travel time estimates. HERE then combines the data from these two data sets into a single travel time statistic meant to be an estimate of average vehicle travel time for both cars and trucks. The intent of the NPMRDS data set is to provide one travel time statistic for each 5-minute interval, for each TMC segment, for each type of vehicle (truck, car, or combined).

In the NPMRDS data supplied by FHWA to the states for any 5-minute interval, if a truck is observed but not a car, then a truck travel time is present, but not a car travel time. That value is reported as not only the truck travel time but also the combined travel time. The opposite is true when a car is observed but not a truck. If neither a car nor a truck is observed on a specific TMC segment during a specific time interval, then that TMC segment is omitted from the NPMRDS data file for that time period. That is, if the records for that TMC segment in the NPMRDS are sorted by date and time, then the record for that epoch is missing.

Rather than providing a specific time stamp, the data records report ‘epoch number’, which ranges from 0 to 287. The 0 epoch is midnight. Epoch #1 is 12:05 AM. Figure 1 shows an example of a time sorted data file for a single TMC segment. In Figure 1, the record is blank for epochs 87 and 100. This indicates data missing in the file provided by HERE.

Segment	Date	Epoch	Combined	Car	Truck
114P04112	2242014	86	63	57	80
114P04112	2242014				
114P04112	2242014	88	87	87	
114P04112	2242014	89	100	100	
114P04112	2242014	90	126	126	
114P04112	2242014	91	214		214
114P04112	2242014	92	154	154	
114P04112	2242014	93	326		326
114P04112	2242014	94	192	144	216
114P04112	2242014	95	235	242	225
114P04112	2242014	96	230	186	775
114P04112	2242014	97	101	103	91
114P04112	2242014	98	144	153	129
114P04112	2242014	99	168	168	
114P04112	2242014				
114P04112	2242014	101	211		211

Figure 1: Example of HERE Data, Sorted by Time for a Single Segment

The NPMRDS does not include a statistic that describes the number of vehicle probe samples that are used to compute the travel time statistics reported for any given epoch and TMC segment. Therefore, at face value, it is not clear whether a reported travel time statistic derives from one vehicle or several hundred.

An analysis of the NPMRDS data gave us considerable insight into how the travel time estimates are computed, although this insight is somewhat speculative, as the exact methodology is confidential to the HERE/ATRI team.

The analysis of NPMRDS data made it clear that the travel time estimates are based on instantaneous GPS speeds from vehicles that carry devices that share their GPS position and instantaneous speed with either HERE or ATRI. The instantaneous speeds reported for a given TMC segment for each 5-minute period are then combined in some manner (likely a simple average) and then converted into a travel time estimate for that segment. This computation divides the known distance of the TMC segment—as reported by HERE—by the computed speed. (Consequently, this paper refers to the HERE data as both speed and travel time because the data are collected as speed values but are reported as travel times.)

The combined travel time appears to be computed as a weighted average of the ATRI and HERE vehicle travel times (or speeds), and the weighting appears to be based on the number of available data points for both cars and trucks combined. Thus, when more truck GPS points are available for a given TMC segment and epoch, the combined speed is weighted toward those truck speeds. If more cars are observed, the weighting is toward the cars. The actual volume of cars and trucks is not available to HERE/ATRI and therefore is not used in the computation of the combined NPMRDS vehicle speed statistic.

TMC Segments

TMC segments are directional roadway segments. They match reasonably well to the WSDOT GIS line-work for the same roads, but that match is not perfect. The TMC segmentation is different than the Highway Performance Monitoring System (HPMS) segmentation that WSDOT uses for reporting to FHWA. (The HPMS segments are not directional. Therefore significant mismatches occur wherever there is a divided highway.) Other differences occur where defined roads end. For example, when a roadway changes route numbers (e.g., I-405 becomes SR 518 at the I-5 interchange), WSDOT changes the route number at the midpoint of the intersecting roadway (I-5)), but HERE's TMC network carries the I-405 designation on that roadway until the on-ramp from I-5 reaches the I-405/SR 518 mainline, at which point HERE starts a new roadway segment and changes the road's designation to SR 518.

The TMC road segments HERE uses are also slightly different from the TMC segment definitions that Inrix used when it sold data to WSDOT[2].

[2] WSDOT purchased INRIX data in the past and used it for roadway performance analysis and congesting reporting.

To use the TMC segmentation for anything other than analyzing the NPMRDS, the TMC segments must be matched to WSDOT's location referencing system. This process is called conflation, and WSDOT staff have performed it for state routes.

TMC segments have a variety of lengths. For example, on I-90, the smallest segment is 0.007 miles, and the longest segment is just over 14 miles. On I-82, the shortest segment is 0.4 miles, and the longest is 12.7 miles. The start and end of TMCs most commonly occur where traffic volumes change (i.e., at ramps). Therefore, for freeways, TMC segments typically start and end at interchanges. This means that rural segments tend to be longer than urban segments. Figures 2 and 3 illustrate the TMC segmentation on I-90.

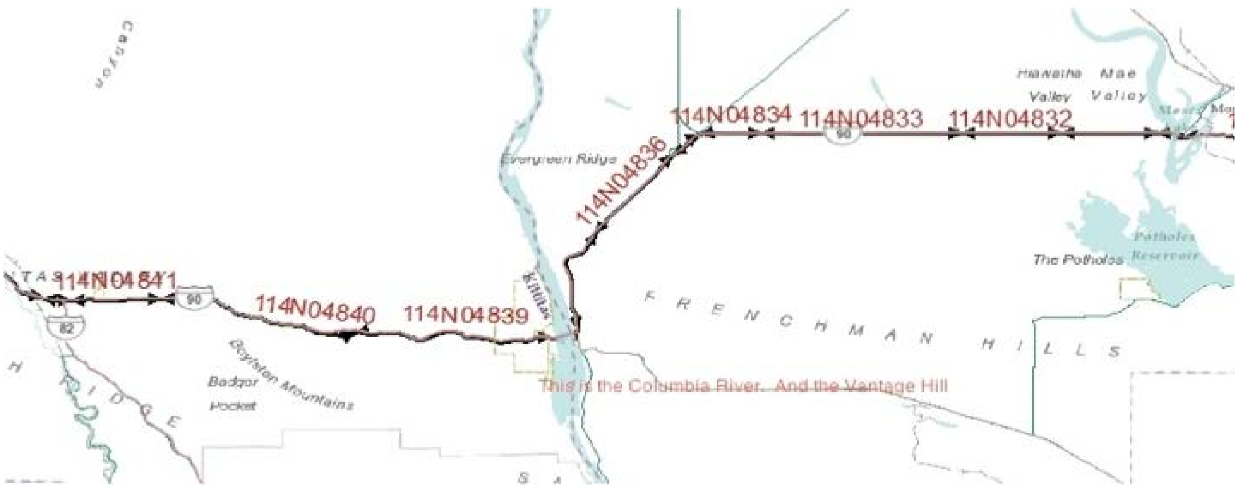

Figure 2: Example I-90 TMC Segmentation in Rural Areas

Figure 3: Example I-90 TMC Segmentation in Urban Areas

LIMITATIONS OF THE NPMRDS

Using the NPMRDS has three major limitations. There are also several minor limitations with the data. The major limitations are as follows:

- The review of the NPMRDS found that many TMCs and epochs contain no data. This means that the size of the probe vehicle fleet is currently insufficient to provide detailed coverage for many segments on the Interstate system.
- The use of instantaneous GPS speed from a vehicle probe fleet that lacks sufficient coverage makes the reported data more variable than actual roadway performance, as many reported travel time statistics appear to be based on one or two instantaneous speed reports.
- GPS devices typically report vehicle speed and location information on a pre-defined interval (e.g., once every 5 minutes), so a slow moving vehicle will produce more speed reports than a fast moving vehicle when both vehicles travel the same distance. This fact creates some bias toward slower speeds in the data set.

These limitations are discussed in more detail below. One mitigating factor for these limitations is that the number of vehicles reporting data to ATRI and HERE is increasing fairly rapidly over time. As the number of vehicle probes increases, the number of epochs without data will decrease, and the variability in the travel times/speeds reported relative to actual roadway performance will also decline.

There are several other limitations present in the data. These include the following:

- The quality assurance tests applied by the NPMRDS contractor have not removed some data that are obviously in error.
- The speeds of heavily loaded trucks on steep grades are generally not representative of roadway conditions. They are representative of performance issues associated with the power to weight ratio of the trucks. This creates roadway performance reporting problems in that the truck speeds reported on these TMC segments are then a function

of the number of heavily loaded trucks versus the number of unloaded and lightly[3] loaded trucks observed during any given epoch, rather than the performance of the roadway.

These issues are discussed in the subsections below.

No Data Are Present for Many Time Epochs for All TMC Segments

The project's initial review examined five months of data on I-90, from October 2013 through the end of February 2014. That examination indicated that a large number of the TMC segments defined in the NPMRDS did not have reported travel times for a large number of epochs. A summary of data availability is shown in Table 1. For example, westbound on I-90, only 50.1 percent of the epochs for TMC segments (henceforth referred to as TMC/epochs) contained a report of car travel times during the AM peak period.[4] For trucks, only 26.1 percent of the TMC/epochs contained data in the AM peak. The data were sparse enough that often when a car was not observed, a truck might be. Thus, the 'combined' data set showed greater data availability, with 60.9 percent of TMC/epochs reporting a travel time data point during the AM peak period. Data availability was slightly better during the middle of the day. Data availability was considerably lower during the night. Data missing in such large percentages has significant implications for computing all types of roadway performance statistics.

Table 1: Data Availability on Eastbound I-90 for Weekdays in October 2013 through February 2014

Time Period	Cars	Trucks	Combined
WB I-90 AM Peak	50.1%	26.1%	60.9%
WB I-90 Mid-day	37.6%	29.0%	64.0%
WB I-90 PM Peak	44.8%	23.9%	56.6%
WB I-90 Night	20.8%	14.5%	30.8%
WB I-90 all time periods combined	33.1%	21.1%	47.1%

[3] In this case "lightly loaded" refers to gross vehicle weight, not to whether the trucks are partially loaded or fully loaded. Truck speed on steep uphill grades is a function of power to weight ratio. Weights can be light because the truck is unloaded, or because the cargo they are carrying is light in weight, even though the truck is "full."

[4] For this simple data availability test, the AM peak period was defined as 6:00 AM to 9:00 AM for all segments.

Luckily, data availability is increasing as more and more vehicles are using technology that reports their position and speed to companies that are willing to share those data. Data availability for October 2014 is summarized in Table 2. For example, an examination of data availability for all sections of westbound I-90 for cars and trucks combined for October 2013 showed data present in only 44.5 percent of the TMC/epochs. However, when data availability was examined for October 2014, travel time estimates were available for 68 percent of the TMC/epochs for westbound I-90, an increase of over 24 percent. For truck data points only, data availability increased from 17.9 percent in October 2013 to 50.6 percent in October 2014.

Table 2: Data Availability on Westbound I-90 for Weekdays in October 2014

Time Period	Cars	Trucks	Combined
WB I-90 AM Peak	60.5%	62.1%	82.6%
WB I-90 Mid-day	63.8%	66.9%	86.6%
WB I-90 PM Peak	56.9%	60.0%	81.6%
WB I-90 Night	28.8%	41.9%	55.9%
WB I-90 all time periods combined	46.1%	53.6%	71.0%

Data availability is not uniform across I-90—or for other NHS routes. In general, data availability is greater for urban road segments than for rural road segments (although truck data availability is not necessarily greater), and the longer the roadway section, the greater the data availability. Conversely, the shorter the TMC segment, the lower the data availability.

In urban areas, data availability for car performance is generally higher than that for truck performance. For example, in October 2014, on I-90 eastbound out of Seattle, the TMC/epochs from downtown Seattle to Issaquah contained car travel time data around 50 percent of the time, whereas truck data were present just over 15 percent of the time. Truck data were present over 27 percent of the time for segments east of the I-405 interchange. For reasons we have not been able to determine, few probe trucks were observed traveling in either direction on I-90 west of the I-405 interchange. The lack of truck data west of I-405 is illustrated in Figure 4. This pattern persisted despite an increase in the number of vehicle probe vehicles reporting data in the latter part of 2014. Conversely, in rural portions of the state, truck travel times were available in October 2014 for about 70 percent of the TMC/epochs, whereas car travel time data were available only about 45 percent of the time.

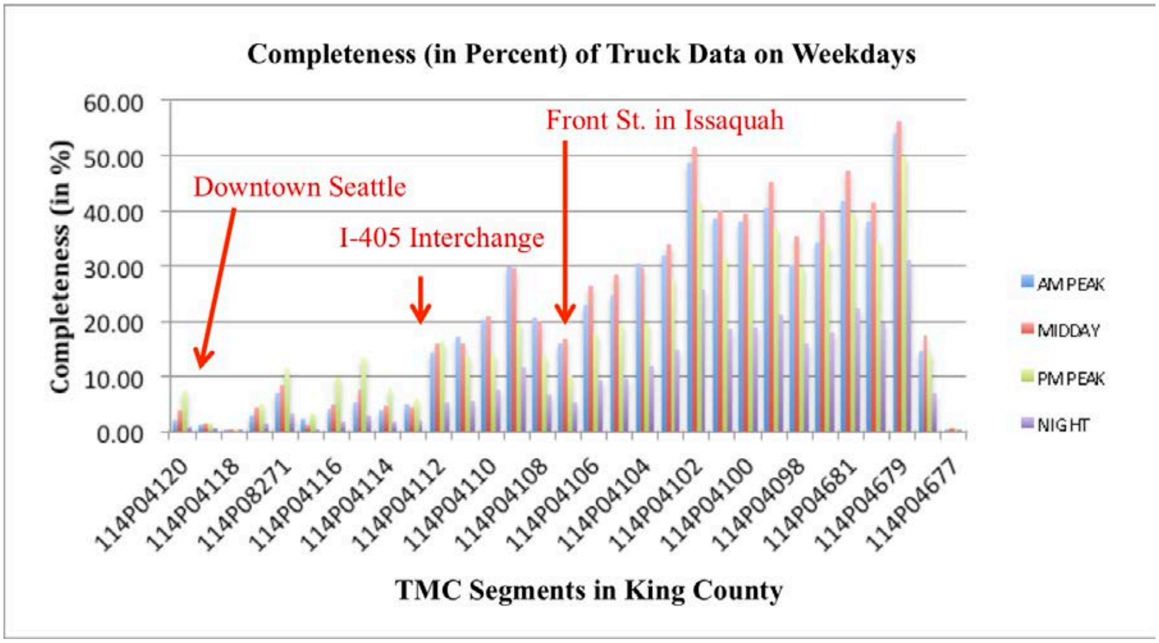

Figure 4: Truck Data Availability on I-90 in King County from October 2013 – February 2014

The relationship between segment length and the availability of data is illustrated in Figure 5, which shows data from the initial analysis of data from October 2013 through February 2014. Basically, the longer a TMC segment is, the greater the probability that a probe vehicle will be observed on that segment during any given 5-minute epoch. Therefore, a longer segment length means that a greater number of data points are reported.

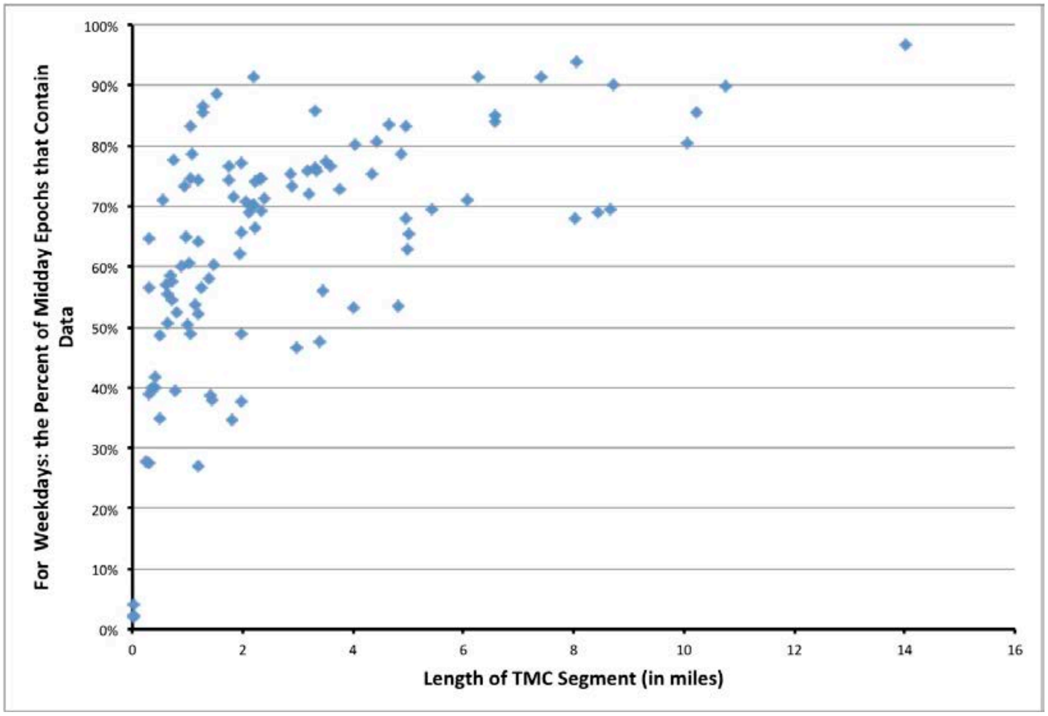

Figure 5: Comparison of I-90 Segment Lengths versus Midday Data Availability

The downside of very long segments is that when only one data point is observed, that single data point may not be representative of travel along that entire segment. This is particularly true with truck travel times on mountainous terrain. A significant number of the I-90 and I-82 TMC segments contain a combination of steep grades and more gently rolling terrain. Heavily loaded trucks must often move slowly on the steep grades while lightly loaded trucks and cars can operate at the speed limit. However, the same trucks that travel slowly on the steep grades may operate at the speed limit on the flatter portions of the same TMC segment. This increases the variability of reported speeds—and thus reported travel times—on these TMC segments. This topic is discussed in more detail in the next subsection.

I-90 also includes several very small TMC segments. The smallest of these are found at the top of Snoqualmie Pass. Eastbound, just after the pass, segment 114N04860 is just 0.007 miles. Westbound, two very small, contiguous segments are defined at the top of the pass. Segments 114P04677 and 114P04860 are 0.018 miles and 0.016 miles long, respectively.

Not surprisingly, there were very few vehicle probe observations for these roadway segments, as vehicles spend very little time within the segment boundaries. For October 2014, westbound, either a car or a truck was observed in segment 114N04860 only 2.7 percent of the time. All but one of those travel times was reported as 1 second, resulting in a speed estimate of 25 mph. The other reported travel time was 37 seconds, which is equivalent to an average speed of 1 kilometer per hour. It is quite possible that none of these vehicles was actually on I-90, but rather was traveling on a surface street near the freeway. (This segment is located in the middle of the Snoqualmie Pass ski areas, which use arterial roads parallel to the freeway. Vehicles moving on those roads could easily be incorrectly assigned to I-90.) In contrast, approaching the summit from the east, segment 114N0677, which is 0.346 miles long, had data 45 percent of the time, and the segment before that, 114N04675, which is 4.22 miles long, had data more than 89 percent of the time.

The holes in the data set create three problems. The first is that large amounts of missing data reduce confidence in the data set. And while the greater data availability in October 2014 increases confidence in the data, many roads that serve smaller truck volumes than I-90 will still have many missing TMC/epochs.

Secondly, the larger the number of data missing from the set, the more likely that bias is present in the data. Many segment-specific performance statistics can be computed with samples of roadway performance. Measures such as vehicle-hours of delay and frequency of congestion can be computed, as long as analysts know how many epochs are truly present in the data. However, when the fraction of epochs with data is small, the potential for bias in the results is high, and the ability to accurately track trends in congestion is greatly reduced.

Finally, having large holes in a corridor's TMC/epoch data set makes computing travel time reliability statistics very difficult. The primary method for computing them is to set up a time-space matrix[5] and use a trajectory algorithm to trace a virtual vehicle through that time-space diagram. Where holes are present in the TMC/epoch time-space diagram, the travel time can not be computed. Periodic holes in the time-space diagram can be filled by interpolating some other analytical mechanism, but when large portions of the time-space diagram are missing, the validity of the travel time computations becomes suspect. TTI has responded to the

[5] The time-space diagram is defined such that each row is an epoch or time period, and each column is a roadway segment. Each cell defined by epoch and road segment contains the travel time or speed being traveled on that segment at that time. This information is used to compute the time when the next segment is reached. At that time, the conditions in the appropriate row of that next column of the matrix is read to determine the new speed of the vehicle, and that information is then used to compute when the virtual vehicle arrives in the next column. A "trip" can be computed for each starting time, and multiple trips can then be summarized to compute both mean travel times and various travel time reliability statistics.

missing data problem by averaging the available data into an average condition for each 15 minutes for each day of the week for each month. While it is possible to perform those same calculations for Washington Interstates, averaging the available data eliminates the ability to measure day-to-day travel reliability.

The data availability for I-82 (see Table 3) showed patterns similar to those for the data on I-90. Data available for cars and trucks by themselves were too sparse to allow the computation of reasonable travel time values, with over 40 percent of the TMC/epochs missing data during the business day, and much higher rates of missing data at night. However, when the car and truck data were combined, over 80 percent of daytime TMC/epochs contained data. As noted previously on I-90, the longer the TMC segment, the more likely that data are available for a given epoch (see Figure 6). These findings, along with the analysis performed on I-90 data, suggest that the number of vehicle probe data points being reported on any given TMC/epoch is very small.

