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Agreement T1461 Task 37
Delay Computation

Review of Travel Data Collection and Analysis Process for Delay Calculations Statewide

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16. ABSTRACT

WSDOT produces and uses estimates of vehicle delay on state highways throughout the state. Large swings in delay computed on some roads and in some corridors by the current statewide delay process resulted in the decision to review the performance of that system. As a result, this project was undertaken to examine the causes of these wide swings in reported delay and to determine possible courses of action for WSDOT. The project reviewed the software used to produce those delay estimates, the input data sets used in those computations, and the steps followed to generate those data sets.

This report recommends changes to the delay computation process.

The report describes several different approaches that could be adopted by WSDOT to compute vehicle delay. It makes recommendations for WSDOT's consideration. The best option is a function of the funding available to WSDOT and the other uses for the data needed to drive each of those various approaches to delay computation.

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EXECUTIVE SUMMARY

WSDOT produces and uses estimates of vehicle delay on state highways throughout the state. Initially delay estimates were one of several screening tool data items that were used as input to the project identification and prioritization process. Then several years ago, statewide delay estimates were included in the Grey Notebook. In the future they are also likely to be included in MAP-21 performance reporting.

Three different versions of delay computations are produced and used within WSDOT:

1) For statewide analyses, WSDOT uses a spreadsheet calculation based on the Highway Capacity Manual (HCM), as modified using material found in NCHRP 387. This spreadsheet, the Highway Segment Analysis Program (HSAP), bases calculations on Average Annual Daily Traffic (AADT) statistics and estimated 24-hour per day temporal traffic curves produced by the Transportation Data, GIS and Modeling Office (TDGMO), and descriptions of roadway geometry (e.g., number of lanes, width of lanes and shoulders, terrain, etc.) extracted from WSDOT's roadway description database. This is the mechanism that has long been used as input to WSDOT's project identification and prioritization process.
2) For urban freeway corridor reporting, summary statistics from freeway management system data are used to produce corridor-specific delay and lost-productivity statistics.
3) For detailed project analyses, more detailed, highway capacity analyses are performed, or detailed travel time statistics are often collected by using probe vehicle data (typically collected with automated license plate readers or WiFi/Bluetooth sensors). When project-specific HCM calculations are performed, mathematical equations similar to those of the statewide computations spreadsheet are used, but site-specific, detailed traffic data are collected as part of the project to ensure the accuracy of the specific project analyses.

Internally within WSDOT, concern has been expressed about the reliability of the statewide delay numbers because of very large swings in delay computed by the current system on some roads and in some corridors. As a result, this project was undertaken to examine the causes of these wide swings in reported delay and to determine possible courses of action for WSDOT in the future.

CONCLUSIONS

The HSAP program WSDOT currently uses to produce statewide delay estimates has significant methodological limitations. These are compounded by limitations in the data that are input to the system and restrictions on making changes to segmentation that have been placed on the computations in recent years.

The HSAP spreadsheet has some modest technical errors, but those errors are not the primary cause of the variation observed in year-to-year delay estimates. The primary cause of that variation is limitations in the technique inherent in the spreadsheet. These include limitations in the ability of WSDOT to estimate AADT and estimate and apply 24-hour curves, but they are mostly due to the application of the resulting hourly volumes within the HCM-based delay calculation equations.

Improvements to the HSAP spreadsheet process are possible but will not provide reliable, accurate, transparent estimates of delay on key corridors in the state.

The HSAP spreadsheet can continue to be used as an indicator of where routine volume is likely to cause delay. But it should only be used as an indicator.

There is no "silver bullet" alternative that can serve as an inexpensive replacement for HSAP for production of a reliable, transparent, and accurate statewide delay estimate.

In general, <u>where they are present,</u> traffic management center data can provide the most accurate estimate of actual delay on major urban freeways. This is particularly true where there are HOV and HOT lanes. Unfortunately, these data cover only a portion of the state roadway system. In addition, because of limitations in the budget for maintenance of the sensor network that supplies these data, the use of these data requires application of substantial effort in data quality analysis.

The limitations and cost of building and maintaining fixed sensor networks are leading most state DOTs to move toward the use of vehicle probe data for monitoring the size and scope of roadway delay.

However, vehicle probe data sets, whether obtained for free from FHWA or purchased from private sector companies, still have significant limitations. In particular, they

- do not differentiate between contiguous HOV and general purpose lanes on urban freeways
- are limited in sample size, resulting in many time periods with no data, especially on lower volume roads
- cannot accurately measure delay on arterials with closely spaced signals.

In addition, if vehicle probe data sets are used to determine the timing and extent of congestion formation, WSDOT must still provide volume data to size those delays. This means that WSDOT must conflate the networks used to report vehicle probe data with the WSDOT linear referencing system.

Purchasing private sector data, rather than simply using the free NPMRDS data set, would provide WSDOT with better probe data but at a cost that would need to be determined by the open procurement process. In particular, private sector data would provide better historical speed estimates than the current NPMRDS data set because of limitations FHWA imposed on the private sector vendors when they performed the initial NPMRDS procurement. Purchased private sector data sets would also be expected to have fewer obvious data errors than the initial NPMRDS data sets. In addition, private sector companies could provide WSDOT with better segmentation (i.e., shorter segment lengths) than are present in the NPMRDS network.

Regardless of how WSDOT decides to move forward, additional software processing capabilities will need to be pursued. It can write its own software or purchase access to existing software programs such as RITIS.

RECOMMENDATIONS

The overall recommendation from the project team on how WSDOT should proceed is a function of decisions WSDOT needs to make that are outside the scope of this project. The "best" step forward is a function of both

- the amount of money WSDOT wishes to spend and
- whether the decision is based on the goal of simply producing a better statewide delay estimate or of providing WSDOT with better roadway performance statistics that are used throughout a variety of WSDOT's work procedures.

That is, more accurate and reliable location-specific and statewide delay estimates can be provided by purchasing private sector vehicle probe data, combined with improved access to existing WSDOT traffic management system data. Purchasing additional computing services along with those data, such as providing integration of those probe data with traffic management center data, including incident response statistics, would provide a far more robust analytics platform for use around the state. However, this would be an expensive solution. It would be a good outcome only if WSDOT wishes to have a much more robust analytical capability for use in managing and reporting on its traffic management activities.

Conversely, if the goal were to improve the statewide delay estimates reported while spending as little money as possible, the recommendation would be to create a hybrid reporting system that uses the traffic management system data where they are available, and the HSAP program where those data do not exist.

However, at only slightly greater cost, WSDOT could move to a new hybrid system that relied not on the HSAP program but on the NPMRDS data for non-urban freeway delay estimation. The continued improvement of vehicle probe data means that this is the future of roadway performance reporting, and replacing HSAP with NPMRDS, while slightly costlier initially, would yield long-term benefits that would likely be worth the expense of the change.

The current inability of the vehicle probe data to account for the performance of the HOV and HOT lanes prevents the recommendation that these systems be used where those types of roadways supply major congestion relief. However, outside of the HOV and HOT lane systems, vehicle probe data—whether the free NPMRDS or purchased variety—would provide estimates that were equal to or better than the estimates available through HSAP, and the vehicle probe-based estimates are expected to continue to improve over time, while the HSAP estimates are not.

Table E-1 provides a tabular summary of the various options and the relative rank assigned to those basic options by the project team, given the overall goals that WSDOT wishes to accomplish. A rank of "1" means that, in the opinion of the authors of this report – *given currently available information*, it is the best option for that specific scenario. Ranks of "2a" and "2b" are meant to indicate that two options are essentially equal. Options are ranked on the basis of costs assumed \ by the project team versus the performance of the resulting system in terms of meeting WSDOT's needs for quick and reliable results. Rankings are only given to the best three options. Additional details on actual costs and performance capabilities are needed on some of the more complex options, as these details are beyond the scope of this project.

Table E-1: Summary Recommendations (Option Rankings) Based on Overall WSDOT Goals

	Inexpensive, Statewide Delay Computation	Sketch Planning at the Corridor Level	Detailed Planning	TMC / IR Analytics Statewide
HSAP				
TMC Data where present, HSAP elsewhere	**3**			
NPMRDS with free RITIS	**1**	**1**	**3a**	
NPMRDS & TMC with WSDOT software	**2**	**2b**	**2**	
NPMRDS and TMC Data - UW built software (DRIVENet)		**2a**		**3**
Private Vendor Probe Data Purchase			**1**	
RITIS High End (WSDOT TMC data and private sector included.)				**1**
Other Vendor Software (PEMS? Etc.)		**3**	**3b**	**2**

If the Department desired greater use of corridor-level delay estimates (e.g., in the corridor sketch process), then the Department should definitely move away from HSAP toward the use of vehicle probe data sets. Only with these data sets could WSDOT realistically hope to examine the impacts of seasonal changes in roadway performance. Seasonal congestion is of major importance to the economies of many communities in smaller population communities in the state, and is thus a significant issue for WSDOT to address as it works to meet the goal of statewide economic vitality. In addition, as the use of these data grew, the value of having a more comprehensive software packages would grow. This would result in higher benefit being associated with software purchased from vendors working with multiple agencies, as the cost of those software features could be spread across multiple agencies. The downside of purchasing software services is that they cost money, and in some cases the approach to data processing and reporting used by commercial service providers might not follow WSDOTs procedures. (For example, few if any other states routinely report MT3I statistics, which are a mainstay of WSDOT's reporting procedures.) This would require either a change in WSDOT's procedures or additional cost to add WSDOT's procedures to the existing software's capabilities.

As the WSDOT's goals expanded, the benefits of purchasing private sector data that are "better than" the NPMRDS data would increase. The more data that are used, the greater the value obtained from better input data. The benefits from purchasing additional software analysis capabilities would also continue to apply.

Finally, the ultimate—and most expensive—option would be to integrate private sector data with the traffic management system data. The concept here would be to provide a very robust, integrated data system that allows both improved, real-time management of the roads and easily used, visually informative reporting that can be used to improve planning for system operations—in addition to meeting the current statewide delay reporting needs.

This is the basic concept of the UW's DRIVENet system. However, the funding for DRIVENet has not been at a level that has allowed the development of software with the reporting capabilities of software currently available in the commercial market. Funding such a system would allow WSDOT to tailor the system to WSDOT-specific needs and interests. However, other systems already exist that perform those functions. RITIS, which is used as the core data processing system by both HERE and Inrix, was originally built to manipulate and report on urban sensor data. PeMS was built by the University of California at Berkeley for Caltrans for the same reason. It would be less risky for WSDOT to purchase one of these—or potentially other—existing software solutions than it would be to fund further development of DRIVENet. Use of existing commercial software would also lower the expected cost of the system, given that development costs would be spread across multiple agencies. The downsides of commercial software would be the potential to become reliant on a specific vendor's solution and the likely need to change some operational or reporting procedures to conform to "group norms" rather than writing the software to conform to WSDOT's current or desired procedures and reporting outcomes. The advantage of funding further DRIVENet development would be that WSDOT could direct that development as it saw fit.

Whichever of these approaches best meets WSDOT's needs will be a function of WSDOT's overriding goals, the availability of funding, and the results of vendor responses to WSDOT solicitations.

In the short term, WSDOT staff requested input on how to approach the needs of the Corridor Sketch process. It is the opinion of the project authors that the Corridor Sketch process should initially take advantage of the NPMRDS data for the "identification of performance gaps"

– at least where those gaps relate to the formation of roadway congestion. The NPMRDS, and in particular, the newest version of that data set which will become available by summer 2017 for 2016, should be capable of identifying the major congestion locations in the state. At a minimum, the "free" NPMRDS tools will allow WSDOT to identify these locations at minimal cost. The NPMRDS data can indicate when and where delays are occurring on the vast majority of state routes. Once identified, these initial findings can be discussed with the regional engineers and planners to better understand the causes and significance of those identified delays. That is, don't take the NPMRDS data as "absolute truth" in the Corridor Sketch process, instead use these results to work with stakeholders as part of the Practical Solutions "root cause" analysis that identifies why these delays are being observed, what is causing them, and thus what technical solutions are the best, most cost effective steps to take to improve the corridor's performance. In many cases, these delays may simply not be the priority of the stakeholders, given other performance gaps identified within the corridor. In other cases, the patterns of when and where delays are occurring will identify specific non-geometric improvements that can be quickly applied.

In the end, starting with the NPMRDS allows a good, fairly inexpensive, first cut at identifying where and when congestion is occurring along a corridor. If appropriate, and warranted, those delays can be more precisely quantified. This improved level of quantification ay require additional data collection, but that data need only be collected where the specific performance gap warrants that level of expenditure.

CHAPTER 1: INTRODUCTION

WSDOT produces and uses estimates of vehicle delay on state highways throughout the state. Initially delay estimates were one of several screening tool data items that were used as input to the project identification and prioritization process. Then several years ago, statewide delay estimates were included in the Grey Notebook (GNB). In the future they are likely to be included in MAP-21 performance reporting.