Table 3: Data Availability on Eastbound I-82 for Weekdays in June 2014

Time Period	Cars	Trucks	Combined
WB I-82 AM Peak	51.5%	57.5%	83.7%
WB I-82 Mid-day	60.2%	52.5%	86.9%
WB I-82 PM Peak	54.6%	56.1%	81.2%
WB I-82 Night	21.7%	57.1%	54.2%
WB I-82 all time periods combined	40.4%	55.9%	70.5%

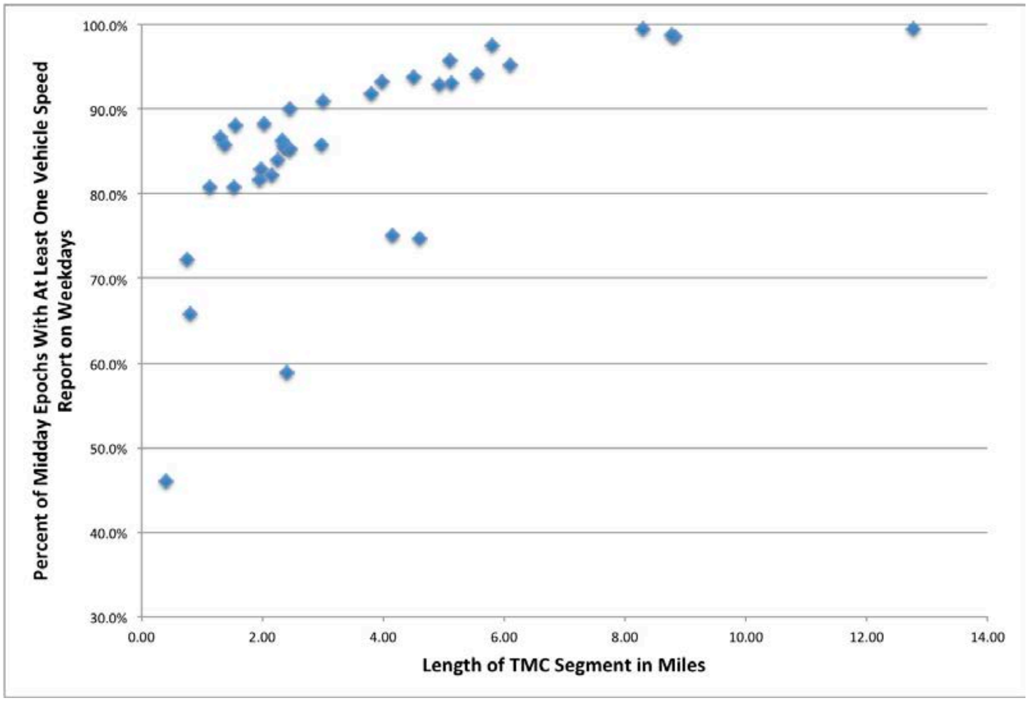

Figure 6: Comparison of I-82 Segment Lengths versus Midday Data Availability

Reported Vehicle Speeds Are More Variable Than Roadway Performance

An examination of the data in the NPMRDS showed that the reported average speeds were more variable than those same statistics based on the fixed sensors traditionally used by WSDOT. A large portion of this added variability is caused by the relatively small sample size of the vehicle probe fleet. That is, because the sample size is small, the NPMRDS is not reporting the true average speed of all vehicles but is instead reporting a value that is based on a larger distribution of vehicle speeds on the roadway.

While the NPMRDS does not report the actual number of vehicle probe speed estimates included in any given epoch for a TMC segment, the number of epochs for which no data are reported, combined with some quality control results, suggests that the number of probe vehicles is actually modest for many Interstate road segments and time periods. This modest number of vehicle probe data points means that 1) there are relatively few vehicles represented in any given epoch sample, and 2) those vehicles represent travel speeds on only a small sample of the road mileage within a longer TMC segment.

While the NPMRDS statistic is reported as if it were a travel time value, the actual data collection statistic is the instantaneous speed reported by GPS devices. As a result, the values also capture added variability from the fact that vehicles speed up and slow down during the course of driving a segment of roadway.

For long segments, and especially long segments that include steep grades, if only a small number of data points are present during a given epoch, the reported "travel time" is likely biased by the location where those points are collected. If the few vehicles reporting GPS speed data are mostly observed when they are on steep grades, then the reported speeds (and travel times) will likely be slower than the true average speed for that TMC segment, especially if some of the reporting vehicles are heavy trucks. Conversely, if only cars are reporting during a given epoch, and those cars are on flatter or downhill portions of the long TMC segment, then the reported speed estimates will likely over-estimate the average segment speed.

If the NPMRDS actually measured and reported travel times in between consecutive location points reported by the vehicle probe fleet, then the effect of terrain would be captured in the reported travel times, and the small sample size would produce less bias. But because the travel times reported in the NPMRDS are computed from instantaneous GPS speeds, the reported performance metrics are significantly affected by the combination of small sample sizes and changing vehicle speeds within the long travel segments.

The NPMRDS travel times and speeds also do not directly describe whether a roadway is operating in uncongested (free flow) conditions. Instead, the available data frequently represent just a small sample of the distribution of speeds at which vehicles are traveling. And since some vehicles travel below the speed limit at any given time (they may be driving slowly, or may be accelerating from, or decelerating to, a ramp), when those are the only vehicles reporting instantaneous speeds, the NPMRDS can under-estimate the ability of vehicles to drive the speed limit.

Figure 7 illustrates the variability present in the NPMRDS and how those data compare to the data reported by traditional, fixed WSDOT sensors. Figure 7 shows data for a specific day (February 24, 2014) and compares the NPMRDS data with data reported by the WSDOT's NW Region traffic management system. WSDOT sensors (the blue line in the figure) report speeds operating at the speed limit (60 mph) when measured average facility speeds are at or above the speed limit. The red squares show the car speeds reported by the NPMRDS. The purple triangles are NPMRDS reported truck speeds.

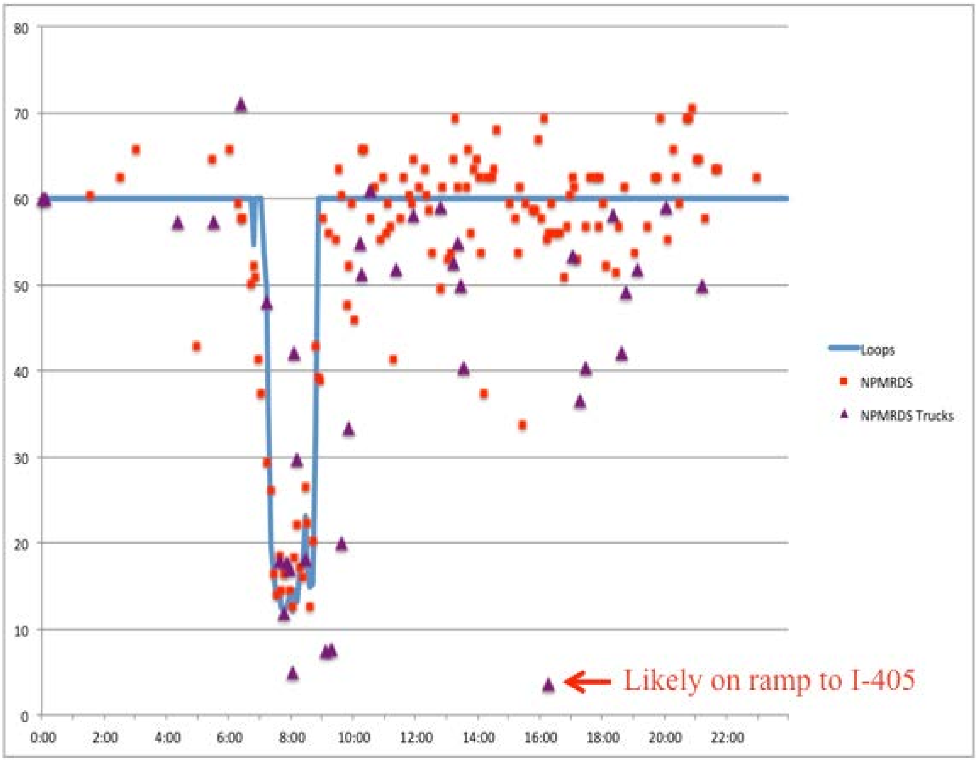

Figure 7: Comparison of NPMRDS Speeds and NW Region Traffic Sensor Data

The scatter of red squares in Figure 6 is an excellent illustration of the variability observed in the NPMRDS. The specific site for which data are displayed is westbound on I-90, just west of the I-405 interchange. The TMC segment includes the ramp terminals for both on-ramps coming from Bellevue arterials and off-ramps leading to I-405. It is unclear whether the wide scatter in the NPMRDS data is caused by vehicles heading to or from these ramps, or whether vehicles in an urban setting simply have that much variability in their instantaneous speeds. The NPMRDS data do track the AM peak period congestion. But if the NPMRDS data were used at face value, the data would significantly over-estimate the delays on the roadway because of the consistent reporting of speeds around 50 mph. There are also several false reports of speeds below 40 mph in the middle of the afternoon.

Figure 7 also shows how little truck data are present on this section of I-90, even though this is a weekday and I-90 serves the Port of Seattle. Just as significantly, the truck speeds are consistently slower than the actual facility speeds. For much of the day, this is a good representation that trucks travel slightly slower than overall traffic on this segment of roadway. However, in the afternoon, a number of very slow truck speeds are reported. These are likely from trucks that were not on the I-90 mainline but reported a GPS location that was associated with the I-90 westbound mainline. Again, the result is that direct use of these NPMRDS truck speeds would over-estimate the actual delay on the facility simply because of the added variability in the data and the lack of a large enough sample of probe vehicles to mask the anomalies.

Reported GPS Speeds Are Biased Toward Slower Moving Vehicles

Figure 7 also points out that because the collected data are instantaneous GPS speeds, the mechanism for collecting them results in a bias toward slower vehicles. This is because if two vehicles make the same trip, the slower vehicle will report its position and speed more times than the faster vehicle. The resulting data set will therefore over-represent the performance of the slow vehicle.

By looking at the uncongested afternoon time period in Figure 7 (after 10:00 AM), one can see that the NPMRDS car data are scattered around a mean value that is very close to the speed limit. (The actual average of the NPMRDS data is 59 mph.) However, because, for performance reporting purposes, WSDOT reports speeds that are at or above the speed limit (60 mph in Figure 7) as the roadway operating at the speed limit, the actual average speed for this road section is likely slightly higher than the NPMRDS mean value. This is an example of how the NPMRDS data are biased to be slightly slower than the actual mean value of roadway speeds.

Figure 8 illustrates a comparison between the NPMRDS data and speed data collected from fixed sensors on I-90 outside of Cle Elum. In Figure 8 the blue line is the WSDOT fixed sensor data. They present the average speed of all vehicles at this specific location. The light green triangles are the raw car data provided by the NPMRDS for the TMC segment that contains the WSDOT fixed sensor. The red squares are a summary speed variable computed with both the car and truck NPMRDS speed data, as well as additional quality assurance steps. Like Figure 6, Figure 7 shows one day of data, but in this case, the speed values are aggregated to average hourly conditions because that is how WSDOT routinely stores the data.

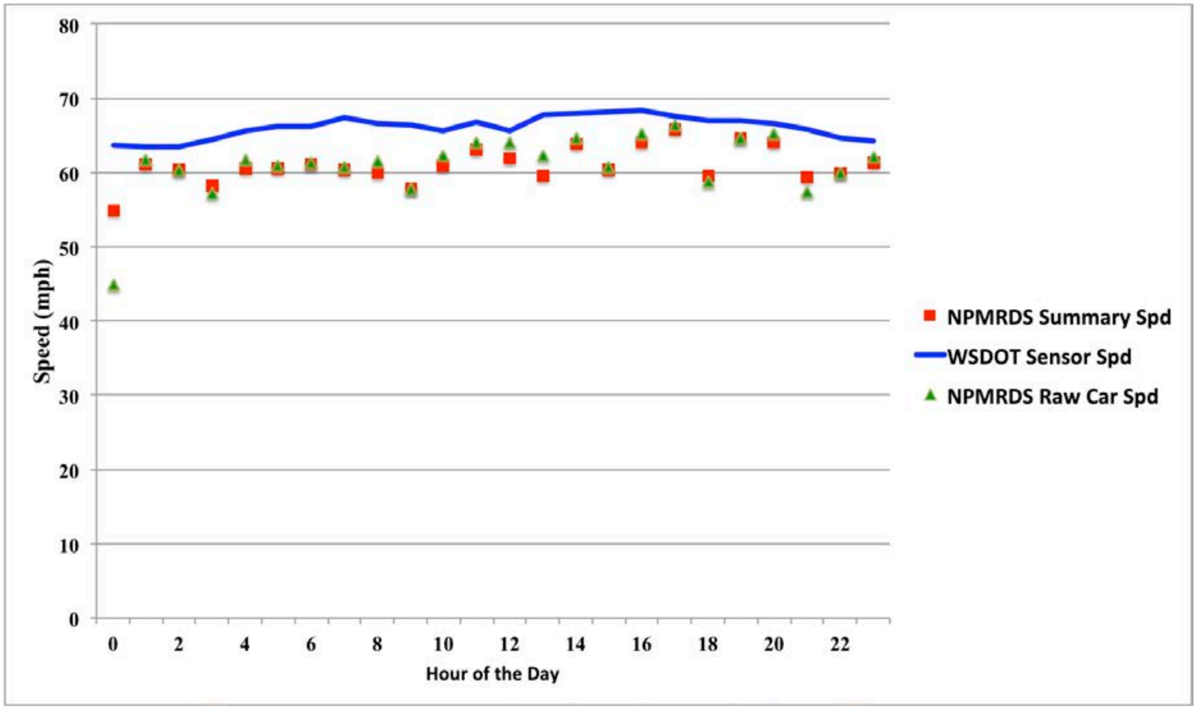

Figure 8: Comparison of NPMRDS and WSDOT Fixed Sensor Speed Data on I-90 Westbound Near Cle Elum

Figure 8 does a good job of showing the speed bias inherent in the NPMRDS data, even in rural areas. For all hourly time periods, the speed reported by NPMRDS is slower than the speed collected by WSDOT. This same test was performed for six locations on I-90. At all locations, this same relationship occurred. The size of the bias varied from location to location, in large part because of the nature of the terrain for a given TMC segment and the location of the WSDOT fixed sensor.

Truck Speeds on Grades Do Not Reflect Roadway Performance

Limits on heavy trucks' power to weight ratio mean that many must travel up steep grades slowly. In addition, for safety purposes, heavy trucks often must also descend steep grades slowly. The result is that some trucks must move slowly on roads where conditions do not prevent other vehicles from traveling at the speed limit. Because the slow moving trucks do not shut off their GPS devices at slow speeds, the NPMRDS data contain data points from both the slow moving trucks and the faster moving cars and trucks. This dichotomy in operating conditions can show up as slow truck speeds while car speeds are fast, or as moderate truck speeds when a mix of slow moving and faster moving trucks report speeds on the same TMC segment during the same epoch. The result of these slow truck reports on segments that otherwise have free flowing traffic is bias in the NPMRDS data toward slower speeds.

Figure 9 shows the site with the largest difference between data from the NPMRDS and the WSDOT fixed sensors from among the six sites tested on I-90. In this case, the TMC segment was westbound, but only a few miles to the east of Snoqualmie Pass. As a result, the TMC segment contained uphill grades as vehicles approached the pass from the east. Because of the grade portion of the TMC segment, more slow moving vehicle speeds were reported to the NPMRDS, and the speed differential in Figure 9 between the WSDOT and NPMRDS data is frequently greater than 10 mph. In this case, the NPMRDS data reflect the effect of the grades on this section of the roadway, whereas the WSDOT fixed sensor data do not. The project team suspects that in this case, the WSDOT data over-estimate the actual average segment speed, whereas the NPMRDS data under-estimate that average speed.

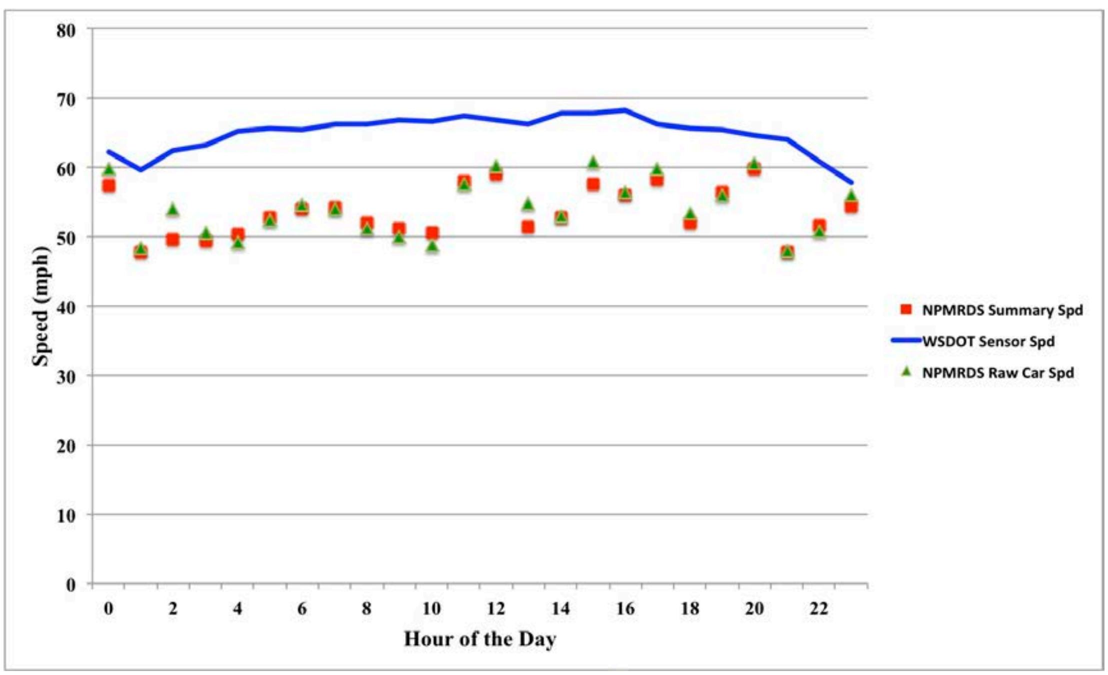

Figure 9: Comparison of NPMRDS and WSDOT Fixed Sensor Speed Data on I-90 Westbound to the East of Snoqualmie Pass (MP 63.8)[6]

[6] TMC Segment 114P04856 goes from milepost 68.30 to milepost 62.04.

When only a few vehicles report data during a given epoch on a TMC segment, the impact of slow moving trucks on the TMC segment can be very large. As the number of vehicle probe data points increases, the effect of slow moving, heavily loaded trucks decreases, but is still present, as shown in Figure 9.

QUALITY ASSURANCE TESTS

A review of the NPMRDS data indicated that a number of data points should be removed from the NPMRDS data set before those data are used for performance measurement calculations. The quality assurance tests described below are the first cut at those tests. Refinements to the tests are expected to be made over time. Consequently, the resulting data set after application of the quality assurance tests should be stored separately from the raw data downloaded from FHWA. This will allow the data to be reprocessed later, both for testing and to apply improved quality assurance tests as they are developed.

The tests are based on vehicle speed in miles per hour. They use both the car and truck data supplied in the NPMRDS. In this first iteration, the combined NPMRDS data set is not used, although a new combined file is created.

Step 1: Format the NPMRDS

In this step, the NPMRDS data are formatted into four tables.

The output of the step is an NPMRDS structured as shown in Table 4. One table is constructed for each direction for each state route for each type of NPMRDS vehicle. That is, I-90 will be structured into four tables: increasing mileposts for cars, increasing mileposts for trucks, decreasing mileposts for cars, and decreasing mileposts for trucks. The order of the segments (columns) should be the order in which vehicles traverse the roadway. Each row is a 5-minute epoch, where time includes both time and date. (Time and Date are stored as separate variables.) The length of each TMC segment (as reported with the NPMRDS) is also associated with each segment, as is the speed limit, which may differ for cars and trucks, for that segment. (The speed limit will need to be obtained from a source other than the NPMRDS.)

Table 4: Example of NPMRDS Table Structure

	Segment 1	Segment 2	Segment …	Segment n
	Segment length	Segment length	Segment length	Segment length
	Car speed limit	Car speed limit	Car speed limit	Car speed limit
	Truck speed limit	Truck speed limit	Truck speed limit	Truck speed limit
Time 1				
Time 2				
Time 3				
Time …				
Time n				

Step 2: Convert Travel Time to Speed

The data contained in the NPMRDS are formatted as travel time in seconds for each segment. In this step, the travel time statistics are converted into speed estimates in miles per hour. This requires knowing the length of each TMC segment. The formula is
speed (in mph) = length (in miles) / travel time (in seconds) * 60 * 60

This computation is performed separately for the car matrix (table) and the truck matrix (table). Cells without a travel time value are treated as missing values (N/A).

These computations produce four additional tables for each state route. These new speed tables are stored for future reference as the raw speed tables and serve as input to the next steps of the quality assurance process.

Step 3: Remove Bad Speed Values

Using the tables produced in Step 2, any TMC/epoch segment that has a speed equal to or below 2 mph[7] is reset to 'not available (N/A)'.

Note that where a truck travel time and/or speed exists, but not a statistic for cars, that car value should be set to N/A. The same is true when there is a value for cars, but not a value for trucks.

[7] The 2 mph threshold may be set higher at a later date, based on continued testing of this parameter.

For various reasons, the NPMRDS contains a number of travel times that reflect very low speeds. For example, for June 2014 on I-82, seven epochs for trucks and nine epochs for cars had travel times that corresponded to less than 2 mph. The slowest speed reported is 1 kph (roughly 0.61 mph.) These very low speeds are not logical or realistic measures of average speed over the length of a roadway segment. For example, a 4-mile roadway segment traveled at 1 kph on I-90 would take a vehicle over 6 hours to traverse. This step simply removes those unrealistic travel times. (Note that at a future date, this 'acceptable lower end speed value' may be changed.)

This step creates four additional tables for each state route (again, one table per direction and type of vehicle). All further changes to the NPMRDS data sets take place with these four new sets of tables.

Step 4: Reset Very Fast Speeds to the Speed Limit

For speeds greater than the speed limit, the speed of the segment is reset to the speed limit. Where the speed limits differ, the car speed limit should be used for the car tables, and the truck speed limit used for the truck tables. Where speed limits change within a given TMC segment, the higher speed limit should be used.

Many speeds for specific epochs reported in the NPMRDS are faster than the speed limit. While these speeds are both distinctly possible (many vehicles travel faster than the speed limit), from a roadway performance perspective, they are simply indications that the road is operating in a free flowing condition. Restricting the speeds being reported to the speed limit when reporting roadway performance has been WSDOT's policy for its urban freeway reporting process for many years. This step applies that policy throughout the state.

Step 5: Compute Refined Car Speed Analysis Data Set

In this step, the same TMC/epoch segment for cars and trucks is examined. If a speed value exists for trucks but not for cars, then the missing value for the car speed is replaced with the available truck speed.

Step 6: Compute Refined Truck Speed Analysis Data Set

In this step, the same TMC/epoch segment for cars and trucks is examined. If a speed value exists for cars but not for trucks, then the missing value for the truck speed is replaced with the available car speed. That value is then compared with the truck speed limit. If the new speed value is greater than the truck speed limit, then the new speed value is reset to the truck speed limit.

Step 7: Compute Revised Travel Time Tables

The travel time for each epoch and TMC segment is computed by using the refined truck and car speed tables computed in steps 5 and 6. (This creates four more NPMRDS tables for each state route.) The units for the travel time statistics computed in this step should be minutes, which would make future computations easier.

Step 8: Check for Physically Possible Travel Times

This next step is an additional process used to find travel times that are unreasonably slow.   For example, if one very slow (e.g., 1 kph) GPS speed, such as we removed in Step 3, is included as one of two GPS speed values used by HERE or ATRI to compute average travel time, the average speed reported by HERE/ATRI for that epoch will be too fast to be removed by Step 3. But the reported speed will still be too slow to be reasonable. To help find these unreasonably slow speeds, this step looks for any reported travel times on specific segments that are so slow that a vehicle arriving at that TMC segment later in the day would be shown to 'pass' a vehicle arriving earlier in the day. For example, because of a bad speed data point, a travel time of 60 minutes is reported for TMC segment A at 5:00. At 5:05 the travel time for that segment is reported as 10 minutes. A vehicle arriving at 5:00 will reach the end of the segment at 6:00. A vehicle arriving at the segment at 5:05 will be computed as reaching the end of the segment at 5:15. To do so, it must pass the first vehicle. Since the travel times being reported are meant to be average conditions, it is not possible for a vehicle to pass an earlier vehicle. This step looks for this condition, and resets the slower travel time to one just fast enough to keep the following vehicle from passing the lead vehicle.

This step is complex. When this passing behavior is observed, the travel times of the very slow moving vehicles are set equal to the travel time required for the later vehicles to catch but not pass the slower vehicles. The speeds reported for those TMC/epoch segments are then adjusted upward to reflect the increased speed associated with the adjusted travel time. (This process assumes that a limited number of overly slow GPS speeds have artificially lowered the segment travel time.)

Process

For a given epoch ($epoch_X$, where $epoch_0$ is the current epoch in the analysis) and TMC segment and type of vehicle (cars must be done separately from trucks),

1. Determine the travel time for that epoch
2. Set N equal to (travel time / 5 minutes) rounded up
   so if travel time = 21 minutes, N = 5 (4.25 rounded up)
3. Examine the travel times in the next N epochs for that TMC segment, where x = 1 to N
4. If travel time in $epoch_0$ > travel time in $epoch_X$ + (5 min) * X
   then reset $epoch_0$ = travel time in $epoch_X$ + (5 min) * X
   (This compares the travel time in the current epoch to the travel time in future epochs plus 5 minutes for each epoch into the future. If the travel time in the future epoch plus the time elapsed between epochs is less than the current epoch travel time, then the data indicate that a vehicle in that future epoch will reach the end of the TMC segment before a vehicle in the current epoch. This is not physically possible, given the definition of the NPMRDS as being the average travel time for all vehicles using that segment during that epoch. Consequently, we reset the current travel time to that later travel time plus 5 minutes for every epoch between the current epoch and the epoch the faster observed travel time. This assumes that very slow vehicle travel times are at least partly in error when faster times are observed later in the day, due to the use of instantaneous GPS speeds.)
5. Repeat this comparison for each of the N epochs computed on the basis of the observed travel time in the current epoch.
6. If a travel time is replaced in the Refined Travel Time tables, then compute the average speed associated with that revised travel time and replace that epoch's speed value in the appropriate Refined Speed Table so that it reflects the modified travel time.

These tasks are performed for all epochs for all TMC segments for each direction of travel. Car and truck tables are computed independently.

The resulting travel time and speed tables will then be used for performance metric computations (unless additional quality assurance checks are developed, in which case those additional procedures will be applied at this point).

Step 9: Compute Non-Power-to-Weight Restricted Truck Travel Time and Speed Tables

This step creates two additional NPMRDS tables for each state route.

The step first compares the car and truck speeds computed in Step 8 and looks for those TMC/epochs where truck speeds (for the same time and location) are more than 20 mph[8] slower than the car speeds. Where these speeds differentials are found, it is assumed that the speeds of heavy trucks on some portion of the TMC segment are being constrained by operational constraints of the heavy trucks. The best example of these constraints is steep uphill grades, where the low power-to-weight ratio of many trucks limits the speed at which those trucks can climb that grade.

Consequently, the new 'non-P/W constrained' truck travel time and speed matrices are created by replacing the truck travel time for those epochs and TMC segments with either the car travel time or the travel time at the truck speed limit, whichever is slower. The speed for that new travel time is then computed and stored in the speed matrix. All other values in these matrices are the same as those that result from Step 8.

[8] The 20 mph value needs more testing and refinement and is appropriate only for high speed, non-signalized roadways such as Interstate freeways.

CHAPTER 2: PERFORMANCE METRICS
THAT CAN BE COMPUTED FROM THE NPMRDS

This chapter discusses the performance metrics that can be computed with NPMRDS data, given the data limitations presented in Chapter 1. In addition, this chapter describes concerns that will need to be addressed before the computation of performance measures is expanded beyond the Interstate system.

Discussions held with the WSDOT Freight Systems Division as part of this project clarified that the Freight Systems Division is interested in three types of performance measures. These are as follows:

- Key performance metrics including delay and travel time that indicate where roadway performance needs to be improved for trucks. This may be used for MAP-21 reporting purpose.
- travel time measures that indicate: 1) the number of 'turns' (from loading origination to unloading destination and back again) that trucks can make and the reliability of those truck trip movements; 2) total travel time and reliability of major supply chain routes;
- measures that indicate locations where trucks perform poorly but where car performance is good, which indicate where truck-specific improvements should be made. The computations must screen out locations such as steep grades that will not be changed, and focus on actionable improvements.

The first category of these measures can be produced with the current NPMRDS data, with the exception of travel time reliability metrics. The second category of measures—along with general travel time and reliability measures—can only be produced after 1) the available NPMRDS data have been improved and 2) specific programming tasks are completed within the DriveNet software system. The third category of measures does not include outcomes from the Interstate roads that are the subject of this research project. Those metrics are therefore not dealt with in detail. Each of these topic areas is explored in more detail below.

GENERAL MAP-21 PERFORMANCE METRICS

The Federal Highway Administration has delayed publication of the MAP-21 performance reporting requirements. However, it is highly likely that several key performance metrics will be requested for freight movements. For example, AASHTO has recommended two measures for MAP-21 freight performance:

- delay (annual hours of truck delay)—travel time above the congestion threshold in units of vehicle-hours for commercial vehicles, and
- reliability (a truck reliability index for the 80th percentile travel time)—the ratio of the total truck travel time needed to ensure on-time arrival to the agency-determined threshold travel time.

The project team thinks other metrics could include:

- frequency of congestion (the percentage of time a specific roadway segment performs at speeds below a congestion threshold), and
- travel time and travel time reliability (reported as the 80th and 95th percentile travel times) between key origins and destinations.

While additional metrics may be needed, these statistics are likely to serve as the basis for those additional reporting statistics. The use and computation of each of these performance metrics is discussed below.

Importantly, these same measures are highly useful for performance reporting at both the state and project levels. Delay and frequency of congestion are highly useful for identifying where roadways are not currently functioning well. These measures can be reported for trucks, cars, and total traffic. Comparing these three different versions of the same basic statistics can inform WSDOT of the relative significance of the delays being observed, as well as describe the population of road users that experience those delays. Variations on how these data are reported (e.g., at the segment level versus the corridor level, or on a per vehicle level versus a total value for all vehicles combined, or on a per mile basis versus total delay for a contiguous segment, or delay per lane versus total facility delay) provide additional insight into the relative value and significance of different congestion locations.

Similarly, by combining these statistics with different causation variables (e.g., the presence of crashes, bad weather, special events, and/or construction activities) it is possible to associate congestion with the factors that may cause congestion. This in turn leads to preliminary insights into the types of projects that WSDOT can implement to improve roadway performance. This functionality will be built into DriveNet, but these comparisons are not being produced as part of this project.

Freight Delay

The freight delay values of interest to WSDOT and FHWA are those that are caused by poor roadway performance.

Consequently, the highway definition of delay assumes that some aspect of how the road is performing restricts the speed of a vehicle below the speed that the driver desires. So, if the driver of a car chooses to drive slowly in order for his/her passenger to see the scenery, that car is not delayed. On the other hand, if that car is using a two-lane road, and its slow speed prevents 10 other cars from driving the speed limit because they are unable to pass the slow moving car, those additional 10 cars are delayed.

Freight delay or truck delay is similar to the example above, in that slow moving trucks may not actually be delayed. On steep hills, some heavily loaded trucks will travel slowly, not because of congestion from other cars or temporary road conditions but because they have insufficient engine power to pull their load up the hill at the speed limit. These trucks have low power to weight ratios. These trucks are not delayed by road conditions, but they are traveling well below the speed limit.

Because the NPMRDS relies on GPS-based vehicle speeds, when heavily loaded trucks are moving up hill, they still report their GPS speeds, and when used, those speeds indicate that delay is occurring. Therefore, from a roadway performance management perspective, it is important to understand when trucks move slowly because of actual road conditions and when trucks move slowly because they are carrying heavy loads. The quality assurance steps described in Chapter 1 attempt to identify when speeds are slow because of power-to-weight ratio performance issues, but those quality assurance tests can only capture some of those conditions. It is therefore important for WSDOT to be aware of the effects of truck performance on delay calculations.

Reporting Different Types of Delays

NCHRP project 08-98 is recommending the computation of delay for four different speed thresholds. Delay is defined as the travel time lost as a result of travel speeds falling below a speed threshold. Delay is typically reported in units of vehicle-hours. WSDOT uses the following formula to calculate the hours of delay for any time period:

$$Hours\ of\ Delay = \frac{Vehicle\ miles\ traveled}{Travel\ Speed} - \frac{Vehicle\ miles\ traveled}{Threshold\ Speed} \qquad [1]$$

This formula can be reformulated slightly to simplify and size the computation.

$$Vehicle\text{–}Hours\ of\ Delay = (Actual\ Travel\ Time - Threshold\ Travel\ Time) * Volume \qquad [2]$$

The four different threshold-based delay measures recommended by NCHRP 08-98 are

- $\text{Delay}_{\text{Free flow}}$
- $\text{Delay}_{\text{Speed limit}}$
- $\text{Delay}_{\text{MaxEfficiency}}$
- $\text{Delay}_{\text{Target}}$.

All of these delay measures can be computed exclusively for truck traffic, or they can be computed for total vehicle traffic. Delays to cars can be computed by subtracting truck delay from total delay. Comparing truck and car delay yields insight into the locations that are of importance to trucks but may not be as significant to cars.

$\underline{\text{Delay}_{\text{Free flow}}}$ is defined as the amount of travel occurring at speeds below the observed free flow speed on a roadway. That is, it uses the free flow speed on the roadway as the threshold value against which delay is computed. $\underline{\text{Delay}_{\text{Speed limit}}}$ is defined as the delay measured when the speed limit is used as the threshold value. It defines delay as occurring whenever roadway conditions prevent vehicles from driving the speed limit. $\underline{\text{Delay}_{\text{MaxEfficiency}}}$ is defined as the amount of travel time lost when vehicles must drive at speeds slower than the speed at which a highway's most efficient (highest traffic volume) condition occurs. Travel at speeds below this threshold indicates that the roadway is operating at less than its design capacity. Finally, $\underline{\text{Delay}_{\text{Target}}}$ is defined as travel time lost when vehicles must operate at speeds slower than a target value set by an agency. Target values can be policy statements (e.g., because congestion is very bad, and we have little funding, our goal will be to keep the roadway operating at 35 mph or faster during the peak period) or the outcome of planning efforts (e.g., the outcome of building the improvements included in this plan is travel speeds on the corridor of greater than 45 mph during the peak periods).

All of these delay measures can be computed with the NPMRDS data by combining the NPMRDS travel time data with volume data available from WSDOT's TRIPS[9] database. However, limitations in the NPMRDS (as explained previously) limit the accuracy and precision of the estimates obtained from those computations.

$\underline{\text{Delay}_{\text{Free flow}}}$ is computed by using the NPMRDS data to determine how fast vehicles drive when unobstructed by other vehicles. This free flow condition is frequently estimated as being the 85th percentile speed observed late at night, under low volume traffic conditions. While a useful measure, $\text{Delay}_{\text{Free flow}}$ has little practical value in terms of WSDOT decision making, as it implies that delay occurs at times and in places where no improvements would ever be contemplated to improve roadway operating conditions. In urban areas, however, it can be used to indicate when volumes have reached the point at which speeds start to be restricted simply because of volume.

$\underline{\text{Delay}_{\text{Speed limit}}}$ is the most commonly used definition of reported delay. For this measure, delay occurs whenever roadway conditions cause vehicle speeds to drop below the posted speed limit. This definition is readily understood and can be applied uniformly across the nation, making it the most likely delay statistic for use in MAP-21 reporting.

The final delay computation, $\underline{\text{Delay}_{\text{Target}}}$, is an important metric for use by the Freight Systems Division as part of both the new Multimodal Corridor Sketch process and as an output of corridor and regional planning efforts. This delay measure is particularly well suited for accountability reporting, as it can be used to track delay versus a state goal or plan outcome. The only difficulty here is the availability of data. This is particularly true for roads that are not limited access roadways. (See the section on "Concerns to Be Addressed Before Performance Reporting Is Extended to Non-Interstate Routes" later in this document.)

Use of NPMRDS for Delay Computations

While all of these delay measures can be computed with the speed data supplied by the NPMRDS, the variability in the NPMRDS data—if they are used directly—will cause over-estimation of actual delay under each of these definitions. The higher the threshold speed, the greater the over-estimation of delay.

[9] TRIPS is WSDOT's central traffic data repository.

The reason for this over-estimation is that the intent of the delay definition is to compute delay only when roadway congestion or other operating conditions force vehicles to drive slower than the threshold limit. When fixed sensors are used to compute average vehicle speed, the reported speeds typically only drop below the speed limit when roadway conditions warrant that outcome. Thus, delay is only computed when the average of all vehicle speeds drops below the threshold level.

Unfortunately, as shown earlier in figures 7, 8, and 9, the use of instantaneous speeds from GPS devices, combined with a small sample size of probe vehicles, results in a significant number of NPMRDS epochs having 'average reported speeds' lower than the speed limit—and occasionally lower than the speed at maximum throughput—when roadway conditions are not actually the cause of those lowered vehicle speeds. These slow speeds are simply the result of variation in the population of instantaneous vehicle speeds found on roadways. And this variation is high in many different road environments, where hills, on-ramps, off-ramps, and other geometric conditions can cause vehicles to slow momentarily. The current NPMRDS data are also limited by the positional accuracy of modern GPS devices, which can cause vehicles currently on ramps (and thus moving slower than the mainline speed limit) to be reported as driven on the mainline.

Therefore, simply using the NPMRDS data will result in delay being reported when no vehicles are actually being delayed by roadway conditions, regardless of which threshold value is used.

The significance of this issue should decline over time as the vehicle probe sample size increases. Even greater improvement will occur if FHWA changes the NPMRDS data collection process to include point-to-point travel time estimation from GPS-based probes, in addition to the use of instantaneous GPS spot speeds, which are the only data currently reported in the NPMRDS. However, as long as instantaneous GPS speeds are the primary source of roadway speed information, some over-reporting of delay will likely occur, regardless of the threshold value used.

While this study only examined Interstate highways, it is clear from the examination of the NPMRDS data on Interstates that the current version of the NPMRDS will also have difficulty reporting effectively on the performance of signalized arterials. More work is needed with NPMRDS data on those facilities before advice can be given on reporting arterial delay.

Use of the NPMRDS in the Short Term for Delay Computation

While the current NPMRDS has significant limitations, the available data do have considerable value for examining current roadway performance. For example, the data can be used to illustrate where and when vehicles are traveling slowly. A variety of useful delay statistics can be computed, and the size and significance of delay locations can be compared.

One significant advantage of using delay as a roadway performance reporting statistic is that it can be computed by segment, and those segment-based computations can be performed with a sample of time periods, as long as the sample is unbiased. This allows WSDOT to examine both where and when delays are occurring, the first step in deploying resources to reduce the size of those delays.

Chapter 3 discusses the absolute accuracy of those delay statistics. However, even if the absolute delay values are less than ideal, the relative size of delay (across time of day, day of week, or month of year) can be used. Delay comparisons can also be made across locations, as long as care is taken to understand the impacts of a few geometric constraints on the delay computations. (For example, very short TMC segments should not be compared with very long segments without considerable care; nor should delay on flat urban segments be directly compared to delay on mountainous rural segments, although it is valid to compare delay on a mountainous segment in January versus the delay on that same segment in June.)

With the exception of roadway closures (this is an issue on I-90 with closures of Snoqualmie Pass due to snow and roadway construction), the NPMRDS is unbiased regarding when speed data are reported, although more data are present for times of the day when volumes are highest. This means that given a good statistical expansion process, the sample of time periods present in the NPMRDS can be used to estimate when and where delays are occurring on Interstates. Variation in delay can also be reported by month and day of week.

Additional steps—and data—are needed to compute delay due to full road closures. The WSDOT Traffic Office has indicated that road closure information is available. The DriveNet project should obtain those data and should be able to incorporate the delays due to closure in its reported delay statistics.

Other than the quality assurance steps described in Chapter 1, no additional changes are needed to the NPMRDS for its data to be used to compute relative amounts of delay for different TMC segments. These values are useful information for many WSDOT needs. The primary concern is that as the NPMRDS improves over time, changes in the delay statistics over time (e.g., over several years) will likely be caused more by the change in data quality than as a result of changing roadway performance. But comparison of roadway performance across similar types of roads, or comparison of roadway performance across different months, or different days of the week at a single location or corridor, are tasks for which the NPMRDS can currently be used.

Frequency of Congestion

Frequency of congestion is a measure that describes the fraction of time a specific location experiences poor roadway performance. It is very useful for describing the reliability of specific roadway segments. It is best used to answer basic questions such as, "How often can I expect to be stuck in congestion at this location during my commute?" Consequently, frequency of congestion is often used in the analysis of urban freeways. It is particularly useful in describing the number of days that heavy congestion occurs, and when the frequency of congestion is illustrated by time of day, it is very good at showing how congestion is spreading to the shoulders of the peak periods.

Frequency of congestion is computed as the percentage of time periods during which speed drops below a threshold value, or lane occupancy (a measure of traffic density) climbs above a threshold value. Freeways tend to either 'work' or 'not work', and vehicle speeds (and traffic density) change dramatically between when the roadway 'works' and when it 'does not work'. Roads without traffic controls, such as freeways, experience stable, moderate speeds for relatively little time. They operate either at stable and fast speeds, or at unstable, highly variable, slow and moderately slow speeds. As a result, vehicle speed distributions for freeways are often bi-modal. There is a group of time periods when speeds cluster near the speed limit, and a group of time periods when speeds are in the low to moderately low range. As a result, the use of mean speed as a measure of roadway performance has significant limitations as a congestion measure. When congestion occurs, mean speed does not really describe either the congested or free flow operating conditions.

In contrast, the 'frequency of congestion' statistic reports on how often (usually as a percentage) a given segment experiences congestion. While it does not report whether that congested speed is 15 or 20 mph, it is often a more effective statistic to use when talking to the public about changing roadway performance. (For example, "This road used to be congested once a week, and now, because of the growth in traffic, it is congested routinely between two and three days per week.")