Three different versions of delay computations are produced and used within WSDOT:

1) For statewide analyses, WSDOT uses a spreadsheet calculation based on the Highway Capacity Manual (HCM). This spreadsheet, the Highway Segment Analysis Program (HSAP), bases calculations on Average Annual Daily Traffic (AADT) estimates produced by the Transportation Data, GIS and Modeling Office (TDGMO), estimated 24-hour per day temporal traffic curves, and descriptions of roadway geometry (e.g., number of lanes, width of lanes and shoulders, terrain, etc.) extracted from WSDOT's roadway description database. This is the mechanism that has long been used as input to WSDOT's project identification and prioritization process.
2) For urban freeway corridor reporting, summary statistics from freeway management system data are used to produce corridor-specific delay and lost-productivity statistics.
3) For detailed project analyses, more detailed, highway capacity analyses are performed, or detailed travel time statistics are collected by using probe vehicle data (typically collected with automated license plate readers or WiFi/Bluetooth sensors). When project-specific HCM calculations are performed, mathematical equations similar to those of the statewide computations spreadsheet are used, but site-specific, detailed traffic data are collected as part of the project to ensure the accuracy of the specific project analyses.

Internally within WSDOT, concern has been expressed about the reliability of the statewide delay numbers because of very large swings in delay computed by the current system on some roads and in some corridors. For example, in the 2015 Corridor Capacity Report

(CCR), delay in the south Puget Sound region, driven primarily by delay reported on I-5, was shown to more than double between 2012 and 2014. The delay statistics from the CCR report are shown in Table 1.

Table 1: South Puget Sound Regional Delay Reported in the 2015 CCR

Year	Delay in Thousands of Hours	Year to Year Percentage Change
2010	1,470	
2011	1,080	-27%
2012	795	-26%
2013	1,145	44%
2014	1,627	42%

Note that the change from 2012 to 2014 is 105 percent. This is a combination of both reported delay in 2012 being 35 percent lower than the delay reported in the second lowest year, and the reported 2014 delay being the highest by more than 10 percent.

As a result, this project was undertaken to examine the causes of these wide swings in reported delay and to determine possible courses of action for WSDOT in the future.

REPORT ORGANIZATION

This report is divided into the following chapters:

- a description of the current statewide delay computation process
- a discussion of the traffic data collection and data processing steps that feed the current statewide delay calculation process
- a summary of strengths and limitations of the current process
- a description of possible ways to improve or replace the current statewide delay calculation process
- project conclusions and recommendations.

In addition, the Appendix describes the specific Highway Segment Analysis Program spreadsheet that is used to compute statewide delay. The Appendix is simply a duplication of documentation maintained at WSDOT that was written in 2009. Readers interested in more documentation on the HSAP program should obtain the report *Highway Segment Analysis Program Documentation*, written by Gary Westby in June 2008, which should be available from the WSDOT library.

CHAPTER 2: CURRENT STATEWIDE DELAY CALCULATION PROCESS

PROCESS DESCRIPTION

The current process WSDOT uses to compute statewide delay for the WSDOT Corridor Capacity report is the Highway Segment Analysis Program (HSAP). HSAP is a complex Excel spreadsheet with macros that was developed by a number of people including, but not limited to, Gary and Karl Westby in 2008 and later updated in 2009 by the Capital Program Development Management Office. It relies on formulas published in the 1994 and 1997 editions of the Highway Capacity Manual, as adapted to estimate travel delay for use in a variety of FHWA's planning software systems, including STEAM (Surface Transportation Efficiency Analysis Model), HERS (Highway Economic Requirements System), and IDAS (ITS Deployment Analysis System). These same basic techniques were used by the Texas Transportation Institute for its early versions of the Urban Mobility Report.

The HSAP spreadsheet was initially deployed as part of the WSDOT project identification and prioritization process. It was specifically intended to identify roadway segments that are either currently likely to experience route traffic congestion or—given an assumed growth condition—will experience routine congestion in the future. Delay values computed for both current and forecast conditions are then used as a starting point for further analysis at those locations as part of the project identification, design, and prioritization process.

HSAP FUNCTIONALITY AND LIMITATIONS

HSAP Functionality

The basic HSAP technique relies on equations published in the 1990 editions of the Highway Capacity Manual. These equations estimate roadway segment speed by comparing hourly traffic volumes to estimates of roadway capacity. Roadway capacity is determined on the basis of a variety of roadway geometry features, including but not limited to the following:

- terrain (level, rolling, mountainous)
- number of lanes
- width of lanes
- existence and size of shoulders
- existence of traffic signals and their spacing.

The data for these values are extracted from the WSDOT GIS system. A specific software program was written to extract these data and summarize the available data by roadway segment. Segments can be predefined (e.g., the Highway Performance Monitoring System segments) or defined on the basis of factors selected from the inventory data stored in the GIS. For example, segments can be created each time pavement type changes, or each time the number of lanes changes, or at every on- or off-ramp.

Segmentation is an integral part of the HSAP program. Ideally, given the desire to compute delay values on the basis of the HCM mathematical approach, a defined segment has consistent geometric features and constant volume for the entire length of the segment. In practice, especially for roads with uncontrolled access (i.e., driveways and side streets), larger segments often contain changes in volume.

Where changes in either geometric features or volume occur, the HSAP program uses the average condition for the segment. For example, if half of a segment has three lanes and half has four lanes, then the capacity computation uses 3.5 lanes.

The HCM (and thus HSAP program) performs its calculations at the hourly level. Therefore, the input needed to estimate delay is hourly traffic volumes for each segment. To obtain hourly traffic volume estimates, the HSAP program relies on two data sources, the MileTraf file and a large number of 24-hour time-of-day traffic curves. Both of these data sources are extracted from the TDGMO traffic database system. The MileTraf file provides an estimate of Average Daily Traffic (AADT) every 1/100th of a mile for all state routes. This file is produced each year as part of the annual process within TRIPS and is used as input to a number of WSDOT management systems, such as the pavement management system.

The 24-hour time-of-day curves provide estimates of the percentage distribution of that daily traffic volume over the 24 hours of each day. The 24-hour distribution curves are directional, reflecting travel in a specific direction on each road segment. Examples of two of these curves are shown in Figure 1. One curve illustrates a segment of I-5 that has a morning peak period, but that peak period is extended over multiple hours, reflecting the spread of the peak commute period as a result of congestion. Afternoon traffic volumes are much lower than those found in the AM peak, with little or no peak. The second curve is taken from a fairly rural section of SR 2. It shows a very peaked morning travel spike. This peak is likely a reflection of local, unconstrained commute traffic.

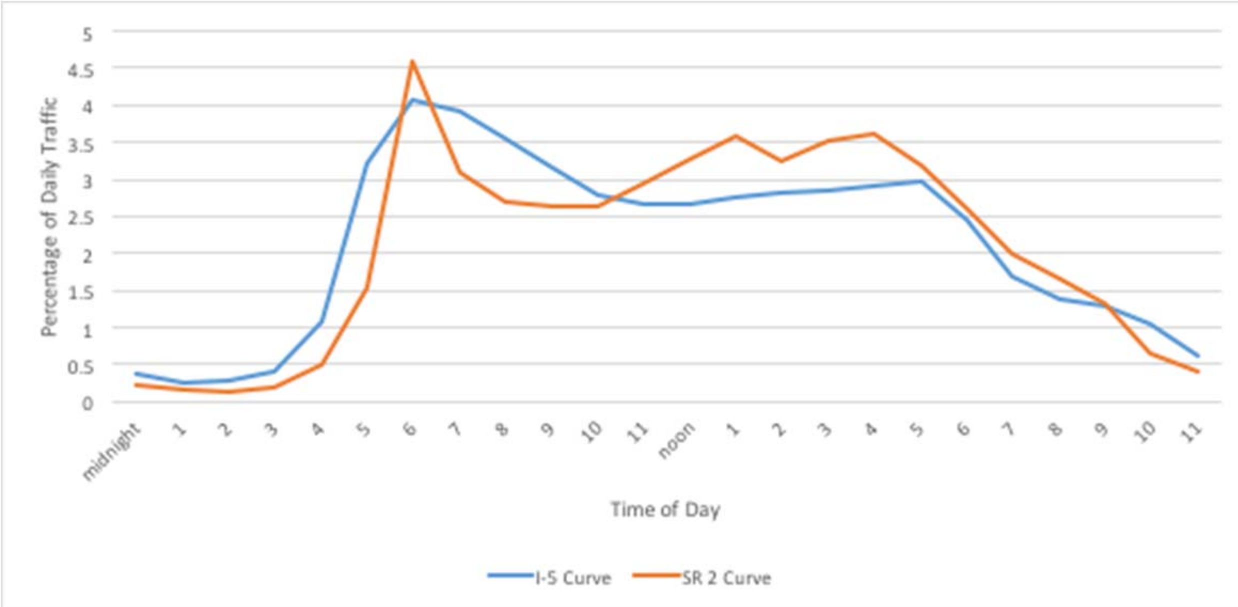

Figure 1: Example 24-Hour Time of Day Traffic Distribution Curves

HSAP currently has over 6,000 24-hour, directional traffic distribution curves. The curves must reflect directional traffic volumes because the highway capacity formulas reflect only one direction of travel. The large number of curves included in HSAP is intended to provide the best possible description of traffic patterns on each roadway segment. The curves are developed primarily from the Department's permanent traffic recorders (PTRs), supplemented by data from short duration counts, where needed. The curves are designed to provide the best available estimate of actual traffic volumes that occurred on each road segment. The 24-hour curves include the directional split on each segment.

This approach differs markedly from that used by TTI, which uses a small number of 24-hour curves. In the TTI model, one of a limited number of 24-curves is assigned to each road segment on the basis of an assumed level of congestion. The TTI approach is simpler but loses the ability to directly account for site-specific traffic patterns. On the other hand, the TTI approach is necessary when limited information is available to describe site-specific traffic patterns or where the goal is to not estimate actual traffic volume but vehicular demand.

The WSDOT approach attempts to use as much site-specific information as can be extracted with reasonable effort from the existing traffic databases. This provides more site-specific accuracy but greatly increases the complexity of the data extraction and update effort.

When combined (the MileTraf AADT multiplied by the fraction of traffic in each hour taken from the 24-hour curves for that segment), the two data sources provide an estimate of hourly traffic volume for all roads in the state. The data collection and processing steps followed to generate the MileTraf and 24-hour data sets are described in the next chapter.

The HSAP process initially computes roadway capacity on the basis of the averaged geometric values extracted from the WSDOT GIS. These values are computed separately for mainline, reversible, and auxiliary lanes, with the additional capacity for auxiliary and reversible lanes added to the base mainline capacity.

Each of the 24-hour (directional) volumes is then used to compute the existence of delay on the segment. If traffic volume significantly exceeds capacity, the "extra" volume is then pushed to the next hourly interval to estimate the impacts of limited roadway capacity on peak spreading.

The HCM formulas are then used to estimate average speed by hour of the day for the average weekday condition. The computed average speed value for each hour is used to compute average travel time for the segment. Speeds are limited to free flow speed. The average travel time is then compared to the travel time at the posted speed limit for the segment to estimate travel delay by hour for each segment for the average weekday of the year.

Where estimated travel time exceeds the travel time at the posted speed, that time is multiplied by the traffic volume during that hour to computed the delay (veh-hours) on that segment for that hour. This process is performed for all segments in the state for all 24 hours of the average day. These values are then multiplied by average vehicle occupancy values to estimate total person hours of delay. They can also be divided into truck and car delay by multiplying the hourly volumes by the percentage of trucks for each segment. (Note: the percentage of trucks is a single value for each segment. It does not account for differences in truck volumes by time of day.)

These hourly values are then summarized by corridor, WSDOT region, county, or other variable.

HSAP Limitations

Routine Volume Delay versus Total Delay

The HSAP process has a number of limitations. The biggest limitation is that the HSAP process models average weekday conditions. The average weekday condition is a poor representation of actual delay when delay is not caused by weekday commute volumes. Therefore, HSAP does a poor job of estimating seasonal, recreational, and event-related delays. Similarly, HSAP does not account for delays caused by incidents or weather conditions. As a result, HSAP will likely under-estimate statewide delay, unless other limitations inherent in the model (see below) create over-estimation errors that cancel out the under-estimation errors.

In general, the HSAP limitations do not detract from the originally intended use of the HSAP approach. That is, HSAP is capable of identifying locations that are at risk of experiencing routine congestion, both currently and at some point in the future. While it may miss some segments where modest amounts of delay are or will occur, and it may over-estimate other locations where delay is occurring or will occur, those errors are of only limited importance in the overall project identification and prioritization process. For example, other aspects of the Corridor Sketch process—or other aspects of the project identification process—are expected to identify locations where delay caused by incidents, weather, and seasonal or event traffic create delay problems that need to be addressed.

Where those types of delays are experienced, corridor- or project-specific data collection and the application of other mathematical techniques can estimate the size of delays caused by those factors. These techniques are applicable on a site-specific, case-by-case basis. They are not applicable for a statewide, sketch planning tool, in large part because the data needed to support them are not available for all state highways.

Nevertheless, even when used for computing average weekday traffic volume delay, the HSAP process—and in particular the actual spreadsheet equations—have limitations.