In rural areas, this statistic can be used to examine the frequency with which crashes and other disruptions cause vehicle delay. Examining when and how often congestion occurs is also useful for determining the effects of recreational movements on rural road performance. In urban areas, it is typically used to measure the fraction of days when commuters can expect to experience congestion on a specific segment of their commute. Examining how this statistic changes, as well as what time of day congestion first occurs and how long that congestion persists, are both excellent ways to examine the growth in congestion in developing urban areas. For example, this statistic is an excellent way to illustrate the growth of congestion in the shoulders of the peak period.

For WSDOT's current congestion reporting on urban freeways, congestion is defined by using Highway Capacity Manual measures of vehicle density based on the inductance loop data collected as part of the traffic management system. Unfortunately, use of this mechanism is not possible in rural areas because of a lack of closely spaced fixed data collection devices. So for road segments for which the NPMRDS provides the only roadway performance data, it is recommended that vehicle speed from the NPMRDS be used as the metric for determining whether a road segment is congested.

Use of NPMRDS for Frequency of Congestion Computations

There are two problems with using reported NPMRDS speeds as the measure of congestion: the length of many of the TMC segments and the high level of variability in the reported NPMRDS speeds. These issues are discussed in more detail in the "Limitations of the NPMRDS" section of Chapter 1.

For computing the frequency with which a given TMC segment experiences congestion, the largest problem is caused by the long segment lengths used for reporting in the NPMRDS. Long segments mean that congestion can be occurring on some portions of the TMC segment but not on others. Therefore, during any given epoch, some portions of the roadway can have very low operating speeds, while the rest of the road segment may be operating at the speed limit. When instantaneous speeds are collected within the long segment, speeds from both congested and uncongested sub-segments are reported (if multiple vehicles report their performance within the segment) during an epoch. The mean speed for the segment then reflects the average of those reported speed values, rather than the fact that part of the roadway is congested.

For example, a 5-mile TMC segment might experience congestion on a ½-mile sub-section of the larger segment (e.g., travel occurring at an average speed of 30 mph for that 1/2 mile – requiring roughly 60 seconds to traverse instead of the expected 30 seconds). If the uncongested travel on the remaining 4.5 miles of the segment occurs at the speed limit, then the probe vehicle is in uncongested conditions for 270 seconds. If the GPS device reports every 5 minutes (300 seconds), then in most cases, one data point will be reported on the roadway. Therefore, there is an 82 percent chance that the reported data point will be 60 mph, and an 18 percent chance that the reported data point will be 30 mph. With a small vehicle sample, all 5 miles will be reported as congestion free 80 percent of the time, and congested 20 percent of the time. If a large vehicle probe sample reports speeds on that segment, the segment will be reported as operating at 54.6 mph (0.82 * 60 mph + 0.18 * 30 mph), which is well within the free flow speeds that might be reported from a small sample size of trucks operating on a rural Interstate.

Thus the longer segment lengths used by the TMC roadway cause some difficulty in the application of this measurement, particularly in rural areas where TMC segment lengths tend to be quite long. For example, almost two-thirds of the I-90 TMC segments in both the Seattle and Spokane urban areas are less than 1 mile long. The vast majority of the remaining segments are less than 1.5 miles long. In contrast, for the rest of the I-90 TMC segments, less than 8 percent of the segments are less than 1 mile long, and the average segment length is over 4 miles.

Given the variability in the speeds reported in the NPMRDS data, as shown earlier in figures 7 through 9, setting a threshold for congestion at 70 percent of the posted speed limit, as is used within the 1992 Highway Capacity Manual, would mean that the 5-mile example segment described above, with heavy congestion occurring on 10 percent of the roadway, would not be reported as containing congestion—even with a very large vehicle probe fleet size. The reported average speed would need to drop to 42 mph for that segment to be reported as congested. That would require 30 mph speeds on at least 3 miles (60 percent) of the road segment, with free flow speeds on the remaining 2 miles.

Interestingly, the delay computation made from these speeds will correctly estimate the delay on the roadway, as long as the individual GPS speed data are not otherwise biased. (That is, ignoring the bias issues discussed earlier and the potential inclusion of GPS speeds from vehicles on ramps.) This is also true for the estimation of annual delay statistics from very small vehicle probe sample sizes, as the errors from these small samples will balance out over long data collection periods. (The individual day delay statistic will not be accurate when small sample sizes are used, because the small sample will ensure that bias exists in the estimate of segment performance. However when aggregated over an entire year, the errors in the daily estimates should balance out.) Unfortunately, the frequency of congestion statistic will not be accurately reported on either an annual or daily level if the NPMRDS data are used in concert with the 70 percent of posted speed threshold for congestion.

Therefore, while frequency of congestion is a useful performance measure, the design of the NPMRDS limits the ability to use a simple speed threshold as the mechanism for identifying congestion on many road segments. The exception to this conclusion is road segments that are of modest length, where the assumption of 'homogeneous conditions within the segment' are reasonably valid. That is, if the roadway section is reasonably short, vehicle speeds within the segment will fall within a small range of values during any time interval, so the speeds being reported will accurately describe the segment's condition. When fixed sensors are placed, the length of a road segment that can typically be assumed to contain homogenous traffic is roughly 1/2 mile.[10] So, if the WSDOT is confident in the speeds being reported by the NPMRDS, the data set can be used to compute the frequency of congestion for segments of ½ mile or shorter. As with loop detectors, TMC segments of up to 1 mile can be used with only a modest loss of accuracy.

For longer TMC segments, it is possible to simply adjust the speed value used to detect delay, with the threshold changing on the basis of the total length of the segment and the fraction of that segment that must experience congestion before the longer segment is reported as congested. For example, if the rule was '1/2 mile of congestion traveling at least half the speed

[10] The issue of whether a road segment contains homogenous roadway conditions also affects loop detectors, which only collect data at a specific point. Considerable research has been performed on this topic. The consensus is that detector spacings of ½ mile or shorter are needed to maintain this assumption. Detector spacings of up to 1 mile are commonly used, but detector systems using this spacing are often slow to observe delay happening within that 1 mile road segment.

limit' on a 4-mile TMC segment, then the threshold speed for the segment would be 53 mph. However, the success of such an approach depends on the precision and accuracy of the speed estimate, because it reduces the size of the difference between the speed limit and the threshold speed at which congestion occurs. Given the high level of variation found in the NPMRDS speed values, it is unlikely that this approach will produce reliable estimates of this important performance metric.

Therefore, the project team recommends that frequency of congestion be reported only for TMC segments of 1 mile or less, until the accuracy and precision of the NPMRDS data set improves.

TRAVEL TIME AND TRAVEL TIME RELIABILITY

The performance metrics needed for MAP-21 are likely to include travel time and travel time reliability. Those measures are also important to WSDOT in indicating the number of turns that freight trucks can make and the reliability of those truck trip movements.

Data Limitations for Travel Time Computation

The data limitations that complicate the computation of delay and frequency of congestion are equally concerning for travel time computations. The basic mechanism for computing travel time from speeds/travel times stored in a time/space matrix (such as the NPMRDS) is called a trajectory algorithm. For each virtual trip, the trajectory algorithm starts in a segment (TMC segment) and uses the travel time in that segment, at that time (epoch), to determine when that trip will reach the next (2^{nd}) segment. It then uses that time to determine which epoch to use to look up the travel time in the 2^{nd} segment, in order to determine when the virtual trip will reach the next (3^{rd}) segment. This continues until the destination is reached, and the total travel time is then computed as the sum of the segment travel times. This process is illustrated in Figure 10.

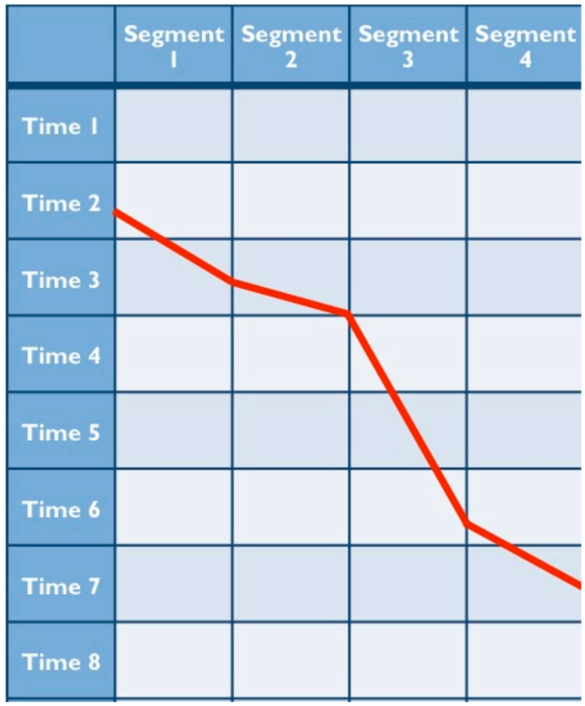

Figure 10: Travel Times Computed with a Trajectory Algorithm

The biggest problem with the NPMRDS for travel time computation is that there are a large number of holes in the data set. This was discussed in the Limitations section of Chapter 1. With the trajectory algorithm, each time there is a hole in the data set, the algorithm cannot compute a travel time for any virtual trip that passes through that hole, unless the travel time for that time period and location is estimated. For the NPMRDS, this becomes problematic when a hole in the database might also mean that the roadway was closed because of snow conditions, a major vehicle crash, or other major event (e.g., flooding on I-5, or a rock slide on I-90 or I-82) because during those conditions, no vehicle probes will be found downstream of the road closure point, and thus a hole in the data will exist.

Therefore, the travel time algorithm used for performance measurement needs to be more robust than simply using the available NPMRDS data and average speeds (or the previous or succeeding epochs' speeds) to supply data missing from TMC segments and time epochs. When road closures occur, the travel time computation needs to directly account for the time periods when roads are closed. For Interstate 90, and to a lesser extent I-5, including road (pass) closures is a very important aspect of computing the reliability of travel times in the corridor.

Computation of Truck-Specific Travel Times

The second issue affecting travel time computations is the desire of the Freight Systems Division to compute truck-specific travel times. Of significance here is the power-to-weight ratio (P/W) issue described previously in the Limitations section of Chapter 1. As a result of the limited P/W ratio of heavily loaded trucks, many truck travel times are reported as being much slower than travel times that are simultaneously experienced at that same location by trucks that are not heavily loaded.

The project team recommends that this issue be addressed in two ways. First, to compute 'travel time for trucks not affected by P/W issues', the car and truck travel times should be used together to determine where the road is generally free flowing but heavy trucks are slow because of their P/W performance. In these cases, the unloaded truck travel time for the segment should be set equal to either the car travel time or the travel time at the speed limit for trucks, whichever is slower. (This is Step 9 in the quality assurance steps described in Chapter 1.) Combining the truck and car data sets also reduces the number of missing TMC/epochs. The only limitation with this recommendation is the fact that many TMC/epochs in rural areas rely on the presence of trucks for data, as relatively few cars report data in rural parts of the state. This limits WSDOT's ability to use car travel times as a quality assurance check on truck travel times.

Additional tests are needed to determine whether the NPMRDS 5-minute epochs have sufficient data to allow computation of a high percentage of the required virtual travel times to meet WSDOT's interest in computing not just average travel times but the reliability of those travel times. The WSDOT Freight Systems Division wishes to report travel times and travel time reliability (the variation present[11] in those travel times over the year) for select origin/destination pairs during the hours when most trucks are traveling.

If the holes in the NPMRDS database prevent performing these computations, then to perform them, it will be necessary to make assumptions about the travel conditions occurring during those holes. At some point, when enough trip calculations are dependent on estimated or assumed performance in multiple TMC/epochs, the computed travel times will lose their

[11] Travel time reliability is typically reported as the 80th or 95th percentile travel time for some given travel period. These percentile travel times are typically determined by computing, for each selected origin and destination, a large number of virtual travel times, each of which starts at a different time and/or day. These travel times are then sorted by trip duration to select the 80th or 95th percentile trip. This process requires the ability to compute a large number of travel times. This typically is done by computing a "virtual trip" starting every 5 or 15 minutes for every weekday (or weekend day) of the year.

meaning and become mostly a function of the missing data assumptions. The testing of the implications of the amount of missing data reported in Chapter 1 on travel time computations must occur within the DriveNet software effort.

The Freight Systems Division is also interested in the travel time and travel time reliability of trips made by heavily loaded trucks (that is, a travel time for trucks with a P/W ratio that limits their speed on steep grades). These travel times are difficult to compute from the NPMRDS because the truck speeds reported by the NPMRDS are a combination of both light (high P/W ratio) and heavy (low P/W ratio) trucks. Thus, the travel times reported are also a function of grade and the number of trucks from either P/W ratio category that report speeds on a specific TMC segment during any specific epoch. For that reason, in many cases the NPMRDS truck travel times cannot be used directly to compute travel times for either heavily loaded or lightly loaded truck conditions. Of course, trucks in both of these loading conditions are also affected by congestion. But slowing due to congestion should be observed in the car travel times, whereas the P/W ratio slowdowns should not be observed in the car travel times. (Luckily, for Interstate highways, the majority of congestion occurs in urban areas, where car travel times are more commonly available.)

The recommended solution for computing 'P/W ratio limited travel times' is described below. It will be programmed and tested once DriveNet is capable of performing those computations.

Step 1: Develop an NPMRDS TMC/epoch travel time/speed matrix for cars and trucks. Remove extremely slow speeds (speeds below 3 mph for the entire segment).

Step 2: Combine the car and truck data sets to reflect the fastest observed travel time between the two data sets, and create two versions of that data set,

- one for cars, in which travel times for each segment are constrained to the speed limit for cars, and
- one for trucks, in which travel times for each segment are constrained to the speed limit for trucks.

Step 3: Using the raw truck data, and comparing them to the raw car data, determine the travel time for slow trucks (those with low P/W ratios) on those TMC segments that contain steep grades or other geometric features that slow heavy trucks.

Step 4: Create a separate file that indicates the travel time for trucks with low P/W ratios for those TMC segments with steep grades. That file would look something like Table 5 below:

Table 5: Example of TMC Segments with Slow Truck Speeds Due to Grade

TMC 1	TMC 2	TMC 3	TMC 4	TMC 5	TMC 6	TMC 7	TMC 8	TMC 9	TMC 10	TMC 11	TMC 12	TMC 13	TMC 14
		X slow				Y slow	Z slow				W slow		

In the example, in TMC segments 3, 7, 8, and 12, trucks are routinely observed to operate slowly when cars are operating at or near the speed limit. This suggests that the P/W ratio of heavy trucks, rather than congestion, maybe causing some trucks to operate slowly. On the basis of an analysis of the truck speeds in these segments and after considering the actual road geometrics, an average slow truck speed (or travel time) for each segment containing one or more steep grades can be computed. This travel time will account for travel across the entire roadway segment, including both the steep grade and parts of the segment that are not steep.

Step 5: When virtual travel times are computed, use the regular travel time matrix (epoch x travel time) for trucks that was computed in Step 2 above to represent actual roadway performance. These matrices will include both fast and slow travel times. The slow travel times will be present when both cars and trucks are observed to be moving slowly. In this matrix, slow speeds represent congestion rather than truck P/W performance issues.

Compute travel times for defined trips from those matrices, and the resulting trip travel times will include delays caused by congestion, vehicle crashes, or any other cause that slows all vehicles on the roadway.

Step 6: To compute slow or P/W ratio-limited truck travel times, substitute the default travel times in cells 3, 7, 8, and 12 in the above example into all corresponding epochs in the Truck Performance epoch x TMC segment matrix.[12] (That is, these

[12] Note that this is an example. Only a limited number of TMC segments will be defined as having low P/W travel times. The exact number of these segments has yet to be determined.

default travel times will replace the actually observed travel times in the appropriate matrix column.)

The assumptions behind this algorithm are that 1) all trucks with poor P/W ratios travel at the same speed, and 2) these trucks move slowly enough that their travel time is not significantly affected by other congestion on those specific TMC segments. (Their travel time is affected by the other congestion experienced along the way, but that other congestion only occurs on the TMC segments that are not speed limited by grades.)

Travel times can then be computed by using this modified travel time matrix, just as with the regular truck and car travel time matrices. The result will be the ability to compute the distribution of travel times for trucks that are constrained by grades during a portion of their trips. This should yield a more realistic estimate of actual travel time for heavily loaded trucks.

When this heavily loaded truck travel time is paired with a regular truck travel time for a trip in the opposite direction, it should be possible to estimate a turn time for a truck trip that includes a loaded trip from the production facility to a destination and an unloaded trip back to that production facility.

Note that one additional limitation in the NPMRDS is that it does not contain the freeway-to-freeway ramp connections that vehicles use to go from one Interstate to another. DriveNet currently provides 'artificial' ramps between Interstates. This is an acceptable initial process, in that it allows multi-corridor trip travel times to be computed. However, because ramps in urban areas can experience significant delays, this process will need to be upgraded once the NPMRDS is modified to include ramps.

IDENTIFYING ACTIONABLE, TRUCK-SPECIFIC PROBLEM AREAS

In the discussions with the Freight Systems Division for this project, WSDOT staff expressed an interest in being able to identify locations where trucks are delayed but cars are not. The project team is of the opinion that GPS speed data can be used for this purpose, but that 1) the NPMRDS data may not have the geographic detail to 'see' these key locations, and 2) Interstate mainlines are highly unlikely to have locations—other than grades—where trucks move slowly but cars moved quickly.

These locations are most commonly associated with tight curves, signal timing plans that do not account for the differences between truck and car acceleration rates, and other geometric conditions that slow trucks but not cars. Those issues are mostly associated with non-interstate highways and therefore outside the scope of this study.

However, the project team has developed procedures as part of the NCHRP 08-98 project to detect these locations. These procedures are being tested within the NCHRP 08-98 project. If these techniques work effectively, they will be implemented in the DriveNet software.

OTHER PERFORMANCE METRICS AND PERFORMANCE ANALYSES

The basic performance metrics identified above describe the locations and sizes of delays. By correlating those locations with variables that cause or influence the formation of congestion (e.g., vehicle crashes, other reported incidents, construction activity, and the occurrence of bad weather), it is possible to identify the events—in addition to total traffic volume—that influence the formation of congestion. As the DriveNet software platform is further developed in the SHRP2 PM Software project, it will be important to link those causation variables to the locations where and times when congestion forms.

Once these variables have been linked in time and space to congestion, it will be possible to report additional performance metrics, such as the fraction of congestion that is associated[13] with each of these influence variables. While the association of different events and congestion is not a direct measure of the cause of congestion, the insight possible from making these associations can be used to guide more definitive analyses of the possible operational and geometric improvements intended to reduce congestion formation. Thus, additional performance measures can be computed from the initial delay and frequency of congestion variables. These include

- the amount of congestion associated with vehicle crashes
- the amount of delay associated with bad weather
- the amount of delay associated with mountain pass closures
- the fraction of trips that are affected by construction activity.

[13] Note that the simple correlation of an event and congestion does not mean that the event caused the congestion. For example, the fact that a crash is present on a TMC during an epoch when congestion occurred, could mean that the congestion contributed to causing the crash, or that a crash may have been the cause of the congestion. Given the length of TMC segments, the crash might also be completely independent of the congestion. The simple correlation of the two variables does not describe the actual causation relationship.

A complete discussion of these influence calculations has been included in the NCHRP 08-98 Task 5 and Task 8 reports. This document will not duplicate that work. Readers may review the NCHRP materials if they are interested in the details of how these causation/influence variables can be used to produce performance metrics that yield insight into the detailed field analyses that are necessary to develop specific project proposals.

CONCERNS TO BE ADDRESSED BEFORE PERFORMANCE REPORTING IS EXPANDED TO NON-INTERSTATE ROUTES

The analysis of the NPMRDS data indicated that many of the data problems identified in the Limitations section of this document will become even more problematic when these analyses are extended to non-Interstate routes, and in particular when extended to signalized arterials. There are three major issues:

- More segments will have either no data or very small data sample sizes because of the lower volume of vehicles using these roads.
- Instantaneous speeds are less accurate measures of roadway segment performance on roads with interrupted traffic flow, both because vehicles spend time at signals not moving and because those zero speeds are not reported and/or are removed from the NPMRDS computations.
- The smaller width of many roads and their proximity to other places where vehicles may be moving increases the chance that the travel speeds of vehicles not on a particular TMC segment are falsely reported as occurring on that road.

The expected small sample size will significantly compound the problem associated with using instantaneous speeds to compute average segment speed on roads where speeds vary significantly because of traffic signals. A small number of data samples will not yield a reliable estimate of average segment performance on road segments that experience interrupted flow.

If all vehicles using the roadway were both instrumented and frequently reporting (i.e., every 10 or 15 seconds) their instantaneous speeds, then those speed values could be used to accurately report on arterial performance for all roads present in the NHS. In addition, the frequent reporting of location would be used by the private sector data vendors to greatly improve the mapping of vehicle locations to specific roads. However, when a road the size of I-90 is missing data in 30 percent of the epochs in rural areas because of a lack of instrumented vehicles, roads with much lower traffic volumes are expected to carry a very limited number of vehicles that report their location and speed during any given epoch. This means that the accuracy of the reported travel times on smaller roads will be suspect until the number of vehicles supplying data to the NPMRDS increases greatly or until the data collection method changes from use of instantaneous speeds to computation of travel time based on the actual distance traveled between locations. These improvements may happen in future NPMRDS submittals but should not be expected for at least several years.