Limitations in HCM Equations and Their Application

The HCM equations and their extensions were developed at a time when detailed roadway performance (i.e., vehicle speed or volume) data were available on very few roadway segments. The equations were therefore designed to be used for making "best available data estimates" in an environment where few data were available. Therefore, they rely on readily available summary data points and statistical models. The planning model equations (e.g, the BPR curve) included in NCHRP report were designed for use with planning model outputs which frequently predicted volumes that exceed actual roadway capacity, a fact which does not happen in reality. While this reliance allows the computation of delay for all WSDOT road segments, the accuracy of the outputs is constrained by the assumptions inherent in those equations, the inability to account for conditions occurring at individual roadway segments that are different from the conditions assumed in the HCM equations, and the underlying variability in traffic performance that is hidden within the summary equations published in the HCM.

For example, roadway capacity is computed on the basis of one specific set of HCM equations. These equations do not directly account for the geometric complexities of many of the roadways WSDOT operates. They can't—because they are generalized equations applied nationwide across a variety of conditions, and the conditions on WSDOT-controlled roads may not have been present on the road segments from which the HCM traffic models were derived.

The equations in the HSAP attempt to account for some of these limitations by allowing for HOV lanes, reversible lanes, and auxiliary lanes. The presence of these roadway features are extracted from WSDOT's GIS and entered into the spreadsheet. The roadway capacity of these specific lane types are computed independently of the general purpose lanes and then added to the roadway's base capacity.

While the basic data flow internal to the spreadsheet does work as intended for auxiliary and reversible lanes, it does not work for HOV lanes. In addition, only one time-of-day plan is present for the WSDOT-operated reversible lanes, whereas those conditions are subject to change on a day-to-day basis for incident conditions. In addition, the capacity equations do not account for the actual roadway performance of these types of lanes. For example, no effort is made to adjust those capacity values for the loss of capacity in all lanes that is caused by vehicles merging into and out of HOV lanes from the general purpose lanes. (This is commonly called "friction" and has been studied by WSDOT with respect to how friction has changed the performance of SR 167 as a result of moving from controlled access High Occupancy Toll (HOT) operations to uncontrolled access.) Therefore, the capacity of the general purpose lanes is likely to be over-estimated by the HCM equations when HOV lanes are present.

Similarly, the spreadsheet does not specifically account for lower roadway capacity near ramps that is caused by merging activity. It does not account for changes in capacity caused by the effects of ramp metering protocols. It does not take into account incident-caused congestion, and it does not take into account the effects of the WSDOT incident management program. It also does not account for the effects of weather on capacity. Finally, it does not account for the fact that the use of "average conditions" under-estimates total delay in comparison to the computation of delay on a day-by-day basis before it is aggregated to total annual delay.

Another reason that errors occur is that congested urban freeways experience a volume drop during congested operation. That is, under congested conditions, actual roadway capacity declines. This is not accounted for in the spreadsheet, although a feature in the model does allow the capacity used in the delay computation to be lowered by a fixed amount for fixed AM and PM peak periods. These percentage reductions must be manually coded, and are applied for all hours in the peak period for those segments for which these adjustments are manually assigned. Figure 2 shows a graph of average weekday traffic volume on I-405, northbound at SE 52nd St. Volume (throughput) declines considerably during the peak period, as illustrated by the yellow and red colors of that line. (Yellow represents an average speed of less than 55 mph, but more than 45 mph. Red represents an average speed of less than 45 mph.) This decline is not caused by lowered demand. It is caused by lowered roadway capacity caused by congestion.

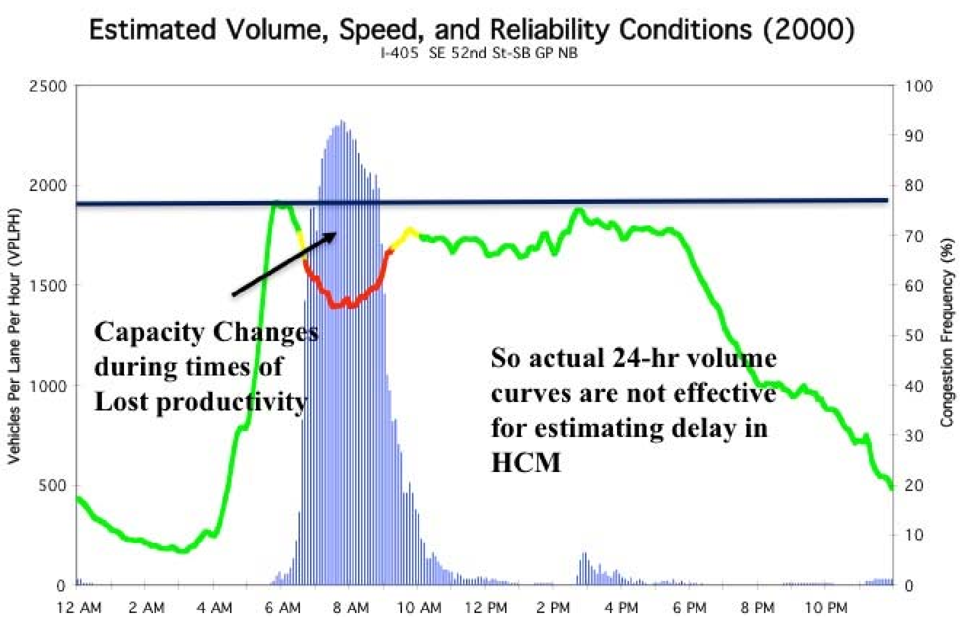

Figure 2: Illustration of Throughput Reduction Due to Congestion

When the actual observed volumes are placed into the HCM equations, these lowered volumes produce delay estimates that are considerably lower than the HCM equations are intended to produce. This is because the equations use a fixed capacity value (even if fixed at lower levels during the peak periods), and therefore lower volumes produce a lower volume to capacity ratio, which results in higher speed estimates and lower delay. In the field, during congested conditions, the opposite is the case: lower volumes reflect lower speeds, and thus greater delay. The HSAP spreadsheet is not capable of modeling these changes in actual throughput capacity. The only "solution" would be to assume a demand curve that represents the "desired" traffic volume demand, as opposed to the actual, measured volume patterns imported into the HSAP spreadsheet. This would leave the spreadsheet reliant on assumptions about unconstrained levels of demand, with little research available upon which to base those curves, especially as conditions change over time in response to regional growth.

Limitations Caused by the Use of Annual Average Conditions

The HSAP spreadsheet uses average annual conditions, as opposed to actual daily conditions. This results in an under-estimation of actual delay on the roadway. This subsection describes a test performed for this project that illustrates this point. The test used NW Region freeway operations data to compute delay statistics on both a daily and aggregated basis. The same data were used for both computations. The only change was whether the roadway performance statistics (volumes and measured speeds) were used to compute daily delay values and then totaled and converted to an average daily statistic, or the roadway performance statistics were averaged, and then that average was used to compute an average delay.

The test corridor was I-405 from milepost 0.5 to milepost 10.5. This is basically Tukwila to the I-90 interchange. This corresponds closely to one specific segment in the HSAP spreadsheet given to the project team by the TDGMO.

The test was performed both for weekdays only and for all seven days of the week. The tests were performed for a four-month period, with northbound and southbound directions computed separately.

Table 2 presents the results of this test for weekdays only. Table 3 presents the results of the test when for all seven days of the week. A 50 mile-per-hour threshold was used as the basis for the delay calculation (that is, no delay occurred unless speeds fell below 50 mph). All delay computations were based on 5-minute volume and speed statistics extracted from the TRACFLOW data archive.

Table 2: Comparison of Averaging Daily Delays versus Computing Delay from Average Daily Conditions: Weekdays Only

	Average Daily Delay Computed from Average Conditions	Average of Delay Statistics Computed from Daily Conditions	Percentage Difference
Northbound	1928	2492	-23%
Southbound	1311	1612	-19%

Table 3: Comparison of Averaging Daily Delays versus Computing Delay from Average Daily Conditions: All Seven Days Included

	Average Daily Delay Computed from Average Conditions	Average of Delay Statistics Computed on a Daily Basis	Percentage Difference
Northbound	746	1789	-58%
Southbound	635	1177	-46%

If a faster delay threshold was used, then more delay was computed by both methods, and the difference in the two methods shrank, but the same bias was present. The reason is that when delay is computed on a daily basis, all delay is accounted for. When data are aggregated first, some "delay" is lost because speeds on other days are fast enough that the average condition remains above the threshold for delay. This is particularly apparent when weekends are incorporated into the computations. Because most weekend travel is above the threshold, those few days when delay occurs do not lower the average condition to a point where delay is reported on the basis of that average condition. However, delay does in fact occur, thus increasing the difference between delay computed each day and that computed on the basis of average condition.

HSAP Limitations Due to Input Volume Data

Even if the HSAP computations produced perfect delay statistics, those computed outputs would only be as good as the volume data input to those equations. Unfortunately, the traffic data input into HSAP are not perfect. There are three specific sources of potential error in the computation of segment-specific delay estimates that occur as a result of limitations in the volume data provided by the TDGMO. Two of these sources are related to AADT values. The third source is in the 24-hour curves.

The first potential error in the AADT estimates results from the number of locations that can be counted by the TDGMO. This limitation directly affects the amount of data available for creation of the MileTraf file. Since the TDGMO's traffic counting budget is heavily constrained, there are often considerable distances between traffic counts. This leads to errors in AADT values attributable to the interpolation process required to estimate traffic volumes at points between count locations.

The second source for errors in the AADT computation process is the inherent variability in traffic volumes. The vast majority of AADT estimates upon which the MileTraf file is based are the result of short duration counts that have been factored to estimate AADT. These counts rely on both the accuracy of the adjustment factors computed for each factor group and the accuracy with which specific short duration counts are assigned to those factor groups. The simple fact is that AADT values computed from short duration counts are not precise. If the factor process is well designed and executed, the AADT values will have errors that are normally distributed about the correct AADT values. This allows some summary statistics, such as statewide VMT, to be accurately computed. However, the delay computations are typically not evenly subject to over- and under-estimation of AADT. This is because delay only occurs above specific volumes. Therefore, under-estimating AADT tends to create less reduction in delay than over-estimating AADT can produce. Errors in AADT estimation could be reduced by operating a much larger traffic counting program, but that is a very expensive undertaking and one not likely to be pursued, given WSDOT's current funding levels.

Errors in the AADT estimation process can also occur both in the data collection itself (e.g., equipment error) and in the processing of the data collected in the field. It is difficult to quantify these errors. WSDOT follows FHWA standards in the collection and processing of its traffic data. However, added funding for newer data collection equipment, more modern data processing software, and additional staffing to perform quality assurance tasks would result in some improvements.

More on the size of AADT estimation errors is discussed in the next chapter of this report.

The last source of the potential errors that occur as a result of the input traffic volume data is related to the 24-hour time-of-day curves. The TDGMO's approach to these curves is to make the curves as site specific as possible. This has the advantage of more effectively identifying the directional and time-of-day patterns captured in the collected traffic data. However, the very large number of these curves makes it easy to introduce errors in the assignment of the curves, especially if the curves are updated annually.

A previous review of unexpected changes in delay estimates showed that errors had been made in the assignment of 24-hours curves within the spreadsheet. It is likely that similar errors will occur in the future.

Limitations Due to HSAP Segmentation

As part of this project, meetings were held with staff from the TDGMO. All of those staff members (three) stated that they had been asked to use a fixed segmentation within HSAP in order to make tracking changes in delay from year to year easier. These checks both make initial quality assurance tests easier to perform and allow WSDOT staff to quickly identify where major changes in delay are occurring (as measured by HSAP).

At the presentation of the results of this project, Office of Strategic Assessment and Performance Analysis (OSAPA) staff stated that they had no such requirement for HSAP outputs. It is the authors' belief that miscommunication between the various offices in WSDOT led to the application of this constraint to the version of HSAP produced for statewide delay.

Regardless of whether or not that constraint was intended, it produces a significant limitation in the HSAP computations that cause some of the delay estimates produced in later years of HSAP calculations for the GNB to be problematic.

HSAP segments should be homogeneous in terms of both roadway geometry and traffic volume. However, under the "fixed" segmentation approach, neither volume nor roadway geometry are homogeneous for many segments, particularly on urban freeways.

This is particularly problematic for the roadway geometry inputs. The code that extracts roadway geometry information from WSDOT's GIS and creates inputs for each HSAP segment averages the available geometric statistics on the basis of the fraction of any HSAP road segment to which they apply. For example, if a given 2-mile segment has four lanes (two per direction) for 1 mile, and six lanes for a second mile, then the value entered into HSAP will state that the segment contains 2.5 lanes per direction.

This type of input invalidates the assumptions upon which the equations within HSAP are based. In reality, assuming a homogeneous volume throughout the segment, the four-lane segment will create a much higher level of congestion than the six-lane portion of the segment. Most, if not all, of the segment congestion will be in that four-lane partial section. Performing a computation using 2.5 lanes per direction will yield inaccurate results.

Similarly, if a given roadway has very different volume characteristics in some parts of the HSAP analysis segment than in others, the delay estimates for the average condition will yield a poor estimate of the actual delays caused by different volume conditions in different portions of the segment.

Potential HSAP Improvements

HSAP Segmentation

There are multiple ways in which HSAP could be improved. The first improvement could be to make sure that the segmentation used within HSAP was configured such that new segments would be defined every time a major change in geometry occurred and whenever major changes in AADT occurred.

Making this improvement would require two additional changes. The first is that a new data summarization program would have to be written that would create a file that summarized delay by fixed segment, computed from the HSAP outputs (which do NOT use fixed segments). This would improve the primary QA/QC of HSAP outputs, as well as allow for quick identification of where delay was changing substantially.

The second major change would be to adjust the 24-hour curves to fit the changing segmentation. This might actually require more staff time to implement than the new segmentation output summarization process. This project did not explore the details of the initial 24-curve assignment process, so is the authors do not know how significant a technical problem it would be to generate new assignment tables for the available curves, given changing segmentation boundaries and especially as new curves are developed. Additional input from the TDGMO staff would be needed before this task could be undertaken.

HSAP Code Improvements

The HSAP program code does not correctly compute and incorporate HOV capacity within the current spreadsheet. Changes to the formulas would be needed to incorporate HOV lane capacity in the spreadsheet.

However, a major restructuring of the spreadsheet would be needed to separate HOV volumes from the general purpose lane volume for each segment. Currently, the spreadsheet allows for only one AADT value per segment. The spreadsheet would need to be rewritten to allow for the entry of separate HOV and GP lane AADT values. Unlike simply adding HOV capacity to the GP and auxiliary lane capacity formulas, this fix would require considerably more effort.

Even if the HOV improvements were made, the spreadsheet does not incorporate, and is not structured to account for, the impacts of either ramps or HOV-GP merge activity. Some work in this area has been accomplished by the freeway operations committee of the Transportation Research Board.

To successfully create new delay equations that replicate actual conditions would require extensive new research into the performance of HOV/GP lanes. Evaluation of the SR 167 HOT lane conversion from controlled access to open access HOT lanes showed that the relationship between GP and HOV lane speeds varied from location to location along the corridor (Hallenbeck et al 2016). Therefore, it is expected that development of a single formula that could estimate delay, given this variable relationship, would be difficult.

Even if such formulas could be developed, applying them within HSAP would likely require the development of an entirely new software system.

HSAP Traffic Volume Data Improvements

Improvements to the traffic data input to the HSAP model could be returned as better delay estimates. While there are not obvious errors in the procedures the TDGMO follows, additional funding would allow the following:

- More traffic data collection—whether more permanent counters, provision of more detailed information at key sites, or more short duration counts—to reduce the need to interpolate between counts.
- Improved maintenance and replacement of traffic data collection equipment, which, like the item above, would both improve the quality of data being collected and increase the amount of data available, thus reducing the loss of data from equipment failures.
- A thorough review of both factor groups and the assignment of short duration counts to those groups. Factor groups do change over time, as traffic patterns change with growth (or decline) or activity over the years.
- Replacement of old data processing software. TRIPS is almost 30 years old. Limitations in the ability to read the native formats of modern traffic counters adds time, money, and data processing steps—with the potential for adding error—to the data collection task. Upgrading the traffic data processing software system would speed the data processing task, improve the QA/QC process by automating additional quality assurance checks, and allow more staff resources to be spent on data review, summarization, and reporting.

Although traffic data collection has not been a priority for many years, these improvements would provide notable benefits not just for the issues investigated for this project but throughout WSDOT.

CHAPTER 3
TDGMO DATA COLLECTION AND PROCESSING

This chapter summarizes the traffic data collection and processing work performed by the TDGMO, with specific emphasis on the development of the traffic inputs used in HSAP. Traffic data are collected by multiple types of equipment for multiple purposes within WSDOT. While the TDGMO is in charge of overall statewide traffic data collection efforts, each of the regions collects some of its own data, particularly as part of real-time traffic management systems. These systems produce data that are accessible to the TDGMO.

The TDGMO itself both manages permanently operating traffic data counters and performs short duration traffic counts. Figure 3 illustrates the flow of data within the TDGMO process as it develops the AADT values used by WSDOT for most traffic analyses. These processes are described in brief below. Much of this work is performed with software (TRIPS) designed and implemented in the mid-1980s.

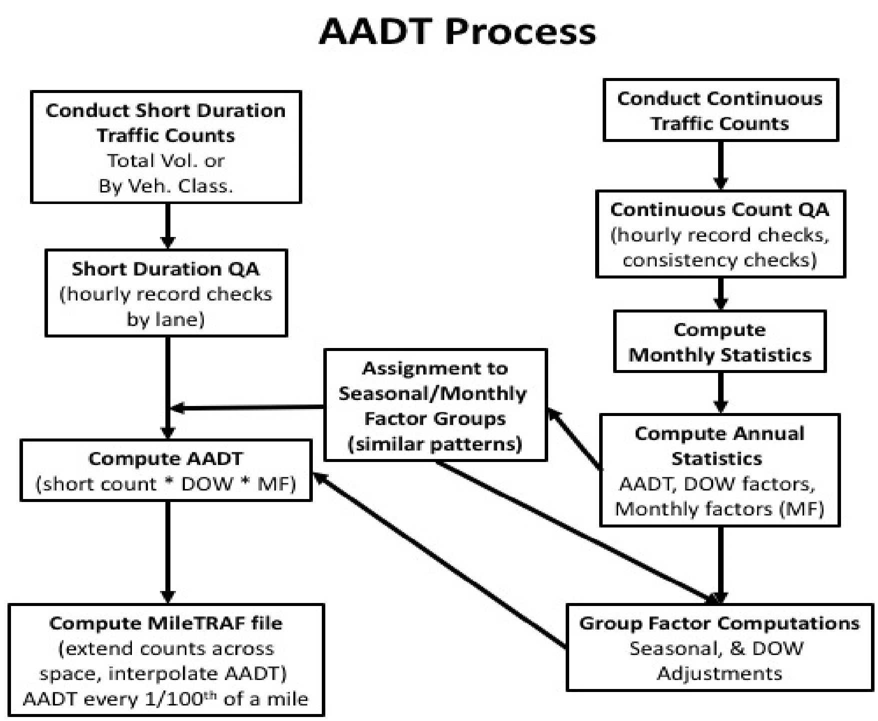

Figure 3: TDGMO Data AADT Computation Data Flow

SHORT DURATION COUNTS

The TDGMO conducts short duration traffic counts at roughly 1,000 locations each year. A formal process is undertaken each year to define the locations to be counted. That formal process includes collecting data to meet the HPMS reporting requirements, which serve as the base level of traffic counting. Additional counts are then identified to meet known project needs. Project counts typically consist of more geographically specific counts that provide detailed traffic information needed for planning, engineering design, and other purposes. Finally, general coverage counts are added to ensure that general geographic coverage is provided around the state.

TDGMO staff place short duration counters in the field. Counter performance is initially checked manually immediately after set-up. Secondary trips are made to each count site to allow manual quality control checks to ensure that the counters are working properly, that sensors have not been dislodged by traffic, and that the counters are counting correctly. Notes that describe any observed anomalies are taken in the field and submitted with the collected data as part of the routine quality control process.

At the end of the scheduled count duration (typically 4- or 72-hours, taken on weekdays), the count records are downloaded into the TRIPS pre-processing routines. These perform a variety of quality control checks to identify unusual traffic patterns that would either indicate equipment failure or make the computation of AADT from those data inaccurate.

Data that fail these checks are either removed from further processing (in the case of bad data) or set aside for use as valid site-specific information but not useful for computation of AADT. (For example, a traffic count might have been affected by a major traffic disruption. The count would still be valid; that was the traffic that the road actually experienced. However, that count could not be accurately factored to represent AADT, so could not be used in the AADT process.)

Where necessary, short duration counts are rescheduled to ensure that valid traffic volume data are obtained.

Once the data have successfully passed the quality assurance process, the count is factored to estimate AADT. Factors are applied for

- axle correction (when axle counts are converted to traffic volumes when a vehicle classifier has not been used)
- day of the week

- month of the year.

Factors are assigned on the basis of a combination of the functional classification of the road and the geographic location of that count. Factors are computed annually by using data obtained from the WSDOT permanent count program (see below).

The computed AADT values are then compared to historical estimates of AADT at that, and nearby, locations. If unexpected changes are observed, recounts of the location are requested to confirm the unexpected changes in volume.

This process follows the state-of-the-practice described in FHWA's *Traffic Monitoring Guide* (TMG) (FHWA).

Note that AADT values produced from short duration counts are subject to considerable error simply as a result of the factoring process. This is a direct result of the variation in traffic on a day to day level. This variation affects both the "representativeness" of any given short duration count and the ability of the factoring process to replicate the traffic variations taking place on a specific day at a specific location. Work performed for FHWA (Krile et al. 2015) has shown that even with perfect traffic sensors and perfect knowledge of the factor group in which a specific traffic site belongs, the "best statistically available" factoring process results in a 95^{th} percentile error bound around the AADT value of +/-15 to 17 percent. These values are minimum error rates, because in practice error is associated with assigning any given short duration count to a statistically derived factor group. If a factoring process is used that focuses on correct identification of the factor group but sacrifices some uniformity of the factor group pattern, then the 95^{th} percentile error bound rises to +/-27 to 28 percent.

Again, these error bounds are a function of traffic variability, not errors in either the equipment performance or the statistical methods used to compute AADT from the short duration count information.

The good news is that the errors at each site are normally distributed around zero. Therefore, when errors are aggregated over many geographic locations, they cancel out. As a result, statewide VMT computed with the HPMS system is not significantly affected by errors in the AADT computation process. However, at the segment level, use of short duration counts to compute trends is subject to these errors. Therefore, it is easy to produce false changes in VMT—or delay—when short duration counts are the basis. This is not a failure of the count process. It is the expected statistical outcome that results from using small samples (two or three days) taken from variable data sets (daily traffic volumes).

PERMANENT COUNTS

TDGMO Permanent Counters

The TDGMO operates roughly 180 permanent traffic counters. The majority of these counters use dual loop vehicle sensors that are capable of collecting both vehicle speed and traffic volumes within four vehicle length categories. The vehicle length categories are designed to separate traffic into

- passenger vehicles
- single-unit commercial trucks
- combination trucks
- multi-trailer trucks.

The TDGMO also operates a number of permanent vehicle classifiers that collect data in the 13 FHWA vehicle categories and weigh-in-motion (WIM) equipment that collects data on axle weights in addition to the FHWA vehicle class.

Permanent Counters Operated by the Regions

In addition to the permanent counters operated by the TDGMO, WSDOT's regional offices also operate a large number of devices that collect traffic data continually. These devices are placed specifically to collect the traffic data used by real-time traffic management systems. For example, the NW and Olympic regions currently have more than 10,000 loops operating as part of their freeway and arterial management systems. In addition, both regions have side-fired radar[1] data collection systems.

Data produced by the freeway data collection systems (but not the arterial loops) are uploaded to WSDOT servers, where purpose built software (CDR and CD Analyst, TRACFLOW, and DRIVENet) can access them, summarize them, and make them available for use by WSDOT staff. These data are retrieved from the field differently than the data collected by the TDGMO equipment.

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[1] Side-fired radar is typically a microwave radar sensor placed on a pole near the roadside. Side-fired radar is easier and less costly to install because it does not require closing a lane to work in the travel lane. However, side-fired radar is subject to occlusion, meaning that on busy, multi-lane freeways it tends to undercount traffic volumes. When correctly calibrated it does produce excellent vehicle speed estimates. For more on traffic data collection equipment, see Chapter 3 of *AASHTO Guidelines for Traffic Data Programs*, 2009.

Differences in Quality Between Data Collected by TDGMO and the Regions

While the physical traffic sensors used by TDGMO permanent equipment are the same as those used by the regional offices, the equipment that is connected to the sensors differs, and the data transmittal, storage, and quality control procedures applied to those data are different.

Most regional traffic management systems collect and summarize data at the roadside over a very short time period and then transmit those data to a central computer system that uses those data as input to the control system logic. The control system then stores the data and transmits them to WSDOT's archive, from which they are available for other purposes. For example, in the NW Region, loop data are aggregated by the equipment in the roadside cabinet every 20 seconds. The 20-second data packet is then transmitted to the Traffic Management Center (TMC) and written to storage. The data are also summarized every 5 minutes, and those data points are then written to storage.

The data are not stored at the roadside after 20 seconds. If a communications failure occurs when a 20-second data transmission is scheduled to occur, that 20-second data packet is lost.

This is not true for the TDGMO data collection equipment. The TDGMO equipment is designed with technology intended to store and forward data. The collected data are aggregated in the roadside cabinet at the specified period (often 1 hour, but 5-minute or 15-minute intervals are also possible). They are transmitted to the TDGMO at a scheduled interval, and when they have been successfully transmitted, they are removed from the field equipment storage. However, if the planned communication fails, the data at the roadside simply continue to be collected and stored. Once communications has been reestablished, the data are transmitted.

Thus, with the TDGMO equipment, communications issues result in fewer lost data than the Type 170 and Type 2070 signal controllers common to the NW Region. This makes data collected by the TDGMO equipment typically more robust than those collected by the regional TMCs.