Another issue with the expansion of performance reporting to roads with traffic signals is the need to redefine the point at which both delay and congestion occur.

Stop delay is the amount of time associated with waiting at a signal while the light is red. Some stop delay is inevitable on a signalized arterial. The consequence of signal delay is that no arterial is expected to provide travel times at the speed limit for a long distance. Vehicles are expected to have to stop at some signals. Therefore, the Highway Capacity Manual indicates that a Class I signalized arterial with a speed limit of 45 mph operates at Level of Service A (LOS A) when the average speed (converted from travel time) is greater than 35 mph. LOS C, which is roughly equivalent to maximum throughput on that same facility, is 22 mph.

Expected travel times for different LOS values change with the character of the arterial, where character includes variables such as how closely the signals are spaced, the posted speed limit, and the level of access control for the land uses next to the roadway. These different LOS travel time values reflect the expectations of drivers in different driving environments.

For performance measurement—given even highly accurate data—it is necessary to understand these different expectations in order to set the thresholds at which delay and congestion occur. The fact that the NPMRDS data include considerable additional variability over what would be considered highly accurate data makes setting these thresholds problematic.

This project has not explored these issues in depth. The project team did not explore the availability (i.e., the percentage of epochs with data) of NPMRDS data on non-Interstate routes. Nor did it examine the accuracy of the NPMRDS data in comparison to actual travel time data collected to 'ground truth' for arterial performance. And finally, the project team has not discussed setting thresholds for defining arterial performance with WSDOT staff. It is expected that some of this work will be performed as part of the SHRP2 TMS&O Framework project in conjunction with the development of the WSDOT Multimodal Corridor Sketch process.

CHAPTER 3: PERFORMANCE MONITORING THRESHOLDS AND PERFORMANCE REPORTING TESTS

This section describes the results of tests performed with the NPMRDS data. These tests were performed after those data had been run through the quality assurance tests described in Chapter 1. These tests were performed only with October 2014 NPMRDS data. Data obtained from the NW Region traffic management system were used as ground truth. The NW Region data have some of their own data quality issues, so the comparison was not a true measure of error in the NPMRDS process. However, the revealed differences are illustrative of the outcomes from computing performance measures with the NPMRDS data, the effects of different thresholds for measuring delay and congestion, and the differences between these performance measure computations and the statistics WSDOT would otherwise report if they used the NW Region loop data.

THE TESTS PERFORMED

The primary tests examined the outcomes of delay computations based on the first three threshold values for delay, as described in Chapter 2. The findings presented in this chapter also showed the effects of performing those computations with the average weekday condition versus performing the computations for each day (or each weekday) and then aggregating those daily computations to represent a monthly total. The steps used to compute delay from the NPMRDS data are given below. (The steps used to compute the traffic volume statistics from WSDOT TRIPS data are provided in Appendix B.)

All computations were made at the 5-minute (epoch) and TMC segment level. The same computations were performed using three different threshold values: 1) the speed limit, 2) the speed limit minus 10 mph, and 3) 70 percent of the speed limit. Computations were done both for all data in October 2014 and for all weekdays in October 2014 (to compute total weekday delay).

The specific computation for delay was as follows:

Step 1: Compute the Threshold Travel Time for each TMC segment for each of the three threshold values (speed limit, speed limit minus 10 mph, and 70 percent of the posted speed).

Step 2: Using the travel time matrices computed after Step 9 of the QA/QC process described in Chapter 1 and the volume data from TRIPS (see Appendix B), compute delay using Equation 2 (see Chapter 2) for each segment and epoch (e.g., (actual travel time – threshold travel time) * volume). This was performed with both car travel times and volume and truck travel times and volumes.

Step 3: If the delay computed for any epoch and segment is negative, set that delay to zero.

Step 4: Where data (either travel time or volume) for an epoch and segment are missing, the delay for that epoch and segment is considered a missing value.

Step 5: Compute the average epoch delay for each hour for each day of the year by averaging all available epoch delay statistics within each hour (including zero values, but not missing values).

Step 6: Multiply this average delay per epoch times 12 to obtain the total delay for that hour.

Step 7: Sum the 24 hourly delays to compute total delay for that day.

Step 8: Sum the daily delays to estimate total monthly delay (or total monthly weekday delay for some tests).

The above method computes delay at the daily level and then adds those delays across all days analyzed. The same technique could be used to compute lost productivity – a roadway performance statistic currently reported by WSDOT in the Grey Notebook. But WSDOT's lost-productivity measure is based on average weekday conditions, rather than on actual daily conditions. Consequently, to test the sensitivity of the delay calculations to the use of average conditions versus actual daily conditions, the above delay computations were also performed using average weekday conditions for October 2014, and the two results were then compared.

For this second computation, the following steps were performed using the same input data sets as for the daily computation.

Step 1: Compute the Threshold Travel Time for each TMC segment for each of the three threshold values (speed limit, speed limit minus 10 mph, and 70 percent of the posted speed).

Step 2: Using the travel time matrices computed after Step 9 of the QA/QC process described in Chapter 1, compute the average travel time and average speed for each epoch and TMC segment for each weekday in the month.

Step 3: If any epoch and TMC segment does not have a valid travel time, then set that travel time value to ‘missing’.

Step 4: Compute the average volume for each epoch and each TMC segment by using the data from TRIPS (see Appendix B).

Step 5: Using the computed average travel time and volumes for each epoch and TMC segment, compute delay for that epoch and TMC segment by using Equation 2.

Step 6: If the delay computed for any epoch and segment is negative, set that delay to zero (not missing).

Step 7: Where travel time data for an epoch and segment are missing, the delay for that epoch and segment is treated as a missing value.

Step 8: Compute the average delay for each hour (by averaging the delays in all available epoch delay statistics for that hour. Including zero values, but not missing values) and multiply that value by 12. (This accounts for any missing epochs.) Do this for all TMC segments.

Step 9: Sum the 24 hourly delay values. This is the average weekday delay for the month.

Step 10: Multiply that average daily delay by the number of weekdays in the month. This is the total weekday delay for the month.

TEST RESULTS

All computations for the comparison tests used the speed limit for cars and the car speed statistic from the NPMRDS. This was done because the NW Region data, which represented ground truth in some of the tests, reports on vehicle volumes and speeds for all vehicles, and the car speed estimate (after the QA/QC process is performed) essentially represents this same value, along with the AADT and time of day volume statistics from TRIPS. The volume estimate used in the computation was also for total traffic. The project team believes that results with relationships that are very similar to those described below will be obtained when just truck volumes and truck speeds (which represent roadway performance for trucks, not speeds associated with limited power to weight ratios) are used for delay computations. This is the set of truck travel time and speed matrices that results from the recommended QA/QC process described in Chapter 1.

The five tests described below used data for the increasing direction of I-90. The primary tests were performed for two long segments of I-90: I-5 to Issaquah, and I-5 to milepost 114.09 (TMC segment 114N04841), whose eastern end is 5 miles east of the I-82/I-90 interchange and 20 miles west of the Columbia River gorge.[14] Tests that compared NPMRDS results to "ground truth" were concentrated on the section of I-90 from I-5 to Issaquah, the section of I-90 that is covered by the NW Region traffic sensor network.

- The first test examined the effect of using the three different delay threshold values (speed limit, speed limit minus 10 mph, and 70 percent of the speed limit). It was performed with delay that was computed by using the actual daily travel times and volumes. The differences in delay were examined for both urban and rural segments of I-90.
- The second test examined in detail the differences between the NPMRDS-based delay computations and delay computations performed with the NW Region TMC data. This test was conducted with delay that was computed with the average monthly conditions in order to match how the NW Region delays are computed.
- The third test examined the differences in VMT estimates produced by using the WSDOT's Transportation Data and GIS Office (TDGO) volume data, modified to estimate 5-minute volumes. This comparison was not sensitive to the computation method. This test was performed only with NW Region loop data.
- The fourth test compared the delay estimates obtained with the NPMRDS data by using the disaggregated approach (i.e., where delay is computed for each day and then aggregated) and by using the aggregated approach (i.e., where average speed is computed for the month, and then delay is computed from that average condition).
- The fifth test compared the reported frequency of congestion calculated with the NPMRDS data against those produced with data from the NW Region loops.

[14] The test was stopped one TMC segment short of the Columbia River Gorge to avoid the long hill that leads to/from the Gorge. The eastern section of the test case was intended to be primarily flat.

Effects of Using Alternative Threshold Values on Delay Estimation

Using the cleaned NPMRDS data and the TDGO traffic volume estimates, delay was calculated three different ways, each using a different speed threshold at which delay was defined to occur. The first threshold tested was the speed limit, 60 mph in urban areas and 70 mph in rural areas. The second threshold was 10 mph slower than the speed limit, and the final threshold was 70 percent of the speed limit. The test was performed with data from eastbound I-90, from I-5 to just short of the Columbia River.

The average weekday delay for October using the speed limit as the threshold was computed as 554,900 vehicle-minutes of delay[15] ($Delay_{SL}$). ($Delay_{SL}$ will be called the 'base delay' in the rest of this subsection, as this was the value against which the other data estimates were compared.) If the threshold 'speed limit minus 10 mph' was used ($Delay_{10}$), only 261,200 vehicle-minutes (47 percent of the base delay) were observed. If 70 percent of the posted speed was used as the threshold ($Delay_{70}$), only 160,000 vehicle-minutes of delay (29 percent of the base delay) were computed.

While the above numbers represent the overall change in delay for that segment of I-90, the relationship between the delay computed with these delay thresholds was very different between segments that experienced a large amount of congestion and those that experienced very low levels of congestion. The difference in computed delay for the three different thresholds was much smaller (in percentage terms) on congested urban segments than on uncongested rural road segments. The differences on rural segments containing major grades, or other factors that cause some traffic slowing, were in the middle of these two extreme cases.

For the three most congested TMC segments (all located near the I-5 interchange) $Delay_{10}$ was roughly 88 percent of the base delay. $Delay_{70}$ was 79 percent of the base delay. Thus, on these heavily congested segments, the computed delay changed modestly when the threshold was changed.

However, in rural areas with mostly flat terrain, the reported delay almost entirely vanished when $Delay_{70}$ or $Delay_{10}$ were computed instead of $Delay_{SL}$. In most of the rural TMC segments that do not contain hills, delay measured when using 70 percent of the posted speed was between 1 and 5 percent of the base delay. If the middle threshold of 10 mph less than the

[15] For I-90 from the I-5 interchange to the Columbia River at Vantage.

speed limit was used, then the computed delay was typically only 10 to 15 percent of the reported base delay.

There was considerable variation among the delays computed with these three thresholds among the individual TMC segments in both urban and rural areas (see figures 11 and 12). Urban segments that experience only modest levels of routine congestion had a $Delay_{10}$ value in the neighborhood of 50 to 80 percent of base delay, and a $Delay_{70}$ value that was roughly 30 to 60 percent of base delay. Rural TMC segments that contain significant grades exhibited relationships among these three different threshold computations that were reasonably similar to those of moderately congested urban segments.

What these comparisons illustrated was as much about the nature of the NPMRDS data as it was about the relationship of the three delay statistics. The NPMRDS data exhibit a wide spread of speeds about the speed limit, with some biased toward slower speeds. (This is in part because slow vehicles report their speed and position more frequently than fast vehicles, partly because trucks using cell phones for positioning data and traffic reports are often reported as being cars, and partly because errors in GPS position reporting can easily result in vehicles that are actually on a ramp—and those moving slower than the mainline because they are on the ramp—having their speed be reported as occurring on that mainline road section. The NPMRDS does not include ramps in its database, so the reverse error does not occur. (Fast vehicles are not assigned to slow roadway segments by accident.) Consequently, the NPMRDS contains a number of epochs that report travel times that are slower than the uncongested travel times that should be reported, despite the quality assurance tests performed both by HERE and TRAC.

In TMC segments where routine congestion was forming, these errors caused less significant errors in the reported travel times and speeds because speeds on the mainline were already slow. Adding a modest number of other slow speed data points had less of an impact on the speeds reported in the NPMRDS. Consequently, the difference in delay computed with the three thresholds was mostly due to the difference in how often traffic actually fell below the travel speed required by these different definitions of delay.

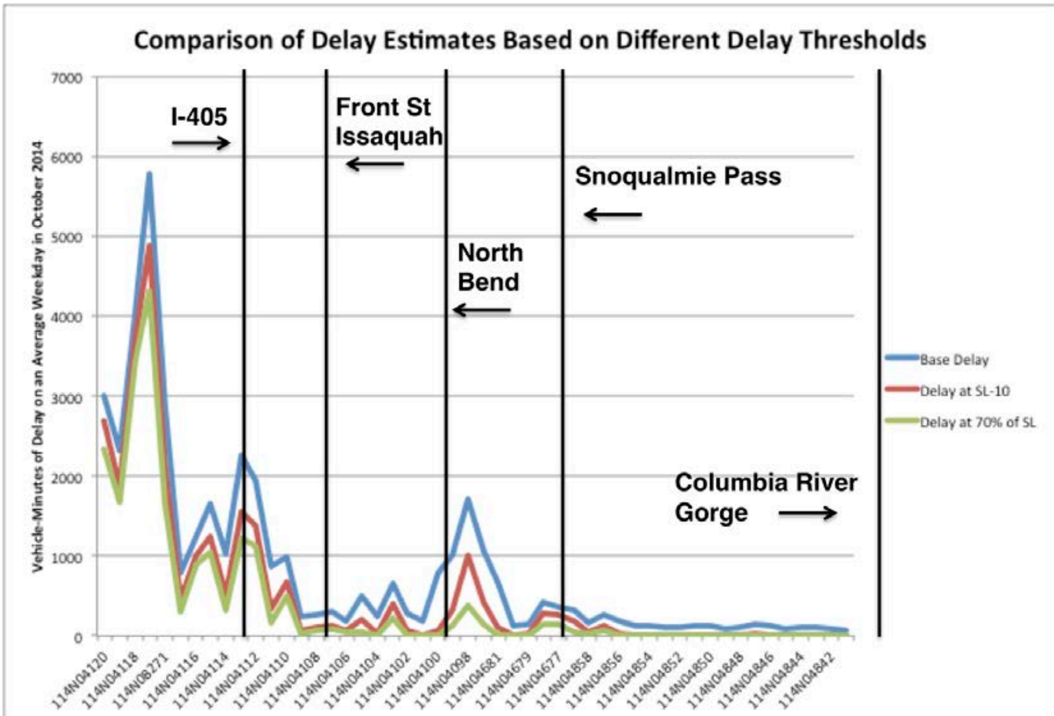

Figure 11: Average Daily Delay by TMC Segment for Three Different Delay Threshold Values

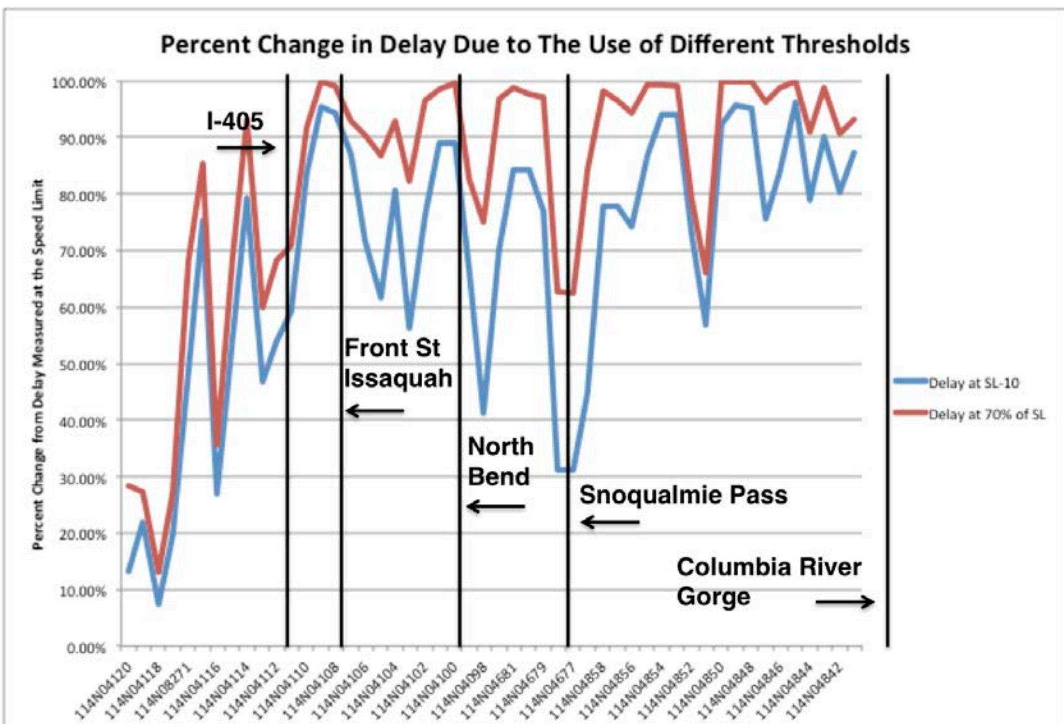

Figure 12: Percentage Change in Delay, Comparing Thresholds of 10 mph Below the Speed Limit and 70 Percent of the Speed Limit

However, on roads that experienced mostly free flow traffic, the added variability (skewed to slower travel times and speeds) in the NPMRDS resulted in delay being reported for many epochs where no delay was actually present. For delay defined as soon as speed drops below the speed limit, the variability in the speeds reported in the NPMRDS data resulted in the computation of a modest amount of delay. As the threshold dropped lower, fewer NPMRDS data points fell below that threshold value. And thus, the amount of delay dropped to zero or nearly zero. Consequently, the percentage change from the amount of delay computed at the speed limit was quite high.

On TMC segments with significant grade changes, the fact that slower moving trucks reported GPS speeds below the speed limit resulted in additional epochs in the NPMRDS data where reported speeds were low or moderately low. This both increased the total delay being reported (even when there was no congestion) and meant that a higher proportion of the time epochs reported speeds slower than even the lower threshold limits of the $Delay_{70}$ statistic. Consequently the percentage change in the size of reported delay fell between the moderate change observed on congested urban segments and the very high percentage change observed on free flow rural segments.

Comparison of NPMRDS Delay Estimates with Delay Estimates Based on the NW Region Inductance Loops

The Comparison

The above findings beg the question, "How do these estimates relate to the estimates WSDOT currently uses?" This subsection answers that question by comparing the delay estimates obtained from the NPMRDS and TDGO data with estimates produced with the NW Region's inductance loop data.

These comparisons could only be made for urban areas because that is where the NW Region's loops are located. Therefore, comparison was made on the section of I-90 that travels eastbound from I-5 to Issaquah (Front Street). However, the comparison was not perfect because the conflation between the two data sets is not perfect. The western-most TMC segment includes the western-most mainline NW Region loop, but the TMC segment also includes a significant portion of the I-90 roadway that leads from 4th Ave and/or Atlantic Street onto I-90 and past the I-5 roadway (see Figure 13). That road segment includes a large number of slower moving vehicles, as vehicles are still accelerating from the ramps from downtown, as well as exiting from the I-90 roadway to both north- and southbound I-5. The project team suspects that the NPMRDS data also include speed reports from a large number of vehicles that are on the ramps leading from I-5 to I-90. The result is that this TMC segment—while overlapping the NW Region's first segment (which is located to the east of the I-5 mainline and does not include any ramp traffic)—contains a lot of delay that is not reported by the NW Region data.

The eastern end of the corridor is also different. The last WSDOT loop used in this analysis is located at milepost 17.48. This extends the computation of delay about one half mile short of the roadway included in the comparison TMC segments. Therefore, as with the western end of the comparison corridor, the TMC segments will report added delay in comparison to the NW Region data because of the differences in the road segmentation covered by the two systems. However, unlike the western end of the corridor, eastbound delays are modest for this section of I-90.

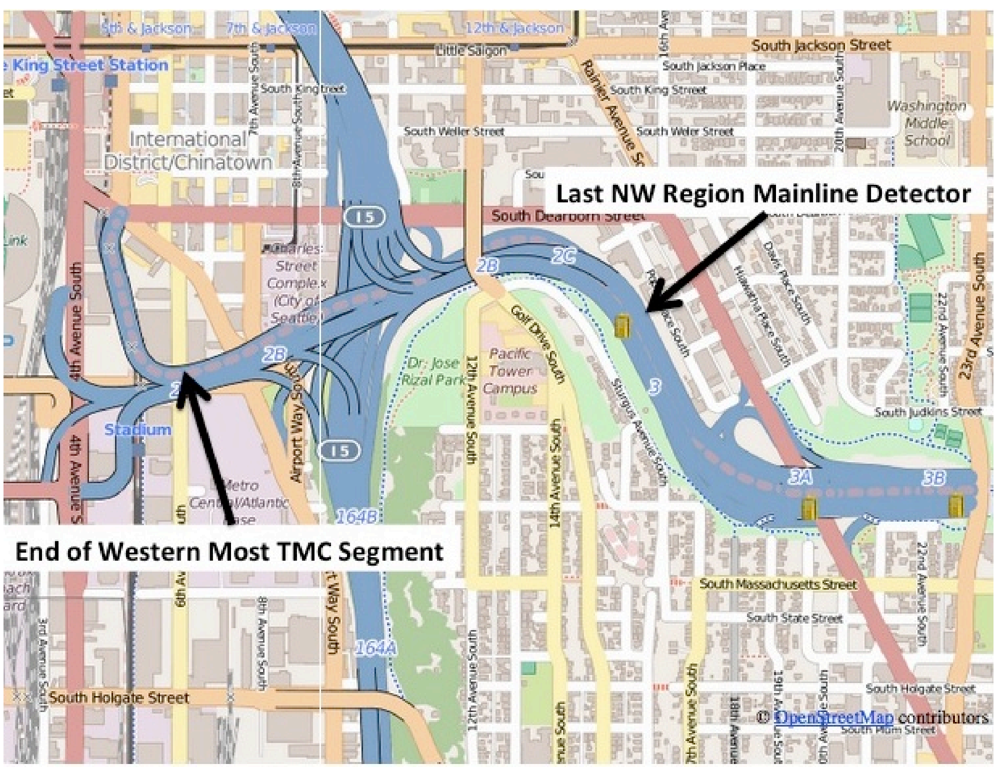

Figure 13: Location of the Western-Most NW Region Data Collection Site versus the Endpoint of the Western-Most TMC Segment

For the delay computations based on NW Region loop data, the NW Region's TRAFFLOW software was used to compute 'average weekday in October 2014' traffic speeds by half-mile interval for every 5 minutes. Total traffic volume, based on the average weekday condition, was also computed for each half-mile interval for each 5-minute period.