Another data quality issue common to the regional TMC data is that the very large number of sensors and pieces of data collection equipment, combined with very limited resources for maintenance, results in a fairly large number of failed loop detectors. While WSDOT has one of the best records in the nation for maintaining TMC data collection devices, often more than 15 percent of the loop sensors are inoperable at any one time. The algorithm that controls the ramp metering system was specifically designed as a fuzzy neural network in order to directly account for the limitations in the data available to control the system.

As a result, for the TMC, this loss of detection is less problematic than it is for the TDGMO. In addition, the primary traffic monitoring statistic used by the TMC, outside of the fuzzy ramp metering algorithm, is average vehicle speed on the roadway. Average speed of the roadway can be computed with relative accuracy even if one or more lanes of data collection are missing because of loop detector or loop amplifier failure. The remaining lanes of data collection provide a good estimate of the speed of vehicles on the roadway. As a result, the loss of a single detector, or even two detectors on a four-lane (each direction) freeway does not produce a dramatic loss of operational knowledge at the TMC. Therefore, fixing these detectors is not a high priority for a TMC that is significantly resource constrained.

Unfortunately, total volume is not as easily estimated as roadway speed when lanes of detection are missing. Thus, while roadway speeds are reasonably accurate for most urban freeways, the volume data that accompany those speeds in the regional databases are less robust.

One major advantage of the TMC-based data is the density of detection. In many portions of the Puget Sound metropolitan region, detectors are located roughly every half-mile. This provides considerable insight into the location and timing of congestion formation. Closely spaced detectors can also provide considerable insight into changes in traffic volume, even given the loss of data from failed detectors.

In a few locations, the TDGMO has worked with regional offices to share loop detectors. Loop wires are run through an amplifier and splitter. One wire passes to the controller used by the TMC. The second wire is connected to a TDGMO data collection unit stored in the same traffic equipment cabinet. This allows the TDGMO to treat the site as a conventional TDGMO permanent traffic recorder.

While this approach appears to be a duplication of equipment, it allows both data systems to work as designed, limiting the need for additional software to handle the translation between the different data systems and data aggregation approaches.

Permanent Counter Quality Assurance Testing

Not surprisingly, quality assurance testing is performed differently for the permanent counters operated by the TDGMO and those control system detectors that also supply data for other purposes.

A variety of QA/QC checks are built into the software used to compute AADT, day-of-week, and monthly factors at each PTR. These are primarily consistency checks. They examine whether all hourly records are being reported at each detector, as well as whether the data on those records follow expected patterns for that location. Unusual patterns are flagged and then reviewed manually. (For example, very low volumes would be flagged, but a review of those data might determine that they were accurate because of a major crash that limited volumes during that time frame.)

The quality control procedures applied to the TMC data vary from software system to software system. The software running in the Type 170/2070 traffic controllers provides hardware level-based errors codes (Ishimaru and Hallenbeck 1999). Error codes are produced for each 20-second data packet. These packets are then summarized with a good/suspect/bad/missing code for each 5-minute data record. The CDR/CD Analyst software reports only the 5-minute summary error codes.

While these codes are helpful, use of the CDR/CD Analyst outputs has shown that other errors in the data are not captured by the base hardware error checking. As a result, when CD Analyst was updated to a Web-based system (TRACFLOW), four additional data quality review tests were added. Those tests look at data at each loop over the course of a month. They look for gaps in the data records, discontinuities in the volumes being reported, excessive variation in the traffic volumes, and shifts in the volumes being reported. These checks, combined with the original hardware checks, result in a preliminary data quality score that is used to determine whether data should be used or treated as invalid. For GNB reporting, these data quality scores were traditionally manually reviewed before final acceptance testing. However, the most recent GNB outputs have been produced without significant manual review to limit the staff time required to produce the GNB.

The newest software for processing the TMC data is DRIVENet. The DRIVENet software uses new algorithms developed by the StarLab at the University of Washington. These algorithms are designed to account for poor calibration of loop amplifiers and to identify and correct for changes in loop sensitivity that occur as loops and loop amplifiers age or as other installation conditions change.

AADT AND FACTOR COMPUTATION AT PERMANENT SITES

The TDGMO uses all permanent traffic recorder data that pass its data quality tests to compute AADT for each permanent recorder. (That is, TDGMO does not include TMC data in this specific AADT computation, except when those data have been collected with TDGMO equipment, which allows those data to pass through the TDGMO data quality process.) The TDGMO does use the volume data provided by permanent vehicle classification and WIM equipment as part of this process.

The TDGMO uses the AASHTO computation procedure described in the FHWA TMG to compute AADT. The AASHTO process is specifically designed to compute an unbiased AADT for use in short count factor development, given that at least a modest amount of data are missing from most counters during a year. Unbiased AADT estimates can be computed as long as at least one week of data is present in each month of the year. Where data are insufficient, an AADT is not computed for use in the WSDOT factor process.

Monthly and day of week statistics are also computed at this time for each counter.

The adjustment factors (day of week, month of year) computed for individual permanent count locations are then aggregated into factor groups. The adjustment factor for the factor group is the mean value of that factor for all permanent traffic count locations assigned to that group. Groups were defined many years ago on the basis of a statistical analysis of traffic patterns. Factor groups are designed to both minimize internal differences in traffic patterns within the group and make it easy to assign groups to individual short duration counts. This process is consistent with the techniques recommended in the FHWA TMG.

AADT COMPUTATION FROM SHORT DURATION COUNTS

Short duration counts provide the majority of AADT values available to WSDOT on state highways. The AADT computation is straightforward. It is

$$AADT = ADT * AF * DOW * MF$$

where:

ADT = the average (weekday) 24-hour volume axle count for the location (both directions) from the short duration count

AF = the axle correction factor applied at that location to convert the axle count to an estimate of vehicles. The axle factor is set equal to 1 if the short duration count is made with a vehicle classifier (which performs this function), or if volumes are collected by a loop detector or similar "vehicle" counter, rather than a simple axle counting device.

DOW = Day-of-Week factor, an adjustment that accounts for the days of the week that were counted and their relationship to average annual conditions for this factor group

MF = Monthly Factor, an adjustment that accounts for seasonal changes in traffic volumes.

Note that these adjustment factors can vary considerably from factor group to factor group. For example, roads leading to ski areas will be part of a factor group that models the increase in weekend and winter traffic that occurs because of the winter recreational patterns on that road, whereas urban traffic patterns typically see lower weekend and winter traffic levels.

CREATION OF THE MILETRAF FILE

Once AADT values have been created, the available data must be used to develop estimates for all segments of the state highway system. In addition to the counts taken each year, the TDGMO has access to traffic counts made in previous years and factored for growth, where growth is computed on the basis of the growth observed in the data collected by the permanent traffic recorders.

Even with growth adjusted older counts, the TDGMO does not have the resources to collect traffic data on all sections of the state highway. Consequently, to provide an AADT estimate for every location (e.g., every 1/100th of mile for MileTraf), volumes between the available count locations must be interpolated. A formal process to perform this is built within TRIPS.

On limited access highways, traffic volumes are assumed to be constant between interchanges. Volumes change at interchanges.

On roads that have open access, volumes change linearly between adjacent counts, except that historical volumes are used to identify discontinuities at major intersections. For example, if AADT values were available on SR 99 at mileposts 39.7 (north of NE 125th St., in Seattle) and then next at milepost 43.9 (the King/Snohomish County line), traffic volumes could be treated as discontinuous at major intersections between those two points, such as at NE 145th St. and NE 175th St., on the basis of previously collected data.

The output of this process is the MileTraf file.

EQUIPMENT USED

The TDGMO uses a variety of traffic data collection equipment. Short duration counts are primarily taken with road tubes[2] and are a mix of simple traffic volume counts and vehicle classification[3] counts. Road tubes are inexpensive traffic sensors that are effective for counting in modest volume environments with no more than two lanes of traffic. For higher volume roads, piezo-electric sensors (BL sensors) are most commonly used. For very high volume counts, roadside equipment—typically side-fired radar unit—are used for short duration counts. The accuracy of these devices is much lower than in-road equipment, but it is cost prohibitive and dangerous for staff to place in-road sensors on high volume roads. In addition, most temporary sensors do not collect traffic data accurately in high volume situations.

The TDGMO has purchased and tested new equipment specifically with the intent of performing short duration counts on high volume roads. In particular, the TDGMO purchased several TIRTLs, a multi-beam, infrared sensor-based vehicle classifier. National tests of this device have shown good accuracy (Kotzenmacher et al. 2005). However, the TDGMO staff found the device to be very difficult to set up and operate. As a result, the actual success rate in collecting accurate traffic data was low, so the devices are not routinely used at this time.

Instead, the TDGMO has relied on tried and true technologies for data collection. This means a heavy reliance on traditional sensors, road tubes for rural counts, loops and piezo-electric sensors for permanent counters, and piezo-quartz and load cells for WIM counts. Roadside equipment is used, but modestly. The vast majority of traffic volume data on urban freeways comes from permanent sensors.

While some innovation has occurred in the traffic counting world in the past ten years, relatively little equipment has proved in the marketplace to have a high rate of return on investment. Traditional technologies generally work as well as needed, as long as the equipment is well maintained. New equipment that produces high degrees of accuracy tend to be expensive and to require permanent installation.

The TDGMO has a limited budget for equipment maintenance and replacement. The available budgets have not allowed the establishment of a consistent equipment replacement

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[2] A road tube is a hollow rubber tube placed across the road that is compressed by the tires on a passing axle. The air expelled from the tube causes a switch on the traffic counter to activate recording the passage of that tire/axle.

[3] Short duration vehicle classification counts use the number and spacing of axles to divide the monitored traffic into 13 vehicle classes that have been defined by FHWA.

cycle. Increases in funding would allow for the purchase of newer equipment, as well as more maintenance of current equipment, increasing the reliability of the data collected with that equipment.

A second issue for the TDGMO is that most traffic data collection equipment vendors provide their own data output formats. The TRIPS system is not designed to accept many of these formats. This increases the time and resources required to download and process data from new devices.

OPPORTUNITIES TO IMPROVE THE TDGMO DATA COLLECTION PROCESS

The basic data collection process the TDGMO follows is well in line with the procedures recommended by FHWA's TMG. However, there are always opportunities to improve those procedures and, subsequently, the traffic estimates that result from those procedures.

Additional funding to modernize and improve the state of repair of the equipment used for data collection—for both short duration and permanent counts—would improve the availability and reliability of the collected data.

Additional funding to increase the number of counts taken would increase the overall accuracy of the MileTraf file, as well as increase the amount and quality of detailed traffic data available to WSDOT staff.

However, even a substantial percentage increase in traffic counts would be unlikely to directly affect the quality of statewide delay values produced with the HSAP model. The fraction of miles of state highway actually counted by the TDGMO is modest, and even a substantial increase in the number of short duration counts, would only modestly increase the number of miles of roadway covered. In addition, as noted earlier, AADT estimates based on short duration counts have a reasonably high level of variation about the true AADT. Therefore, performing short duration counts more frequently (e.g., every year versus every three years) would not guarantee a more accurate estimate of the traffic volume trends on specific road segments. This is because the inherent variation in traffic volumes is high relative to the annual growth that typically occurs.

Instead, if money is available for increased traffic counting, it might best be focused on improving AADT estimates across the state (i.e., counting more locations) or on counting more sites continuously, especially in key areas of the state. That is, adding more geographic coverage and a better understanding of temporal travel patterns in key parts of the state would improve the accuracy of the MileTraf file, as well as provide better insight into the seasonal and day-of-week travel that cause congestion in areas where delay is not commuter oriented. These improvements, while beneficial for many WSDOT uses, would not necessarily improve the estimates of year-to-year changes in volume or VMT for all segments.

CHAPTER 4:
SUMMARY OF THE STRENGTHS AND WEAKNESSES OF THE CURRENT PROCESS

This chapter summarizes the findings of the review of the current WSDOT statewide vehicle delay computation process, the Highway Segment Analysis Program.

STRENGTHS

The software that produces the statewide delay estimates is based on procedures used by FHWA for a wide variety of analyses of national importance.

The system can be applied on all state highways.

The data needed to run the software system exist and can be extracted from WSDOT's existing data systems.

WEAKNESSES

When it was developed, the HSAP program was not intended to be used for producing statewide delay estimates that were tracked year by year. As an input to the project identification process, it was intended to identify where traffic volumes either currently exceed or were expected to exceed roadway capacity. The delay estimates are one of several measures the spreadsheet produces to quantify the size of the congestion problem indicated by the difference between experienced or expected volumes and the roadway's capacity.

The formulas used within HSAP do not actually measure the experienced delay. They produce an expected value that is based on national statistical models.

The formulas in the HSAP spreadsheet do not adequately account for the existence or performance of HOV lanes.

When actual volumes collected during congested conditions are input to the HSAP delay equations, the lower throughput volumes observed during congestion cause the HSAP equations to under-estimate actual delay. Therefore, collecting more accurate traffic volume data on congested urban freeways is actually detrimental to the performance of the HSAP equations. This is because the HCM equations used by HSAP treat roadway capacity as a fixed value, whereas it actually varies by congestion levels.