Whenever speed dropped below 60 mph, delay was computed as the difference in the travel time reported by the NW Region loop data for that half-mile interval minus 0.5 minutes (travel time for half-mile at the 60 mph speed limit), and that value was then multiplied by the average 5-minute volume for that half-mile segment and time period. The results were then summed for the entire corridor (14 miles) and for all 5-minute periods during the day. The comparison was made only for the eastbound direction of traffic.

Results of the Comparison

Average weekday delay ($Delay_{SL-NWR}$), as computed with the average weekday October 2014 conditions reported by the NW Region loop data, was 42,600 vehicle-minutes. Since there were 23 weekdays in October 2014, the total weekday delay for the corridor, based on the average weekday condition, was 979,400 vehicle-minutes. Using the NPMRDS data to compute an average weekday speed for each TMC segment and 5-minute epoch, and using that speed value to compute whether delay was occurring, the average daily delay computed at the speed limit was 174,700 vehicle-minutes even if the western- and eastern-most TMC segments were left out of the computation. (This made the TMC segment corridor one-half mile shorter than the NW Region corridor, but it removed the overly large delay occurring on the western-most TMC segment. The eastern-most segment was dropped because it is 1.5 mile long and would make the NPMRDS segment over a mile too long.) This NPMRDS-derived value was more than four times the delay derived from the NW Region loop data.

Table 6: Comparison of Delays Computed with NW Region Loop Data and NPMRDS/TRIPS Data

Data Set Used	**Computed Delay Speed Limit Threshold $Delay_{SL}$ (Veh-Min)**	**Computed Delay 70% of Post Speed Threshold $Delay_{70}$ (Veh-Min)**
NW Region Loops	42,600	8,600
NPMRDS & TRIPS	174,700	67,900

If instead of using $Delay_{SL\text{-}NPMRDS}$, we used $Delay_{70\text{-}NPMRDS}$ for the comparison, we got an estimate of 67,900[16] vehicle-minutes of delay for the average weekday in October. This was still more than 50 percent more delay than was measured by the NW Region loops, even when the 60 mph speed limit was used as the threshold for the NW Region loops and was compared to the delay from the NPMRDS using the lower 70 percent of posted speed threshold.

It is clear that in urban areas, the added variability in the NPMRDS data results in a substantial increase in the amount of delay that will be estimated and reported in comparison to the delay reported from the NW Region loop data. Further investigation is needed to evaluate whether the same level of dramatic difference exists in delay values computed with loop detector data and NPMRD data at other locations of the Interstate system in Washington.

Comparison of Vehicle Miles of Travel Estimates from the TDGO Data and the NW Region Inductance Loops

The differences in delay reported using these two different data sets resulted not just from differences in the variability of the NPMRDS speed values. Differences also exist between the volume estimates developed from the TDGO data and the volume data from the NW Region. To examine these differences, VMT estimates were computed for the two data sets. Note that the VMT comparison also had to consider the differences in corridor length between the two different roadway segmentation systems.

In fact, VMT does not change as dramatically as delay at either end of the corridor, so the segmentation length differences did not result in differences as significant as to the effect on the delay values of including or removing the western-most segment of the I-90 roadway.

VMT was computed for one specific day, October 2, 2014, from both the TDGO data set (processed as described in Chapter 1) and the NW Region Loop data. The TDGO data set produced a corridor-wide, daily VMT estimate of 921,000 vehicle miles. The VMT estimate from the loop data was 869,000 (roughly 6 percent lower than the TDGO based value).

[16] File: NPMRDS Avg Wkday Spd_VMT_Delay.xlsx – on \Home\tracmark\
This value assumed the “short” corridor definition—segment 114N08270 through 114N04107. If we used the entire corridor, as defined by the NPMRDS, then delay in the corridor increased to 118,118 on the average weekday.

Table 7: Comparison of VMT Estimates between NW Region Loop Data and TDGO TRIPS Data

Data Set Used	**October 2, 2014 VMT**	**Average Weekday VMT October 2014**
NW Region Loops	869,000	837,000
TDGO TRIPS	921,000	870,000
Percent Difference	6%	4%

VMT was also computed for all of October. VMT computed for just the first 13.95 miles of the TMC segments using the TDGO data resulted in a value of 870,000 vehicle-miles for the average weekday. The NW Region data computation for 14 miles was 837, 000 vehicle-miles for the average weekday in October. If the TDGO VMT computation was shifted eastward so that the approximate 14.0 miles being examined ended at the TMG segment that includes Front Street, then the VMT estimate grew slightly to 881,000 vehicle-miles for the average October weekday.

These results suggest that the TDGO volume estimation process produces a VMT estimate for the corridor that is similar to, but slightly greater than, the value produced by the NW Region. The TDGO value appears to over-estimate the NW Region VMT value by between 3 and 6 percent. This represents a small fraction of the over-estimation seen in the delay computation, indicating that the majority of the delay over-estimation results from the difference in the NPMRDS and NW Region speed data, not the TDGO and NW Region traffic volume data.

Comparison of Aggregated and Disaggregated Delay Computation Methods

WSDOT has traditionally estimated delay and lost productivity on the basis of average weekday conditions. This was initially done because the aggregation process limited the CPU time needed for the computation and because the aggregation process limited the impact of missing data. Unfortunately, the use of average weekday statistics under-values weekend congestion, which occurs frequently on some rural Interstate segments, and it under-estimates the delay effects of holiday traffic.

Therefore, the project team decided to examine the impacts of using a disaggregated approach to delay computation (i.e., computing delay for each 5-minute time period) versus performing those computations with average operating conditions (e.g., computing delay with an average speed for a 5-minute epoch across every Monday in the data set).

In the traditional aggregated method, the average weekday speed, travel time, and traffic volume are computed for each road segment and 5-minute time epoch. Then average delay for each epoch is computed from those aggregated statistics. Thus, delay only occurs when the average speed for a given epoch falls below the threshold speed. When the average speed falls below the threshold speed, delay is computed, it is summed across all time periods of the day, and that value is then multiplied by the number of weekdays in the month to get total monthly delay.

In the second method, delay is computed for each day's epochs. These delay values are then added to compute total daily delay. The daily values are then added to compute total delay for weekdays for that month, or the daily delays can be averaged to estimate average weekday delay for the month.

A comparison of the delay computations that resulted from these two methods is shown in Table 8. Using delays computed with a speed limit threshold ($Delay_{SL}$), the average daily delay computed by averaging the daily delay computations was 183,000 vehicle-minutes. If the average condition was computed first, and then that average condition was used to compute delay, then the total delay per day was 174,000 vehicle-minutes. This is only about 5 percent less than the delay computed with each individual day's roadway performance.

Table 8: Comparison of Delay Computations

Data Set Used	**Computed Delay Speed Limit Threshold $Delay_{SL}$ (Veh-Min)**	**Computed Delay 70% of Post Speed Threshold $Delay_{70}$ (Veh-Min)**
Daily Delay is Computed and then Averaged	183,000	95,000
Average Monthly Conditions Computed and then Delay is Computed	174,000	68,000
Percentage Difference	5%	40%

For the $Delay_{70}$ value, however, the methodology had a much bigger impact. Computing the delay on a daily basis and then averaging the daily values yielded a delay of 95,000 vehicle-minutes, while $Delay_{70}$ for the average condition was only 68,000 vehicle-minutes, a change of almost 40 percent.

As shown in these numbers, computing delay on the basis of each day's road performance will increase the reported delay because delay that occurs in non-routine locations will be captured. When average monthly or annual travel conditions are used as the basis for computing delay, these bad days are frequently cancelled out by multiple good days during those periods. As a result, the average speed does not fall below the threshold value, and no delay is computed.

The major advantage of computing the average condition is that it handles missing data more easily. The NPMRDS data, in particular, are randomly present (except for very short segments, which tend to have little data). The missing data are assumed to be similar to the data present, and thus, the average condition is a good estimate of the population mean unless a large amount of data is missing. When delay is computed on a daily basis, more complex data replacement algorithms are needed. These typically involve the assumption that conditions during epochs that are missing data are similar to those immediately before and after the missing epoch. This is a reasonable assumption except during periods when conditions change rapidly.

In order to more closely match the NW Region loop data, it would be better to base delay on the average condition. However, computing delays on a daily basis would be the better approach for tracking the effectiveness of WSDOT's operational improvements. It is the recommended approach for freeways once the NPMRDS data improve in quality and quantity.

Comparison of Frequency of Congestion Outcomes

For this analysis, the NPMRDS data for weekdays in October 2014 were used to compute the frequency of congestion during the 3-hour AM peak period (6:00 AM through 8:59 AM), 6-hour midday period (9:00 AM through 2:59 PM), and 4-hour PM peak period (3:00 PM through 7:00 PM). For the test, frequency of congestion was computed as the percentage of 5-minute epochs that fell below the threshold. The threshold used by NW Region is 19 percent lane occupancy. This correlates to approximately 45 mph, given the typical volume to capacity on urban freeways. For the NPMRDS data, two separate values were tested, 35 mph and 45 mph.

Because congestion is highly localized, the test was performed by matching specific TMC segments to the NW Region mileposts that correlate to those TMC segments. Table 9 presents the results of this comparison.

Not surprisingly, the NPMRDS data showed the same basic patterns in the locations where congestion frequently occurs. In general, the larger the congestion (e.g., see segment 114N04113) problem observed by the NW Region loops, the closer the NPMRDS frequency of congestion value was to the NW Region value. And the NPMRDS value based on the 35 mph threshold was more closely aligned to the NW Region loop data than the 45 mph threshold.

The two data sets did not match well for locations where the NW Region data did not show frequent congestion. For example, starting in the middle of Mercer Island (starting with TMC segment 114N04114), the NW Region data showed very little congestion except in the PM peak period. And even in the PM peak period, the frequency of congestion was well below 10 percent. However, the NPMRDS data continued to show significant congestion in all three time periods. The cause of this discrepancy is the same as the cause of the added delay computed when the NPMRDS data are used. The NPMRDS has a number of data points that fall below the 35 or 45 mph thresholds. These data are simply slower than the speeds reported by the NW Region loops.

Table 9: Comparison of Frequency of Congestion Results, NW Region Loops versus NPMRDS

TMC Segment	114N 04119	114N 04118	114N 08271	114N 04117	114N 04116	114N 04115	114N 04114	114N 04113	114N 04112	114N 04111	114N 04110	114N 04109	114N 04108	114N 04107
AM Peak														
NW Region	55%	55%	13%	2%	3%	3%	2%	2%	0%	0%	0%	0%	0%	0%
NPMRDS 35 mph	58%	73%	35%	6%	4%	5%	6%	14%	12%	2%	1%	0%	0%	1%
NPMRDS 45 mph	65%	75%	71%	25%	6%	14%	16%	31%	21%	8%	2%	0%	0%	2%
PM Peak														
NW Region	11%	11%	5%	7%	10%	6%	4%	6%	1%	6%	3%	2%	4%	3%
NPMRDS 35 mph	12%	19%	15%	11%	21%	25%	7%	22%	19%	7%	24%	2%	4%	3%
NPMRDS 45 mph	22%	26%	40%	14%	24%	33%	23%	41%	32%	20%	36%	7%	9%	12%
Midday														
NW Region	9%	9%	2%	2%	2%	0%	1%	1%	0%	0%	0%	0%	0%	0%
NPMRDS 35 mph	5%	8%	8%	1%	3%	3%	2%	5%	5%	1%	1%	0%	0%	1%
NPMRDS 45 mph	11%	9%	28%	3%	4%	9%	6%	14%	11%	5%	2%	0%	0%	2%

CHAPTER 4: RECOMMENDATIONS AND NEXT STEPS

CONCLUSIONS AND RECOMMENDATIONS

The National Performance Research Monitoring Data Set (NPMRDS) provided by FHWA has several major data limitations that need be accounted for before being used to compute performance measures: 1) limited size of vehicle sample and many missing data points; 2) the reported speeds much more variable than actual roadway performance; and 3) bias toward slower speeds. The project team recommends to the Freight Systems Division the following actions for using the NPMRDS:

- NPMRDS may be used for computing delay on Interstates and other freeways, but it overestimates actual delay because of the high level of speed variability in NPMRDS data as well as its bias towards slower speeds.
- We recommend computing truck delay based on a performance threshold of 70 percent of posted speed on the Interstate system to minimize the NPMRDS data limitations
- Delay values should be used primarily to compare the relative size and timing occurring within the freeway system, but should <u>not</u> be used for trend analysis over multiple years. At this time we do not recommend using NPMRDS data in computing truck freight delay because it is still evolving, and the trends observed in the data will more likely be the result of changes in the dataset rather than a result of actual trends in roadway performance. The data source must improve to enable WSDOT to use it to track truck delay and meet MAP-21 performance reporting requirements.
- The WSDOT may use the NPMRDS to compute frequency of congestion statistics for roadway segments that are one mile in length or shorter because the travel time data from NPMRDS for longer segments reflects the average condition and could “hide” congestion occurring on a small portion of the segment.
- As with the delay computations, frequency of congestion results computed with the NPMRDS should primarily be used for analyzing when and where congestion is occurring. The NPMRDS data should <u>not</u> be used to compute multi-year trends in the frequency with which congestion occurs.

- Delay should be reported on a segment basis separately for cars and trucks.
- Delay and frequency of congestion should be reported by month and for weekdays and weekends separately.
- Both the $Delay_{70}$ and frequency of congestion statistics with using the NPMRDS likely over-estimate the actual delay occurring with a threshold set at the speed limit due to its data limitation.

Additional work needs to be performed with the NPMRDS data, testing different approaches to computing travel times, before definitive conclusions and recommendations can be made regarding the computation and reporting of travel time and reliability. At this time, the preliminary recommendations to be confirmed or further refined are as follows:

- Travel times should be computed at the 15-minute interval level, rather than the 5-minute level, to reduce the impact of missing data. This means averaging the available 5-minute epoch travel time/speeds into a single 15-minute value, and then computing travel times every 15 minutes.
- Three different travel times should be computed: cars, truck travel times for trucks that have power-to-weight ratios that do not limit their speed on hills, and travel times for trucks that are restricted by low power-to-weight ratios.
- Travel time reliability (80^{th} percentile and 95^{th} percentile travel times) should also be computed from these 15-minute interval travel times.

NEXT STEPS

This project completed the design and testing of the basic performance measures process for truck performance on Interstates in the state of Washington. A number of additional steps need to be taken before WSDOT can create performance measures for the entire state. The first of these improvements will be to code the algorithms developed into the DriveNet software system, which must also routinely download and make available the NPMRDS and traffic volume data that drive the system. In addition to the work described above, the following tasks need to be completed before WSDOT can produce these measures statewide:

1) Work with FHWA to obtain a significantly improved version of the NPMRDS.
2) Determine the average travel time of heavily loaded trucks on segments where trucks have slow travel times because of power-to-weight ratio limits.

3) Code the travel time algorithms described in this report.
4) Test and refine the travel time algorithms, with specific attention paid to the ability to compute travel times for heavily loaded vehicles.
5) Determine the accuracy of arterial travel times from the NPMRDS data.
6) Determine the availability of NPMRDS data on "last mile" segments of importance to the Freight Systems Division.
7) Determine how to extend the volume count estimation process to state routes that are not monitored by a specific PTR that can be used to estimate changing traffic volumes by day of week and time of day.
8) Extend the refined volume count process into DriveNet.

Each of these tasks is discussed briefly below.

Work with FHWA toward an Improved Version of the NPMRDS

FHWA is aware that the NPMRDS may be unable to meet the MAP-21 performance monitoring needs for which it was purchased. WSDOT has the opportunity to weigh in on how the NPMRDS needs to be improved to meet those monitoring needs.

Determine the Slow Power-to-Weight Travel Time Segment Travel Times

The WSDOT Freight Systems Division wants to be able to compute trip turn times—and their reliability—for key freight movements. This can only be achieved if it is possible to estimate the time that a heavily loaded truck takes to make that trip. This is why the project team developed the computation for restricted power-to-weight limited travel time. While the concept is good, and it is possible to identify TMC segments that frequently contain slow truck travel times while simultaneously exhibiting fast travel times, the project team has not yet proved that it can develop the required power-to-weight ratio limited travel times for those segments. It is important that this process be constructed, tested, and verified.

One way to verify estimates derived from the NPMRDS data would be to use the GPS data currently available to TRAC from Trimble. This would likely allow us to compute both origin-to-destination travel times and segment-specific travel times for some epochs that can be used to validate the NPMRDS data.

Code the Travel Time Algorithms Described in This Report

Once it is clear that these 'slow trip segments' can be identified, the travel time algorithm that uses these specific, segment-long travel times must be coded within DriveNet.

Test and Refine the Travel Time Algorithms

It is important that the DriveNet travel time computations be validated. The best way to perform such a test for truck travel times is to use the GPS data that TRAC maintains as a result of the Freight Systems Division project that tested the use of GPS for monitoring freight performance.

Determine the Accuracy of Arterial Travel Times Derived from the NPMRDS Data

This project did not examine the accuracy of the NPMRDS data off of the Interstate system. Performing those tests and determining how the NPMRDS can be used on signalized arterials will be necessary before performance metrics can be extended to those roadways.

Determine the Availability of NPMRDS Data on Last Mile Segments

The WSDOT Freight Systems Division is concerned about origin-to-destination travel times. A key part of those travel times is the time spent on local connectors leading to the actual freight origins and destinations. Some of these route segments have been included in the NHS as key intermodal connectors. WSDOT needs to determine which last mile connectors need to be monitored and then determine whether those last mile connectors are part of the NPMRDS data set.

If those connectors are not part of the NPMRDS, the Freight Systems Division will need to determine what the options are for collecting those data and whether the value of those data is worth the cost of collecting them.

Extend the Volume Count Estimation Process to Non-Interstate Roads

The volume count estimation process for Interstates takes advantage of the fact that permanent counters are located on all of the Interstate freeways. This allows the performance monitoring process to estimate traffic volumes by day or year and time of day. Most state routes do not have this type of data. It is therefore necessary to develop and test a process for taking the available WSDOT permanent count data and transforming them so that traffic volumes by day of week and time of day can be estimated accurately for those state highways.

Extend the Refined Volume Count Process into DriveNet

Once the process has been developed, it will be necessary to code that process within the DriveNet.

APPENDIX A: EXAMPLE PERFORMANCE REPORTING

This chapter presents example performance reports for Interstates for 2014. The actual data tables will be provided to WSDOT upon request. The basic graphic shown is for the annual truck delay for weekdays in 2014. The graphics illustrate delay per mile, in units of vehicle-hours of delay. The graphic format chosen is a scatterplot showing the milepost (X-axis) at the start of the TMC segment versus the delay per mile. This allows WSDOT to determine where freight delays are most significant.

Also shown on these graphics is the relative importance of different time periods (AM peak, versus, midday, PM peak, or night time periods. Figures A-1 through A-10 show the total weekday truck delay ($Delay_{SL}$) occurring on Washington Interstate freeways.

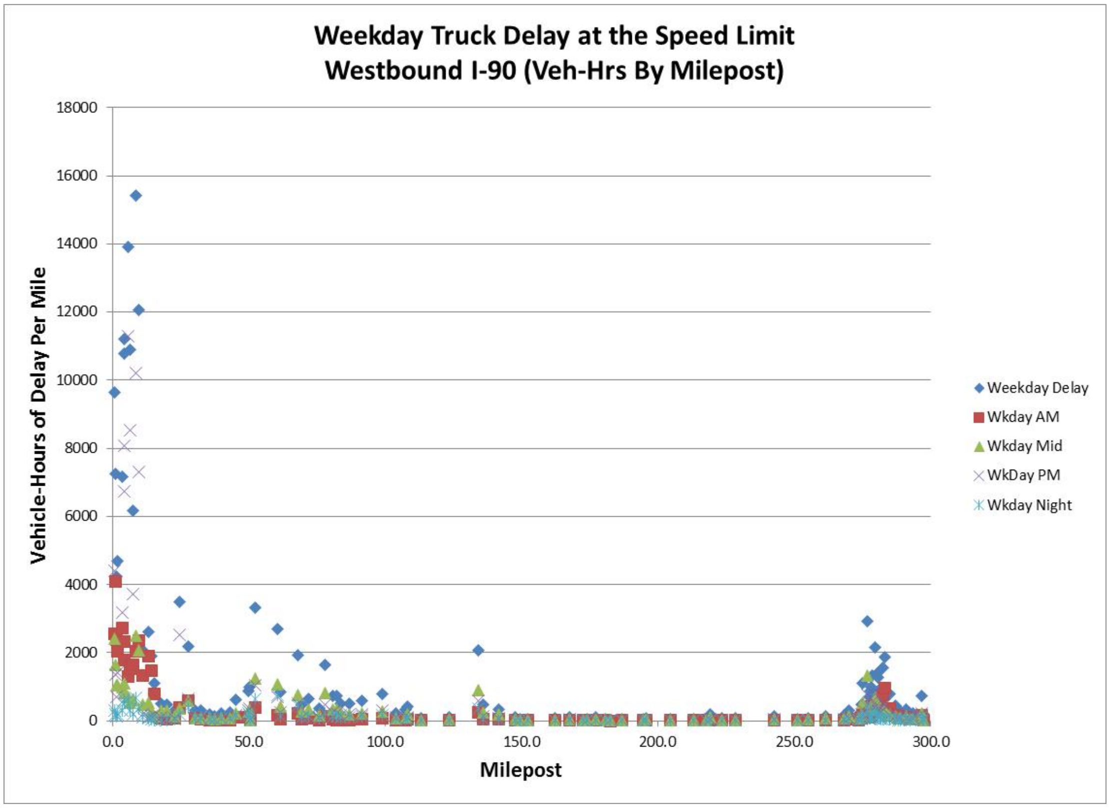

Figure A-1: Annual Weekday Truck Delay on Westbound I-90

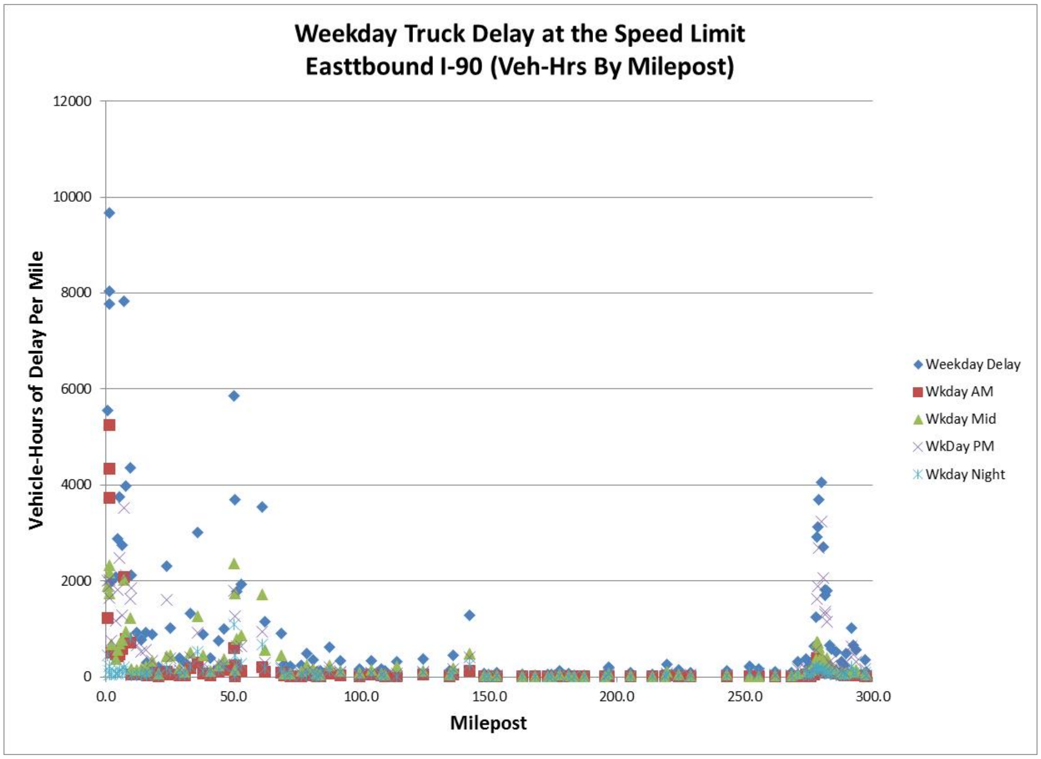

Figure A-2: Annual Weekday Truck Delay on Eastbound I-90

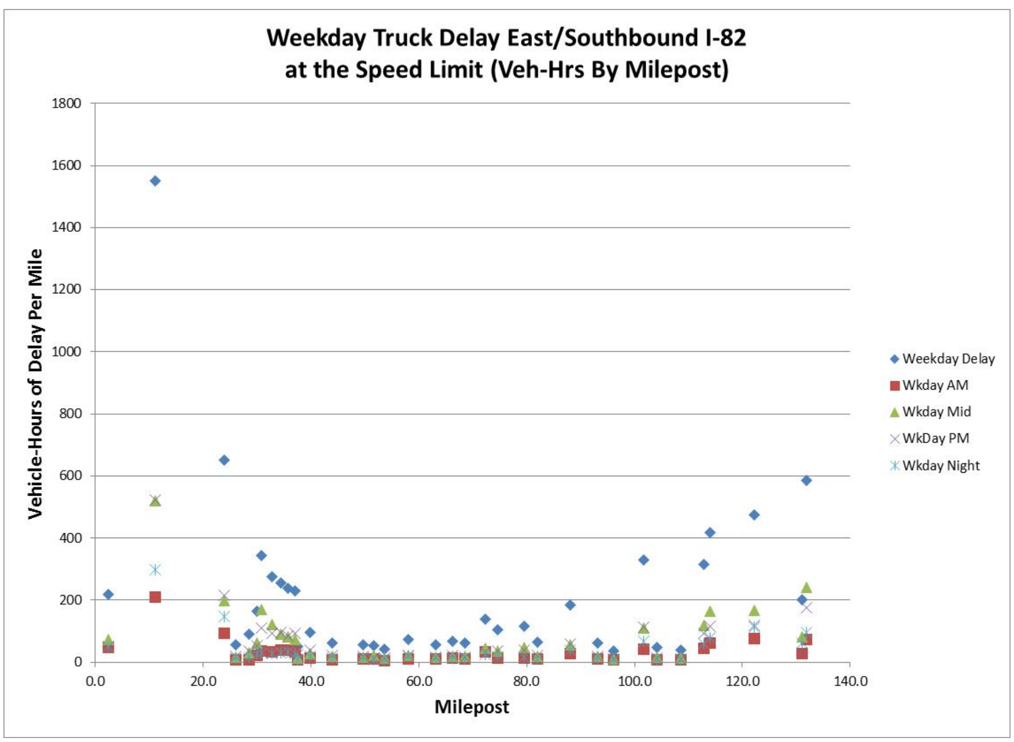

Figure A-3: Annual Weekday Truck Delay on Eastbound I-82

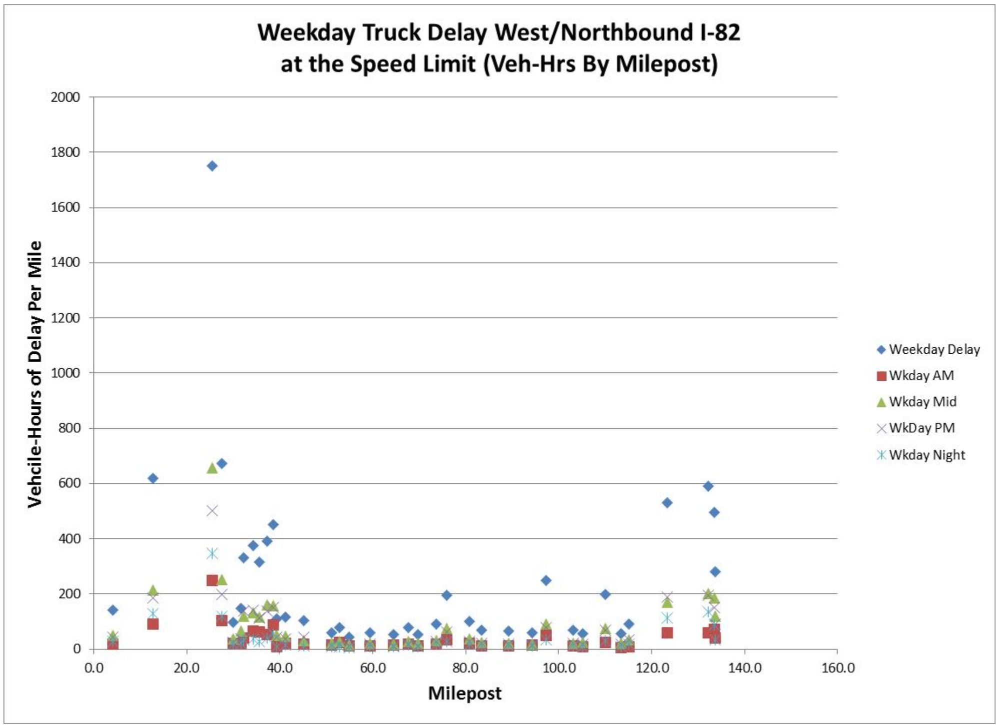

Figure A-4: Annual Weekday Truck Delay on Westbound I-82

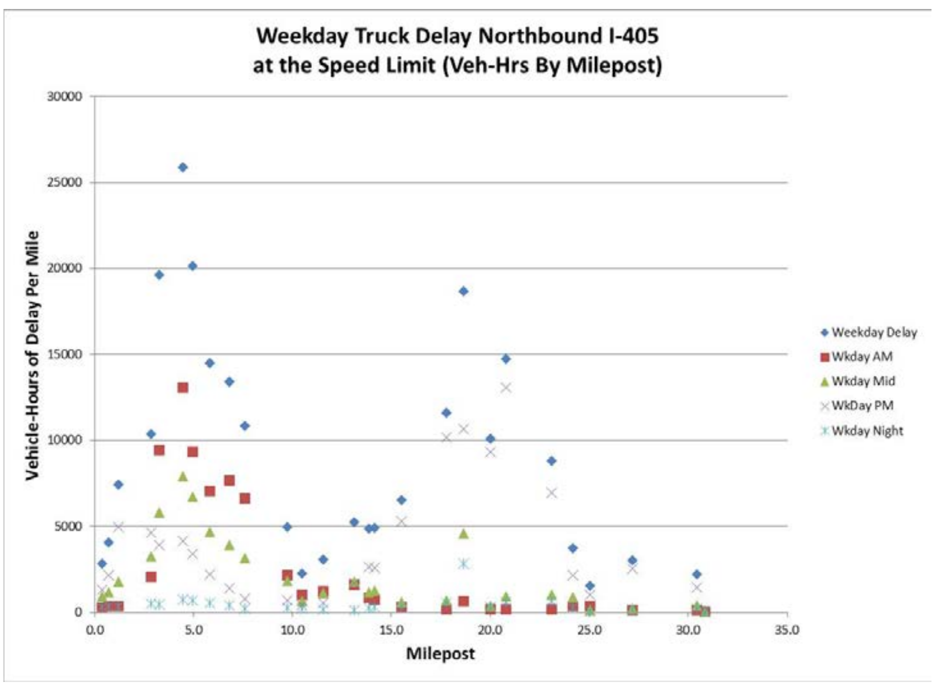

Figure A-5: Annual Weekday Truck Delay on Northbound I-405

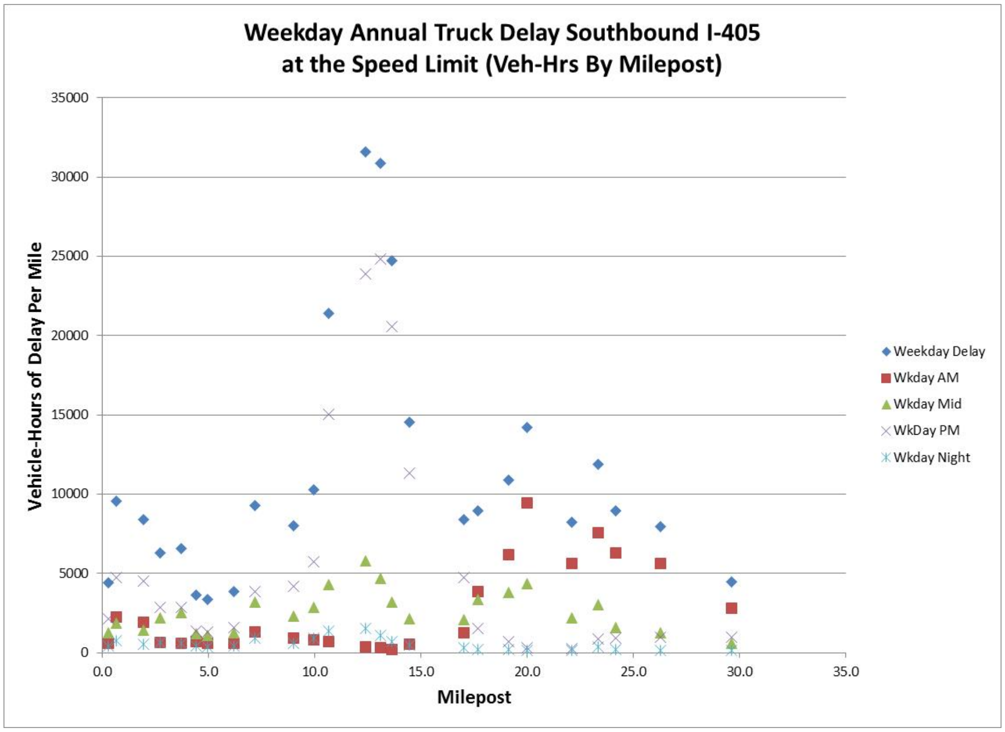

Figure A-6: Annual Weekday Truck Delay on Southbound I-405

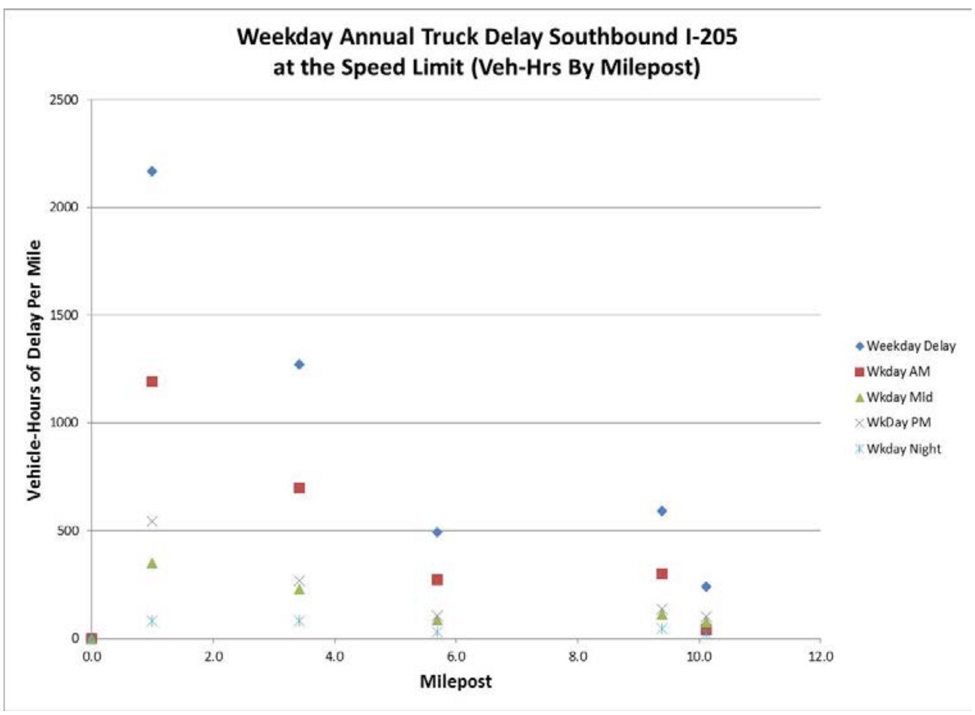

Figure A-7: Annual Weekday Truck Delay on Southbound I-205

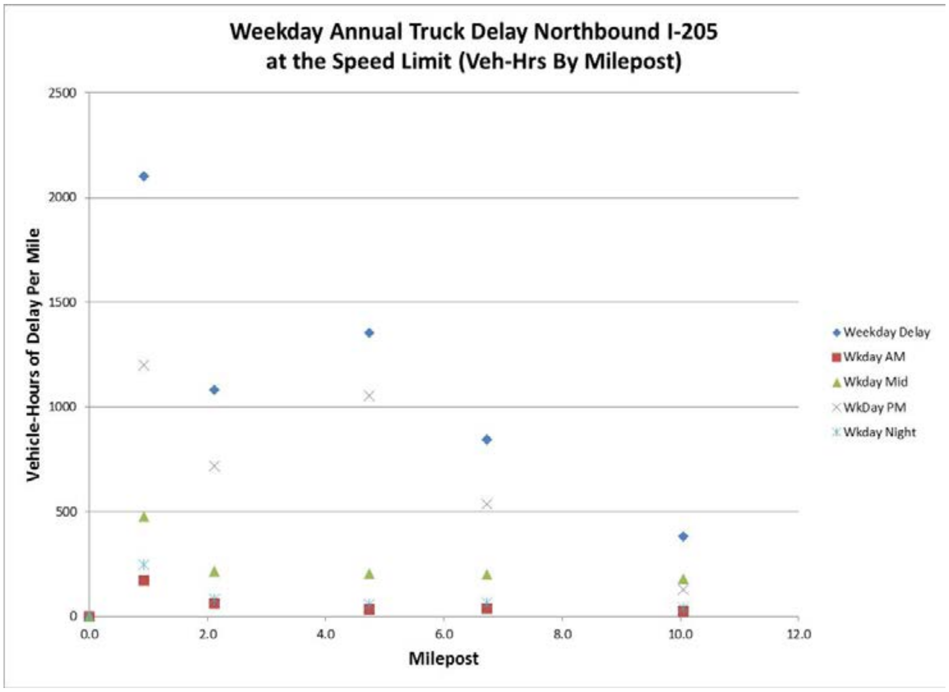

Figure A-8: Annual Weekday Truck Delay on Northbound I-205

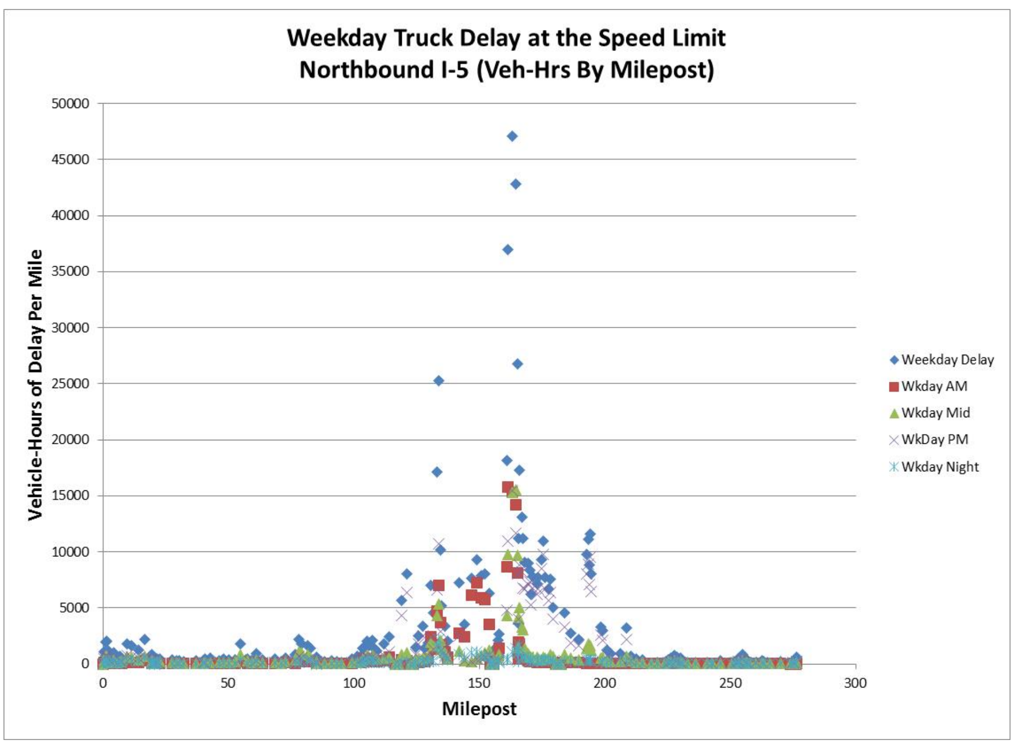

Figure A-9: Annual Weekday Truck Delay on Northbound I-5

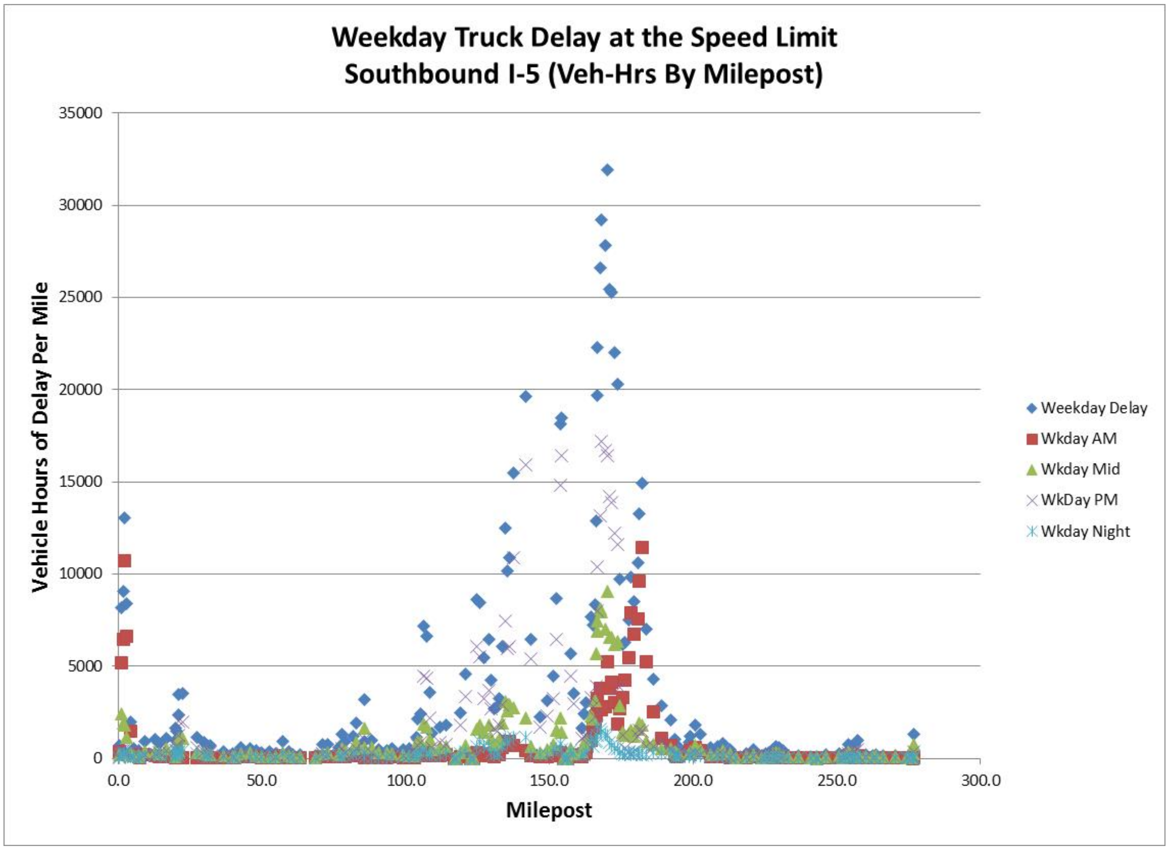

Figure A-10: Annual Weekday Truck Delay on Southbound I-5

Not all delay occurs on weekdays. Thus, it is also useful to analyze the amount of delay which occurs on weekends. Figure A-11 shows an example of how total annual weekday delay can be compared to total annual weekend delay. Figure A-12 shows this same weekday/ weekend comparison for northbound I-5 using the 70 percent of posted speed delay computation. Figure A-13 shows a close up of northbound I-5 from milepost 210 to 231, using the 70 percent of posted speed delay computation to illustrate how some road segments see more weekend delay than weekday delay. Figure A-13 helps illustrate the need to scale graphics to see some of the interesting details possible in the delay analysis.