HSAP, as it is currently being used, does not employ the appropriate roadway segmentation. Roadway segments that are not homogeneous in geometry or traffic volume produce errors in the delay computation process.

HSAP relies on a combination of AADT and 24-hour time-of-day curves assigned to each mile of roadway for traffic volumes. While these are the “best available data,” the fact that they are both the source of the estimated size of the traffic movement and the amount of delay being experienced means that the quality of the traffic volume estimates is extremely important. Unfortunately, while these traffic estimates are available statewide, their quality is moderate at best, given the limited data on which they are based.

CHAPTER 5:
OPTIONS FOR IMPROVING STATEWIDE DELAY COMPUTATIONS

The previous chapter's discussion indicates that there are significant weaknesses in the current statewide delay computation process. This chapter explores options for improving that process.

There are basically four major options for improving the Department's statewide delay computations. These are as follows:

- Improve the functioning of the HSAP program.
- Take better advantage of the urban freeway roadway performance data already collected by WSDOT.
- Use the National Performance Management Research Data Set (NPMRDS) provided to WSDOT by FHWA.
- Purchase a private vendor's vehicle probe-based roadway performance data set that is more robust than the NPMRDS.

Each of these options has strengths and weaknesses. There are also a number of sub-options that combine with the major options to provide a number of different possible paths forward. These options are briefly discussed below.

IMPROVE THE HSAP PROGRAM

It is possible to make improvements to the current HSAP program. In fact, if the HSAP continues to be used, some improvements must be made. This topic is discussed more fully in Chapter 2, Possible HSAP Improvements. To summarize that discussion, it is possible to make the following improvements to HSAP:

- Ensure that all segmentation within HSAP has homogeneous geometric profiles and reasonably homogeneous traffic volume profiles.
- Spend more money to increase the amount of traffic volume data collection, both short duration counts and permanent counts. This will improve the accuracy of the data that are used within HSAP.
- Spend more money to improve the number of permanent counters available to the TDGMO, replace existing, older counters, and improve the maintenance and reliability of the traffic counting equipment the TDGMO currently uses, thereby

increasing the number of counts the TDGMO can perform and their accuracy and reliability.

- Make minor fixes to the existing HSAP equations to improve handling of HOV lane capacity.
- Re-write the HSAP code and equations to allow the system to account for weaving movements, ramp metering, and traffic operations strategies, as was done by TTI as part of the Urban Mobility Report just after the turn of the century.

These improvements will all make the statewide delay estimates provided by HSAP more reliable and less volatile. However, these improvements will not resolve the biggest limitation inherent in the use of HSAP.

HSAP is not an actual measurement of delay. It is an estimate of the delay that should be occurring on routine days based on previously developed statistical models. It relies on models that are static in nature and subject to a number of significant, known limitations. In fact, these limitations occur in exactly those locations that produce the vast major of statewide delay: heavily congested urban freeways.

TAKE ADVANTAGE OF WSDOT'S FREEWAY PERFORMANCE DATA

Another option is to increase the use of the freeway performance data currently collected by the regional offices. Many of these data sources are already being used to produce the performance statistics reported in the GNB.

Use of these data would have four significant advantages:

1) The data are already collected, and those data describe roadway use and conditions during all parts of the year, not just the average annual condition. This makes these estimates more accurate measures of annual delay.
2) The collected data cover a very large proportion of the urban freeway system in the state. The roads covered represent a very large proportion of the delay experienced statewide.
3) Software exists that can be used to compute delay on these urban freeways.
4) The statistics produced by the traffic management center's fixed sensors (volume and speed) directly measure the roadway performance statistics needed to compute delay.

There would be three major limitations with adopting this option:

1) the collected data have significant data quality issues

2) the data cover only a portion of the state highway system
3) the current software systems (TRACFLOW, DRIVENet, and CD Analyst) do not currently allow automated computation of delay on a daily basis and then aggregate those statistics to an annual condition.

The first weakness of this option is that the data collected by TMCs that can be used for delay computation have significant availability and, in some cases, quality control problems. These data are collected to inform TMC personnel about problems occurring on the freeways so that the appropriate traffic management activities can be identified and implemented. The traffic management systems that collect and use the data are designed to operate with less than complete data sets. This is because the modest budgets allocated to the WSDOT regional offices for maintenance of their data collection devices is not enough to keep all traffic data collection devices operating. Consequently, as much as 15 percent of the data collection equipment is nonfunctional at any given time.

For many TMC tasks, the loss of some data is not a significant concern. The primary data point TMCs need for most tasks is current roadway speed, not volume. The loss of one or more lanes of data collection at a site due to equipment failure, typically does not seriously degrade the estimate of roadway speed at that location, and therefore the loss of some detection does not degrade TMC operational capability. However, equipment failures that result in the loss of one or more lanes of traffic data do have a much more significant impact on the accuracy of the volume statistic estimated for that location. Consequently, TMC data sets more accurately measure and report the occurrence of delay than they can the size of that delay.

Both the occurrence and size of delay are important for the computation and reporting of vehicle delay. Consequently, the current procedures that use these data put considerable effort into data quality checks and decisions about how to handle missing data. Improvements in either data collection or automated error handling would likely be needed before TMC data could be used for delay computations.

The second major issue with using the TMC data for delay computation is that these data only cover urban freeways in parts of the state. That leaves the vast majority of the state highway system miles uncovered by this approach. It would be necessary to use a second approach—whether HSAP, one of the approaches described below, or even a third approach, such as using a number of Bluetooth readers to collect travel time data on key road segments across the state—to compute delay on the rest of the state highway system.

This would mean that different computational methods would be used on different roadways in the state. However, this approach would use the "best available data" for making delay computations. In some respects, this "best available data" approach is already conducted, in that the AADT values used in the HSAP program for different locations are based on very different sources. Some data come from permanent counts, some are based on factored short duration counts, and some are simply interpolated values based on nearby AADT values. Thus, not all HSAP segments use input data of the same quality. However, if WSDOT TMC data were used to directly compute delays on those roads where such data were available, but other methods were used where such data were not available, the entire approach used to compute delay would vary for different parts of the state.

While the lack of consistency in approach is of concern, this approach would make the best use of available WSDOT data. It would also provide the most detailed analysis in those locations where the majority of delay in the state takes place.

It would also be possible to use three different approaches in order to take advantage of the data WSDOT already has, while providing good delay estimates on road segments that experience delay at times (e.g., weekends) that the HSAP program is not suited to estimating. This third approach would use a modest number of Bluetooth or WiFi sensors to directly measure travel times on key corridors that are not covered by existing TMC data collection. The intent would be to spend some additional money to collect data that directly lead to better WSDOT decision making. Thus these additional sensor systems would be placed only where non-weekday commute demand was an issue identified through the corridor sketch process and warranted measurement.

The lack of these data statewide would slightly under-estimate total statewide delay, as this type of delay would not be captured by the HSAP process used for all other roads not covered by the urban freeway management systems. But the lack of significant delay on those segments would not warrant the cost of the added data collection on those segments.

The last of the weaknesses of this approach is that the current software has limitations in its ability to produce these statistics. This is actually the least important of the limitations in this approach. Improvements to either TRACFLOW or DRIVENet to allow production of the annual delay statistics for defined corridors with only modest human intervention (outside of the quality control function) would not be difficult. In fact, these improvements would be considerably less expensive than rebuilding the HSAP model to allow it to more directly account for HOV delay. Both of these programs can already produce the base data structures (speed and volume matrices by time and location) on a daily basis that are needed to directly compute delay. What is needed are additional routines to automate this process for every day of the year and then aggregate those results. Such improvements would be only modestly difficult coding endeavors, since they would primarily repeat existing code functionality.

USE THE NPMRDS

The previous options all focus on the use of traditional traffic sensing devices. Those are either fixed sensors or portable sensors placed to observe traffic passing a point on the roadway.

Most of the recent advances in the area of roadway performance monitoring relies on the use of vehicle probe data. Vehicle probe data consist of a sample from vehicles that provide measures of their individual speed and/or travel time and a GPS location point to indicate the road on which they are traveling. These measurements are then summarized on defined road segments to provide an indication of the speed at which vehicles are traveling on that segment during specific periods.

To support reporting on the performance of the National Highway System (NHS), FHWA has purchased the rights to a specific set of vehicle probe data. It has made those data available to every state DOT and every metropolitan planning office free of charge. This data set is called the National Performance Management Research Data Set (NPMRDS). Reporting of roadway performance using the NPMRDS meets all USDOT reporting requirements.

The initial (current) NPMRDS data set is intended to provide three statistics for each 5-minute period (where each 5-minute period is called an "epoch"). These three data points are to be provided for every roadway segment (defined by using the TMC code definition) as that TMC network is defined by the selected NPMRDS vendor. The three statistics reported for each epoch for each road segment are the estimated average travel time required to traverse that road segment at that time for 1) cars, 2) trucks, and 3) all traffic combined. The travel time and road segment length can then be converted mathematically to average speed for the segment.

The initial NPMRDS data produce travel time estimates by averaging the instantaneous speed reported by the participating probe vehicles. The NPMRDS data set does not provide a value that describes the size of the data sample within each epoch for each road segment; however, when no vehicles are observed on a given road segment during a specific epoch, then no travel time is reported. So, the one condition when sample size is known is when no data are reported, which means the sample size equals zero for that road segment and epoch. If only one car and no trucks are observed during an epoch on a specific TMC road segment, a travel time is reported on the basis of the observed speed of that car. No truck travel time is reported for that epoch on that road segment. The "all traffic" travel time reported is set equal to the car travel time.

The WSDOT Freight Office funded a study of the feasibility of using the initial NPMRDS dataset for producing freight performance measures (Hallenbeck et al. 2015). That study determined that many roadways, especially lower volume state routes on the NHS, produce a large number of epochs that have no data. The vast majority of those are late at night when traffic volumes are particularly low, however, even on rural interstates, significant holes exist in the NPMRDS data set even during midday on weekdays. In addition, when vehicle volumes are low, individual vehicle speed values can be erroneous as a result of map-matching errors that assign slow moving vehicles to roads they are not currently using.

Despite the observed data problems in the NPMRDS data set, the Freight Office study concluded that the NPMRDS could be used for performance reporting, but that substantial quality assurance work would be needed before those results would be reliable. In addition, some level of data aggregation would be needed, in that daily computations of travel times and delays were not always possible because of missing and invalid data.

TTI has used the NPMRDS and other vehicle probe data sets to produce roadway performance metrics and has come to similar conclusions.

The solution TTI has adopted for its Texas 100, and many other performance reporting projects, has been to perform a partial aggregation of the vehicle probe data. Rather than computing an average annual speed for each epoch, or for each hour of the average day, with which to compute delay statistics, TTI has picked a middle ground. It computes statistics for seven average days of the week (e.g., an average annual Monday, an average annual Tuesday). It also computes average statistics for 15-minute epochs, rather than 5-minute epochs. To compute these values, it averages all 5-minute values within the time period on any day of the year that falls on that day of the week. For example, to compute the average Monday speed for the epoch between 8:00 and 8:15, it would average any Monday travel time in the NPMRDS that occurred in the 8:00-8:05, 8:05-8:10, and 8:10–8:15 NPMRDS epochs on a Monday.

Delay is then computed for each roadway segment for each of these 672 epochs (7 days x 24 hours x 4 epochs/hr). These values can then be combined and either expanded to an estimate of total annual delay, or averaged to obtain average daily delay.

The intent of this approach is to use the aggregation process to account for holes in the data set. It slightly under-represents total annual delay, as specific days of delay may be masked by other days when travel speeds are high. However, it does a better job of capturing actual delay than the use of AADT and the HCM equations, as it uses actual observed travel speeds to determine when delay is occurring and is thus sensitive to all types of external factors, including crashes, traffic control systems, weather, and variations in volume. For roads with high levels of data (where delay is most likely to occur), this approach could also be modified to measure average day-of-the-week by month for the 15-minute epochs. This would capture even more of the transient delays which are missed at higher levels of aggregation.

One major limitation in the use of NPMRDS is that this data set does not include a traffic volume component. WSDOT would need to supply this volume in order to "size" the delays observed by the vehicle probe data.

The best source of these volumes on the state's NHS are the same data files used as input to HSAP: the MileTraf file and the 24-hour curves.

The same problems that limit the accuracy of those files as inputs to the HSAP program would also be present if they were used with the NPMRDS. The major difference is that in that case, these files would only size the delay. The existence of delay in the first place would be totally independent of the volume estimates. This means that errors in the initial delay estimation process (i.e., when delay is actually occurring) would be limited to the ability of the NPMRDS data to observe traffic delays.

In addition to the number of holes in the database, NPMRDS does have one other major limitation in its ability to measure delay. In many locations, the roadway segmentation used by the NPMRDS consists of fairly long road segments. In rural areas, some segments can be over 10 miles long.