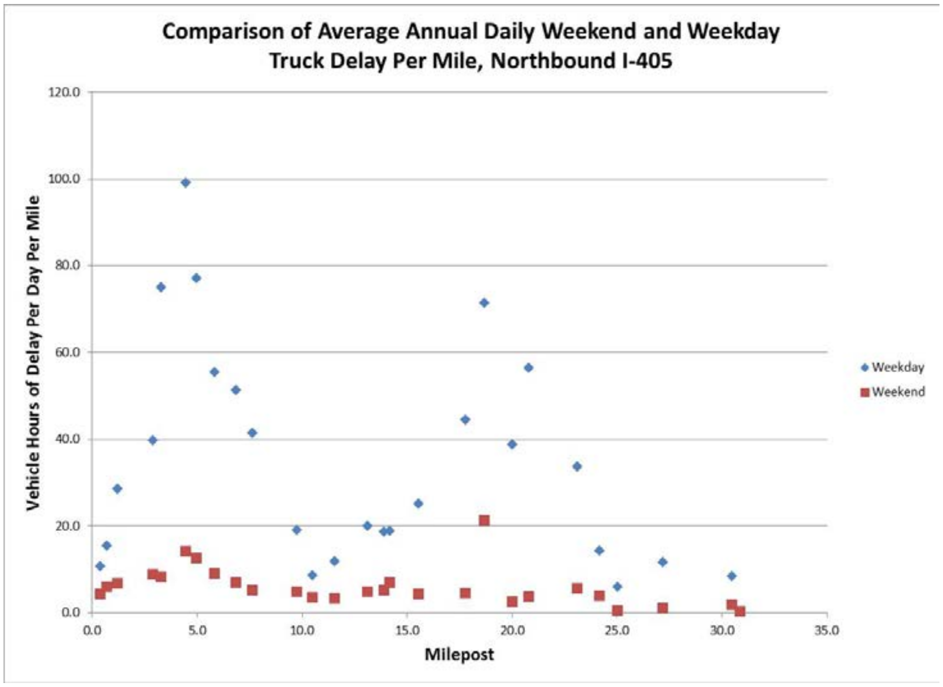

Figure A-11: Comparison of Annual Weekday and Weekend Truck Delay on Northbound I-405

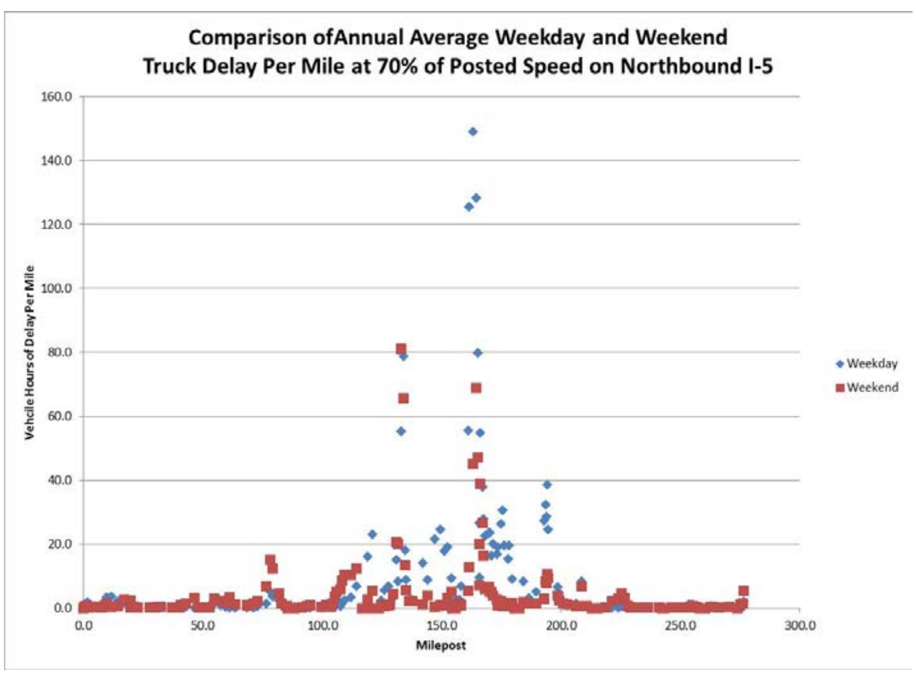

Figure A-12: Comparison of Annual Weekday and Weekend Truck Delay on Northbound I-5 Using the 70 Percent of Posted Speed Threshold

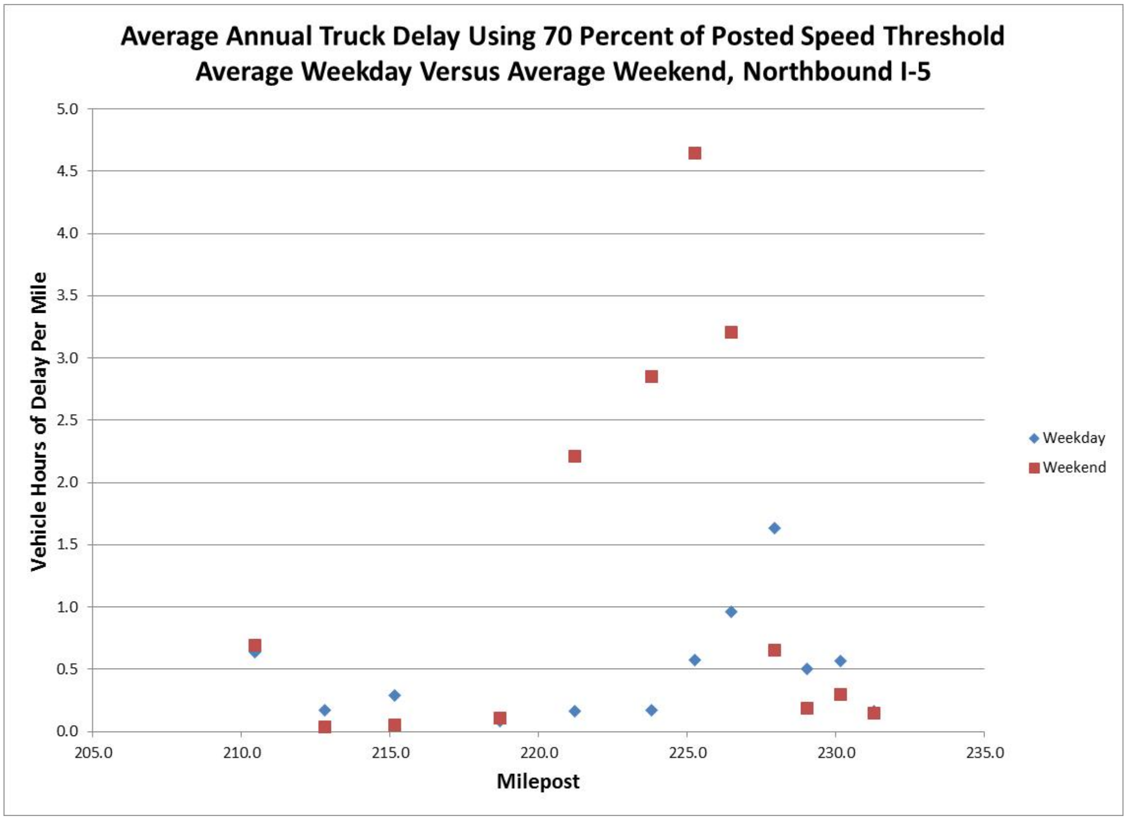

Figure A-13: Comparison of Annual Weekday and Weekend Truck Delay on Northbound I-5 Using the 70 Percent of Posted Speed Threshold

Additional clarity for these graphics would occur if additional information on the location of mileposts was included as part of the graphic. (A graphic that can be incorporated in these graphs for this specific purpose has not yet been developed.)

While the total amount of delay occurring by time of day is important, sometimes we are interested in the rate at which that delay is occurring. Figure A-14 illustrates how annual weekday delay by time period can be expressed as an hourly value (e.g., Average Hourly Delay Per Weekday Per Mile, versus Total Hourly Delay Per Weekday Per Mile. Comparing Figure A-14 with Figure A-4 gives a somewhat different appreciation for the relative importance of when delay is occurring, as it accounts for the fact that the AM peak contains a small number of hours relative to the midday time period.

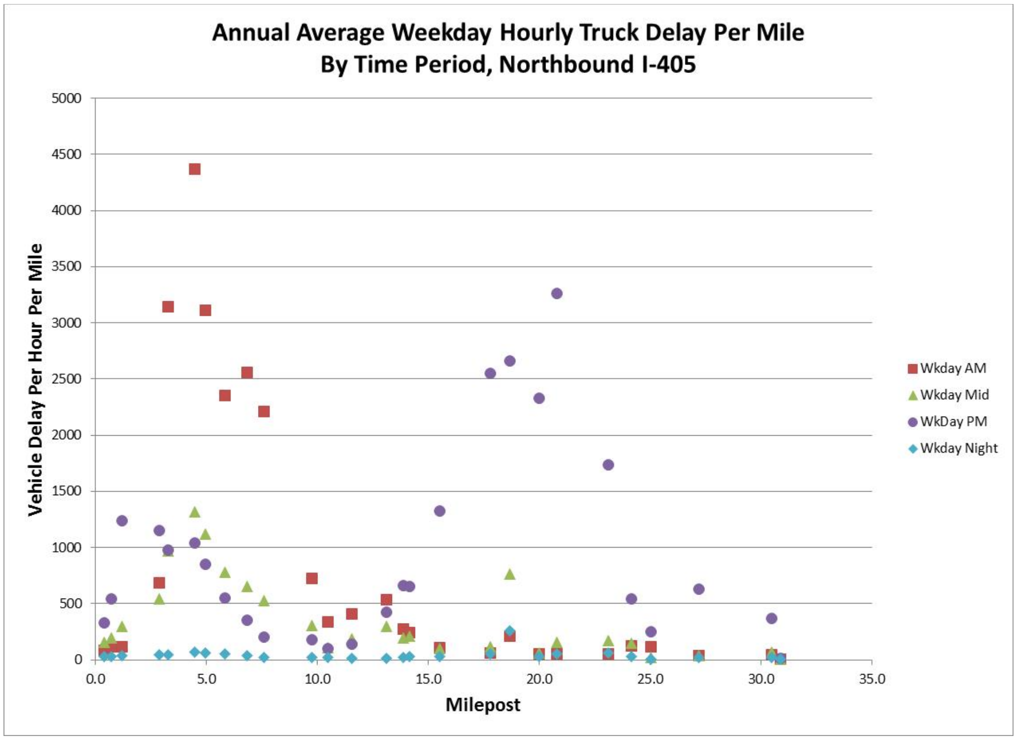

Figure A-14: Comparison of Weekday Truck Delay per Hour on Northbound I-405

APPENDIX B: USE OF TDGO DATA TO COMPUTE 5-MINUTE EPOCH VOLUME DATA ON INTERSTATE FREEWAYS

INTRODUCTION

In order to use the NPMRDS data to compute vehicle-delay, it is necessary to obtain traffic volume data to match with the NPMRDS speed and travel time data. The data used for this purpose need to be available for all state routes.

The selected source for these data is the TDGO. The TDGO maintains a series of count programs which produce data that can be used for this purpose. Existing data collection and processing steps performed by the TDGO produce AADT and AADTT values for every road segment on every state highway. In addition, the TDGO operates a significant number of permanent counters that provide data on the variation of traffic volumes by time of day and day of year.

From these existing processes, the TDGO can produce two files which are used for input in the computation of volume data which can be matched against NPMRDS travel time and speed data. These are data from permanent counters (called PTRs at WSDOT) and the AADT and AADTT estimates available for every 1/100th of a mile for each state route. This second file is called the "Miletraf" file at the TDGO. The PTR data file is generated as a special request.

To support the computation of volume data for use with the NPMRDS on interstate roadways, the TDGO provided a third file which assigns each 1/100th of a mile of roadway to a specific PTR. The PTR data is used to determine the time of day and day or year variation in traffic occurring on the roadway. For the Interstate system in Washington, it is possible to assign every Interstate road segment to a specific PTR, because each of these roads has a PTR that can be reliably used to provide time of day and day of year variation data for that road segment. This is not possible for all state routes. Thus, additional steps will be needed to develop detailed traffic volume data off the interstate system.

Finally, it is necessary to access the NPMRDS conflation table which describes the starting and ending mileposts for each TMC segment.

TDGO FILE DESCRIPTIONS

The TDGO provides four files. The Miletraf file provides AADT and the percent of that AADT which are single unit trucks, the percent which are double unit trucks, and the percent which are multi-unit trucks. By combining these percentage values, and multiplying the total truck volume times AADT it is possible to compute AADTT for each $1/100^{th}$ of a mile for each state route.

The TDGO also provided – and will need to maintain – a file which assigns a PTR counter to each mile of freeway. This file lists the name of the PTR, the route the PTR is located on, the starting milepost of the road segment to which is assigned and the ending milepost of the road segment to which it is assigned. This file is referenced in this appendix as the "PTR Assignment File."

The next file contains the detailed volume data collected by each of the PTRs on interstates. The PTR data file contains all of the hourly traffic volume data (by count location, leg, and direction) which has passed the TDGO data quality checks. For this initial computation of delay, only total volume was used. It is possible to use a subset of PTRs that also collect truck volume data by hour in order to compute truck volume patterns independently from total volume. However, because many PTRs do not collect truck volume data, this would require both a second PTR-to-roadway milepost table, and a significant reduction in the number of PTRs which can be used to measure time-of-day and day-of-year variability. This project chose to use more PTRs and a single assignment table. This decision was made because the limitations found in the NPMRDS data made it unlikely that the effort required to compute truck volume specific time of day and day of year volume patterns would result in significant improvements in the accuracy of the delay estimates computed with those volume data.

All of these files can be currently obtained from the TDGO by submitting a written (e-mail) request.

COMPUTATIONS

Miletraf File

As noted above, the AADT and truck percentage data in the Miletraf file must be used to compute AADTT. This is done for each $1/100^{th}$ of a mile for all interstates. The computation is:

$$AADTT = AADT * (\text{single unit truck percent} + \text{combination truck percent} + \text{multi-unit truck percent})$$

The AADTT value is then stored as an additional variable in the Miletraf file.

<u>Use the PTR Data to Compute Average Hourly Volume by Day-of-Week for Each Month</u>

All computations are performed by leg, by direction, by count location.

For all days of data available in a month, compute **<u>average hourly volume by day of week by month</u>** (that is, compute the average number of vehicles observed at 1 AM on all Mondays in January, then the average number of vehicles observed at 2 AM on all Mondays in January, etc. then progressing on to all hours and all days of the week, for all months of the year.) Ignore missing data to compute the simple average by hour by day by month. So, for every hour "h" compute that hour's traffic as the average of the available data for that hour and day of week for that month.

$$AHDWT_{hij} = \frac{1}{n}\sum_{k=1}^{n} HCT_{hijk}$$

Where:
AHDWT = Average traffic volume for hour "h" for day of the week "i" for month of the year "j"
n = the number of days of the week (i) in the month (j) that have valid data for hour "h" (usually four or five, unless some days of the week have missing data)
HCT = hourly traffic volume for hour h for day k of day of week i

<u>Compute AADT for Each PTR (by Leg and Direction) from the Average Hourly Volume by Day of Week by Month Statistics</u>

Compute average annual traffic (**<u>AADT)</u>** for each permanent counter by leg and direction.

Sum the 24 hourly volume for each average day of the week and month to get average daily traffic by day-of-week and month-of-year.

Compute AADT as the average of the 12 months of 7 day of week values.[17]

$$AADT = \frac{1}{7}\sum_{i=1}^{7}\left[\frac{1}{12}\sum_{j=1}^{12} ADWTV_{ij}\right]$$

where:

[17] Where sufficient data re not available to compute AADT in this manner, the AADT will be computed using the default supplied by the TDGO.

AADT = average annual daily traffic

ADWTV = Average daily traffic volumes for each day of week i, and month of year j

(Annual averages are computed in this manner to avoid the minor differences in AADT and monthly factors caused simply by having different numbers of weekend days in a month from year to year. It also provides a simple mechanism for limiting bias in the AADT calculation caused by missing data.)

Compute the Fraction of Traffic Occurring for Each 5-minute Epoch for Each PTR by Leg and Direction

For each permanent counter, compute the **fraction of annual average daily traffic,** that occurs during each 5-minute epoch of the year at that PTR. Where no hourly data are available (e.g., the PTR did not report valid data during a specific time interval), the average hourly volume for that hour for that day-of-week, for that month will be used to estimate the missing 5-minute value. The fraction of traffic for each 5-minute epoch is computed as follows:

$$FCT_{hd\text{-}epoch} = (Totalvol_{hd} / AADT) / 12$$

Where:

FCT = the ratio of actual traffic volume to AADT occurring in a given epoch (five minute period) for hour "h" for day "d"

Totvol = the hourly volume measured for hour "h" for day "d"

h = the hour of the day

d = the day of the year (can be expressed as day of month + month)

The result of these computations is a file which contains for each leg and direction for each permanent counter, an estimate of the fraction of average annual daily traffic which occurs in each 5-minute period of the year.

Compute AADT and AADTT for Each TMC Segment

For this task, the starting and ending milepost for each TMC segment is obtained from the WSDOT NPMRDS conflation table. The AADT and AADTT for each TMC segment is then computed by averaging the AADT and AADTT values from the Miletraf file for each $1/100^{th}$ of a mile within that segment. The output is the AADT and AADTT value for each TMC segment (by direction.) (Note that AADT and AADTT need to be directional volumes. If they are not directional volumes, divide both values by 2.)

Assign Each TMC to a PTR

For this task, first compute the location of the midpoint for each TMC segment. This is done by adding the beginning milepost from the NPMRDS conflation table and the ending milepost from the conflation table and dividing that value by two.

Use that midpoint to look up which PTR is assigned to that location

Compute 5-minute Epoch Volumes for Each TMC Segment

The five minute volumes for every day for each TMC segment are computed by using the PTR Assignment File to look up which PTR (leg and direction) is assigned to the milepost that is the midpoint of each TMC segment.

The 5-minute fraction of AADT for each epoch for each day of the year for that PTR (and leg and direction) is then multiplied by the AADT and AADTT for that TMC segment. This yields the 5-minute epoch traffic volume and truck volume for each epoch of the year.

These volumes are then used in the delay calculations.