Since, in the current version of NPMRDS, travel times and speeds on road segments are based on an average of all observed GPS points on a segment during a given epoch, it is possible for a small sample of vehicle speeds gathered during any given epoch to not be representative of travel conditions throughout the entire road segment. For example, on a 10-mile segment (with a 60 mph speed), a delay (speeds of 30 mph) might be occurring in the last half mile. Data points collected over the majority of that 10-mile segment would report high speeds, and no, or a very small number of, data points might report the slow speeds within that half-mile slow segment. For example, nine vehicles might report speeds of 60 mph, and one would report a speed of 30 mph. The resulting average speed would be 57 mph. If delay was not assumed to occur (e.g., delay occurs only when speeds drop below 55 mph), no delay would be reported for this long segment. If instead of one 10-mile long segment, this roadway was split into ten 1-mile segments, delay would be computed in the last 1-mile segment.

These limitations in the current NPMRDS data set have been reported to USDOT when it requested feedback on the use of the NPMRDS. USDOT recently signed a new contract for NPMRDS data. This new contract contains new clauses meant to respond to these limitations. At the same time, the number of vehicle probes has continued to grow over time. This means that the utility of the NPMRDs is expected to grow over time.

The next issue that would have to be accounted for would be the need to conflate the NPMRDS TMC roadway network with WSDOT's linear referencing system. Conflation would link the TMC road segments definitions to WSDOT's linear referencing system, allowing computer software to link data associated with each TMC code to data linked to WSDOT's linear referencing system.

Unfortunately, both the TMC network and the WSDOT network change over time. The NPMRDS contractor submits road network changes for each state twice a year. The WSDOT road network can change every week or two. This means that the conflation between these two network descriptions would have to be re-done at least once every year. However, if the WSDOT linear referencing system did not change substantially, then these changes would be fairly minor for most years.

TTI estimates that its annual conflation effort for Texas DOT's Texas 100 effort takes roughly three staff-months of effort each year.

The final key piece of information to consider before using NPMRDS for performance monitoring is the need for software which can both compute the presence of delay, and link those delays to the volume data maintained by WSDOT.

Currently, the University of Maryland CATT lab maintains a free subset of functions available in their traffic analytics software program (RITIS) that will compute delays with the NPMRDS. However, the free RITIS system does not include any data quality control checks. Neither does RITIS match the delay estimates to traffic volume estimates. At a minimum then, WSDOT would have to write software to connect the MileTraf and 24-hour curve data to the RITIS delay computations on the basis of the conflation table that links the TMC network to the WSDOT linear referencing system.

Alternatively, the WSDOT could contract with the CATT lab to perform this function within RITIS. WSDOT would be responsible for sending a new MileTraf file to the lab each year, as well as any changes to the 24-hour curve assignment.

Finally, WSDOT could construct its own software to perform this task. One possible alternative would be to have the DRIVEnet software platform at the University of Washington perform these tasks. DRIVENet is capable of storing NPMRDS data and currently contains one full year of NPMRDS data. It has routines that allow the computation of travel times from any segment to any other segment within the state of Washington, and could be upgraded to compute delays for each TMC segment. It does not currently contain either the last two years of NPMRDS data, nor the MileTraf and 24-hour curve files. In addition, its conflation table has not been kept up to date. However, it could be upgraded to perform these tasks.

PURCHASE AND USE PRIVATE SECTOR ROADWAY PERFORMANCE DATA

Two, and possibly three, of the major limitations of using NPMRDS could be removed if WSDOT purchased vehicle probe data from a private sector vendor, rather than using the free NPMRDS data set. The downside of this approach is that it would add an annual expense (the cost of purchasing a private sector data set) to the cost of operating this system.

The primary reasons to purchase a data set would be to obtain a more detailed roadway network, and to gain access to metrics that describe the number of data points contained in each epoch travel time.

For example, Inrix sells data in an "extended" TMC road segmentation file. This file typically has much smaller road segment lengths. Inrix also provides a meta data flag indicating when data are based on little data, a moderate amount of data, or a considerable amount of data. It can also provide a "historical average" for epochs for which no data are present.

Other private sector vehicle probe vendors can provide similar improvements to their data sets.

The smaller road segments would resolve many of the issues with delays occurring on long rural road segments. The availability of meta data flags that indicate the relative size of the probe samples that underlie a given statistic make the data quality process much more easy, reliable, and robust.

It is also possible to purchase both conflation services and software for analyzing the data from the private vendors. The only downside to purchasing this software is that WSDOT would get a canned approach to computing performance measures. Changes to these existing routines (for example computing measures used by WSDOT such as MT3I, which are not routinely used elsewhere) would cost extra and might take time to code, given the need for the private vendor to respond to multiple clients' needs.

Still, as with the NPMRDS, the quality of the total delay estimates would be subject to the errors in traffic volume estimates inherent in the MileTraf and 24-hour curve data sets, and to the limitations in vehicle probe data. Most private sector vendors of probe data have improved on the techniques used to supply the original NPMRDS data set (e.g., averaging of GPS data points.) The degree to which the private sector data sources are better than the upcoming NPMRD data set is not known at this time.

DIFFERENCES IN COMPUTATIONAL OUTCOMES

It is important to realize that any change to the computational system used to produce statewide delay estimates will result in a change in the computed value being reported. That is, each of the systems described above—including making improvements to the HSAP spreadsheet—will result in a different estimate of statewide delay. This is true even if the same input values are used. This is demonstrated in tables 2 and 3 in Chapter 2. When different data sets are used to determine when delay is occurring, the results will show even greater changes in delay.

An analysis was performed using I-405 data. All data were from 2014 except that 2013 data were used for HSAP because that year was readily available to the project team. The delay computation examined the southern section of I-405. Just over 10 miles of roadway were included in the test. Table 4 presents the resulting values from four different computations. The computations were performed by using

- HSAP
- the TTI Texas 100 software, Inrix vehicle probe data, WSDOT HPMS volumes, and a threshold of 75 percent of free flow speed being set as the start of delay
- the TRACFLOW software, with NW Region traffic management data, with average conditions for only weekdays computed first and then delays computed on the basis of a 50 mph threshold
- the RITIS free software, using NPMRDS vehicle probe data, with volume data supplied by TRACFLOW being the sum of both GP and HOV volumes averaged to match the TMC segmentation lengths.

Table 4: Estimated Delay on the Southern 10 Miles of I-405

Technique	Daily Vehicle Delay
HSAP (2013)	14,000 veh-hrs
TTI (Inrix probe data,75% ref speed)	4,800 veh-hrs
TRACFLOW (50 mph threshold, weekdays only, annual computation)	3,540 veh-hrs
NPMRDS – free RITIS, with volumes from TRACFLOW (GP+HOV)	8,764 veh-hrs

For these four analyses, there were minor differences in corridor length as a result of the different segmentation approaches used by the different programs. However, the differences in vehicle delay caused by the different end points were small. Rather, a combination of the data used and computational methods resulted in the very significant differences in reported delay.

Interestingly, the TRACFLOW computation is the only approach that specifically accounts for delays in the HOV lanes independent of the delay in the general purpose lanes. In TRACFLOW these calculations must be performed separately and then added together.

The HSAP computation does not correctly account for HOV capacity, but even if it did work as intended, it would simply add capacity to the mainline roadway capacity. The two vehicle probe data sets are not able to differentiate travel speeds on the HOV lane from travel speeds in the general purpose lanes. The "average speed" reported by these data sets is based on the number of probe vehicles that are using the HOV lanes versus those using the general purpose lanes. Since trucks are typically over-represented in the vehicle probe data sets, this bias is likely one reason why the two probe data sets produced higher delay estimates than those resulting from the data collected by the NW Region traffic management system and summarized by the TRACFLOW database.

These types of differences would occur on all roadways across the state. The technique that produced the "best" delay value would vary from location to location across the state, depending on the availability of data and the nature of the data collection system. (That is, where dense sensor networks are in good working order, they would provide the more accurate estimate of delay. Where data from traditional sensors were sparse, vehicle probe data would provide better estimates of delay.)

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes conclusions drawn from the material presented in the previous five chapters of this report.

CONCLUSIONS

The HSAP program WSDOT currently uses to produce statewide delay estimates has significant methodological limitations. These are compounded by limitations in the data that are input to the system and restrictions on making changes to segmentation that have been placed on the system in recent years.

The HSAP spreadsheet has some modest technical errors, but those errors are not the primary cause of the variation observed in year-to-year delay estimates. The primary cause of that variation is limitations in the technique inherent in the spreadsheet. These include limitations in the ability of WSDOT to estimate AADT and estimate and apply 24-hour curves, but they are mostly due to the application of the resulting hourly volumes within the HCM-based delay calculation equations.

Improvements to the HSAP spreadsheet process are possible but will not provide reliable, accurate, transparent estimates of delay on key corridors in the state.

The HSAP spreadsheet can continue to be used as an indicator of where routine volume is likely to cause delay. But it should only be used as an indicator.

There is no "silver bullet" alternative that can serve as an inexpensive replacement for HSAP for production of a reliable, transparent, and accurate statewide delay estimate.

In general, where they are present, traffic management center data can provide the most accurate estimate of actual delay on major urban freeways. This is particularly true where there are HOV and HOT lanes. Unfortunately, these data cover only a portion of the state roadway system. In addition, because of limitations in the budget for maintenance of the sensor network that supplies these data, the use of these data requires application of substantial effort in data quality analysis.

The limitations and cost of building and maintaining fixed sensor networks are leading most state DOTs to move toward the use of vehicle probe data for monitoring the size and scope of roadway delay.

However, vehicle probe data sets, whether obtained for free from FHWA or purchased from private sector companies, still have significant limitations. In particular, they

- do not differentiate between contiguous HOV and general purpose lanes on urban freeways
- are limited in sample size, resulting in many time periods with no data, especially on lower volume roads
- cannot accurately measure delay on arterials with closely spaced signals.

In addition, if vehicle probe data sets are used to determine the timing and extent of congestion formation, WSDOT must still provide volume data to size those delays. This means that WSDOT must conflate the networks used to report vehicle probe data with the WSDOT linear referencing system.

Purchasing private sector data, rather than simply using the free NPMRDS data set, would provide WSDOT with better probe data (mostly due to having smaller segments in the data file than is provided with FHWA's NHS TMC segmentation), but at a cost that would need to be determined by the open procurement process. In particular, private sector data would provide better historical speed estimates than the current NPMRDS data set because of limitations FHWA imposed on the private sector vendors when they performed the initial NPMRDS procurement. Purchased private sector data sets would also be expected to have fewer obvious data errors than the initial NPMRDS data sets. In addition, private sector companies could provide WSDOT with better segmentation (i.e., shorter segment lengths) than are present in the NPMRDS network.

Regardless of how WSDOT decides to move forward, additional software processing capabilities will need to be pursued. It can write its own software or purchase access to existing software programs such as RITIS.

RECOMMENDATIONS

The overall recommendation from the project team on how WSDOT should proceed is a function of decisions WSDOT needs to make that are outside the scope of this project. The "best" step forward is a function of both

- the amount of money WSDOT wishes to spend and

- whether the decision is based on the goal of simply producing a better statewide delay estimate or of providing WSDOT with better roadway performance statistics that are used throughout a variety of WSDOT's work procedures.

That is, more accurate and reliable location-specific and statewide delay estimates can be provided by purchasing private sector vehicle probe data, combined with improved access to existing WSDOT traffic management system data. Purchasing additional computing services along with those data, such as providing integration of those probe data with traffic management center data, including incident response statistics, would provide a far more robust analytics platform for use around the state. However, this would be an expensive solution. It would be a good outcome only if WSDOT wishes to have a much more robust analytical capability for use in managing and reporting on its traffic management activities.

Conversely, if the goal were to improve the statewide delay estimates reported while spending as little money as possible, the recommendation would be to create a hybrid reporting system that uses the traffic management system data where they are available, and the HSAP program where those data do not exist.

However, at only slightly greater cost, WSDOT could move to a new hybrid system that relied not on the HSAP program but on the NPMRDS data for non-urban freeway delay estimation. The continued improvement of vehicle probe data means that this is the future of roadway performance reporting, and replacing HSAP with NPMRDS, while slightly costlier initially, would yield long-term benefits that would likely be worth the expense of the change.

The current inability of the vehicle probe data to account for the performance of the HOV and HOT lanes prevents the recommendation that these systems be used where those types of roadways supply major congestion relief. However, outside of the HOV and HOT lane systems, vehicle probe data—whether the free NPMRDS or purchased variety—would provide estimates that were equal to or better than the estimates available through HSAP, and the vehicle probe-based estimates are expected to continue to improve over time, while the HSAP estimates are not.

Table 5 provides a tabular summary of the various options and the relative rank assigned to those basic options by the project team, given the overall goals that WSDOT wishes to accomplish. A rank of "1" means that, in the opinion of the authors of this report – *given currently available information*, it is the best option for that specific scenario. Ranks of "2a" and

“2b” are meant to indicate that two options are essentially equal. Options are ranked on the basis of costs assumed by the project team versus the performance of the resulting system in terms of meeting WSDOT’s needs for quick and reliable results. Rankings are only given to the best three options. Additional details on actual costs and performance capabilities are needed on some of the more complex options, as these details are beyond the scope of this project.

Table 5: Summary Recommendations (Option Rankings) Based on Overall WSDOT Goals

	Inexpensive, Statewide Delay Computation	Sketch Planning at the Corridor Level	Detailed Planning	TMC / IR Analytics Statewide
HSAP				
TMC Data where present, HSAP elsewhere	**3**			
NPMRDS with free RITIS	**1**	**1**	**3a**	
NPMRDS & TMC data with WSDOT software	**2**	**2b**	**2**	
NPMRDS and TMC Data - UW built software (DRIVENet)		**2a**		**3**
Private Vendor Probe Data Purchase			**1**	
RITIS High End (WSDOT TMC data and private sector included.)				**1**
Other Vendor Software (PEMS? Etc.)		**3**	**3b**	**2**

If the Department desired greater use of corridor-level delay estimates (e.g., in the corridor sketch process), then the Department should definitely move away from HSAP toward the use of vehicle probe data sets. Only with these data sets could WSDOT realistically hope to examine the impacts of seasonal changes in roadway performance. In addition, as the use of these data grew, the value of having a more comprehensive software packages would grow. This would result in higher benefit being associated with software purchased from vendors working with multiple agencies, as the cost of those software features could be spread across multiple agencies. The downside of purchasing software services is that they cost money, and in some cases the approach to data processing and reporting used by commercial service providers might not follow WSDOTs procedures. (For example, few if any other states routinely report MT3I statistics, which are a mainstay of WSDOT's reporting procedures.) This would require either a change in WSDOT's procedures or additional cost to add WSDOT's procedures to the existing software's capabilities.

As the WSDOT's goals expanded, the benefits of purchasing private sector data that are "better than" the NPMRDS data would increase. The more data that are used, the greater the value obtained from better input data. The benefits from purchasing additional software analysis capabilities would also continue to apply.

Finally, the ultimate—and most expensive—option would be to integrate private sector data with the traffic management system data. The concept here would be to provide a very robust, integrated data system that allows both improved, real-time management of the roads and easily used, visually informative reporting that can be used to improve planning for system operations—in addition to meeting the current statewide delay reporting needs.

This is the basic concept of the UW's DRIVENet system. However, the funding for DRIVENet has not been at a level that has allowed the development of software with the reporting capabilities of software currently available in the commercial market. Funding such a system would allow WSDOT to tailor the system to WSDOT-specific needs and interests. However, other systems already exist that perform those functions. RITIS, which is used as the core data processing system by both HERE and Inrix, was originally built to manipulate and report on urban sensor data. PeMS was built by the University of California at Berkeley for Caltrans for the same reason. It would be less risky for WSDOT to purchase one of these—or potentially other—existing software solutions than it would be to fund further development of DRIVENet. Use of existing commercial software would also lower the expected cost of the system, given that development costs would be spread across multiple agencies. The downsides of commercial software would be the potential to become reliant on a specific vendor's solution and the likely need to change some operational or reporting procedures to conform to "group norms" rather than writing the software to conform to WSDOT's current or desired procedures and reporting outcomes. The advantage of funding further DRIVENet development would be that WSDOT could direct that development as it saw fit.

Whichever of these approaches best meets WSDOT's needs will be a function of WSDOT's overriding goals, the availability of funding, and the results of vendor responses to WSDOT solicitations.

Corridor Sketch Needs

While the needs of the Corridor Sketch process were not specifically called out in this project's scope of work, comments on the draft version of this document requested input on those needs. This short section provides those recommendations.

It is the opinion of the project authors that the Corridor Sketch process should initially take advantage of the NPMRDS data for the "identification of performance gaps" – at least where those gaps relate to the formation of roadway congestion. The NPMRDS, and in particular, the newest version of that data set which will become available by summer 2017 for 2016, should be capable of identifying the major congestion locations in the state. At a minimum, the "free" NPMRDS tools will allow WSDOT to identify these locations at minimal cost.

What even the latest version of the NPMRDS does not accomplish is cover all of the state, nor does it provide free conflation that is needed to compute vehicle delay. In addition, the NPMRDS does not come with tools that allow the forecasting of the delay reduction impacts which potential projects might allow. (That is, unlike HSAP, the current NPMRDS tools do not allow adjustment of the values of "V" and "C" in order to predict delay statistics ten years from now, given expected growth and a planned geometric improvement.) These are limitations to this recommended approach.

However, the authors believe that <u>for the initial Corridor Sketch "performance gaps" identification process</u>, these limitations are not crucial. Instead, the NPMRDS analysis can indicate when and where delays are occurring on the vast majority of state routes. Once identified, these initial findings can be discussed with the regional engineers and planners to better understand the causes and significance of those identified delays. This task is part of the "root cause" analysis that should be performed as part of the Practical Solutions approach. (That is, are the delays caused by routine demand? Seasonal demand? Incidents? Construction? Are they an artifact of the limitations of the NPMRDS data –e.g., the road is a small road with little data, where signal spacing is causing delays to be over represented – according to the stakeholder review process.) The outcome of the root cause analysis both instructs the region and stakeholders as to what technical solutions are the best, most cost effective steps to take to improve the corridor's performance, and it gives the stakeholders the chance to determine whether the delays observed are significant enough to warrant their prioritization over other performance gaps identified within the corridor.

In the end, starting with the NPMRDS allows a good, fairly inexpensive, first cut at identifying where congestion is occurring along a corridor. If appropriate, and warranted, those delays can be more precisely quantified. This work can be limited to simply performing a more detailed analysis of volume data used to compute delay, or it could involve the collection of addition travel time and volume data (e.g., using Bluetooth or WiFi sensors and short duration volume counts, set to capture data during the time periods identified as problematic by the NPMRDS analysis), in order to more precisely define the size and scope of the performance gap.

These data would also then be available as input into models specifically selected to identify the benefits of the selected approaches for dealing with the problems that are now more carefully quantified. (For example, if the issue is truly seasonal fluctuations in volume causing delay, a cost effective approach to that problem involving improved use of off-system parallel routes, would not be captured in HSAP, but could easily be captured via use of a simple network model designed to reflect the benefits of improved traveler information systems.)

Thus, NPMRDS is recommended for this task because it supplies a very useful, low cost mechanism to identify the location and timing of roadway delays. These performance indicators can then serve to guide the next step in the Practical solutions analysis process.

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APPENDIX

HIGHWAY SEGMENT ANALYSIS PROGRAM 2009

DOCUMENTATION

(HSAP 2009)

Date August 2009

Prepared by
Capital Program Development Management Office

INTRODUCTION

The Highway Segment Analysis Program is a tool used by Capital Program Development and Management (CPD&M) staff to analyze mobility data and provide consistent evaluation of the through traffic movement on statewide highway system. This software is used to identify highway segments that operate below 70% of posted speed limits in year 2030. These segments are included as Mobility Needs in the 2011 – 2030 Highway System Plan (HSP).
The HSAP program has been used to analyze and identify mobility needs since mid 1990s. During the last HSP (2007) update and subsequent technical update (2008) several discussions took place between management and technical staff regarding the data, segmentation, and equations used in the program. A decision was made that an update of the program was needed to address the following items and bring the program up to date:

- Segmentations
- AADT
- Growth Rates
- 24 hours Horizontal curve
- Free Flow Speed Equations
- Capacity Equations
- Speed Flow Curve

The following sections explain the changes made and the data and equations used for this update.

SEGMENTATIONS

With the sophisticated software, we are able to create a can report that applies very year with minimum manual works based on the list of segmentation definition below;

1. Jurisdiction (Region & County Boundary)
2. Urban/Rural
3. Functional Class
4. Change in number of lane (GP lane only)
5. Begin and End HOV lane
6. Begin and End Auxiliary lane (Truck climbing, weaving and slow vehicles lanes.)
7. Begin and End Reversible lane (based on HPMS Section break)
8. Change in Legal Speed (based on Increasing direction)
9. Significant change in AADT (based on HPMS Sections break)
10. Change in Terrain

AADT

Software weighted average AADT based on available traffic data

GROWTH RATE

The 20-years growth rate calculated were based on Federal county and Federal functional growth table.

24 HOURS HORIZONTAL CURVE

Developed specialize 24hr distribution curve for a couple of highways and reversible lane.

MEDIAN TYPE

SOME OTHER MODIFICATION

FREE FLOW SPEED EQUATIONS, CAPACITY EQUATIONS, AND SPEED FLOW CURVE

Speed Estimation Procedure

The segment speed   is computed in three steps:
- Step1. Estimate segment free-flow speed (FFS)
- Step2. Estimate segment capacity
- Step3. Compute segment average speed

Freeway

Step1. Estimate Free Segment Free-Flow Speed

The FFS estimate equations are used because the FFS field measurements for all segments are unavailable. (From NCHRP Report 387 p80)

If Posted speed (PS) > 50 mph
FFS (mph) = 0.88* PS +14

If Posted speed (Sp) <= 50 mph
FFS (mph) = 0.79 * PS +12

Step2. Estimate segment capacity

Due to the limitation of data, we simplified the capacity equation from Highway Performance Monitoring System (HPMS). http://www.fhwa.dot.gov/ohim/hpmsmanl/appn.cfm
Adjustment factors for lane width, right shoulder lateral clearance, number of lanes, interchange density, and driver population were dropped because they are a minor adjustment (Total difference will make less than 5%), and rarely comes into play in planning studies. The following equation was developed based on this information:

Capacity (vph) =Ideal Capacity* N * Fhv * PHF

where:
Ideal Capacity = 2400 (pcphl) for FFS >= 70 mph
Ideal Capacity =2300 for FFS< 70 mph
N = number of lane
PHF = peak-hour factor – used default 0.92 for urban facilities and 0.88 for rural facilities
(From HCM 2000 Chapter 13.)

Fhv = heavy vehicle adjustment factor
Fhv = 1 / (1 + Pt (Et-1))
Pt = Proportion of trucks and buses in the traffic stream, expressed as a decimal (e.g., 0.15 for 15%)
Et = Passenger-car equivalents
= 1.5 for level terrain
= 2.5 for rolling terrain
= 4.5 for mountainous terrain

Step3. Compute segment average speed

The equation used for this update is based on the NCHRP report 387 which is the updated version of the standard BPR equation. We adjusted the *a-value* to fit our system criteria. The following equation was developed based on this information:

$$s = \frac{s_f}{1 + a * x^b}$$

Where
s = **predicted space mean speed**
s_f =**free flow speed**
x =**v/c ratio**
a = **0.3**
b = **10**

Multilane highway

Step1. Estimate Free Segment Free-Flow Speed

The FFS estimate equations are used because the FFS field measurements for all segments are unavailable. (From NCHRP Report 387 p80)

If Posted speed (PS) > 50 mph
FFS (mph) = 0.88* PS +14

If Posted speed (Sp) <= 50 mph
FFS (mph) = 0.79 * PS +12

Step2. Estimate segment capacity
Due to the limitation of data, we simplified the capacity equation from HPMS.
Adjustment factors for access points and driver population were dropped because they are a minor adjustment. Adjustment factor of lateral clearance is determined based on median typed data and minimum shoulder width data because of limited data availability.

Capacity (vph) = Ideal Capacity * N * Fhv * PHF*Fw *Fc

Where:
Ideal Capacity = 1,000 + 20*FFS; for FFS <= 60
Ideal Capacity = 2,200 for FFS > 60
(From HCM 2000 Exhibit 21-3)
N = number of lane in one direction
Fhv = heavy vehicle adjustment factor
Fhv = 1 / (1 + PT (ET-1))
PT = Proportion of trucks and buses in the traffic stream, expressed as a decimal (e.g., 0.15 for 15%)
ET = Passenger-car equivalents
= 1.5 for level terrain
= 2.5 for rolling terrain
= 4.5 for mountainous terrain

PHF = peak-hour factor – used default 0.92 for urban facilities and 0.88 for rural facilities
(From HCM 2000 Chapter 12)
Fw = lane width factor
= 0.94 for Lane width less than equal 10ft
= 0.98 for Lane width less is 11 ft
= 1 for Lane width is 12 ft
Fc = 0.93 for if median is undivided and right shoulder is less than equal 2
=0.95 for median is undivided and minimum right shoulder length is more than 2 and less than equal 4.
=0.97 for median is undivided and minimum right shoulder length is more than 4

Step3. Compute segment average speed

The equation used for this update is based on the NCHRP report 387 which is the updated version of the standard BPR equation. We adjusted the *a-value* to fit our system criteria. The following equation was developed based on this information:

$$s = \frac{s_f}{1 + a * x^b}$$

Where
s **= predicted space mean speed**
s_f **=free flow speed**

x =**v/c ratio**
a = **0.3**
b = **10**

Two lane highway

Step1. Estimate Free Segment Free-Flow Speed

The FFS estimate equations are used because the FFS field measurements for all segments are unavailable. (From NCHRP Report 387 p80)

If Posted speed (PS) > 50 mph
FFS (mph) = 0.88* PS +14

If Posted speed (Sp) <= 50 mph
FFS (mph) = 0.79 * PS +12

Step2. Estimate segment capacity
Due to the limitation of data, we simplified the capacity equation from HPMS.
Adjustment factor for grade was dropped because of the limited data availability.

Two-Way Capacity = (3,200 pch * PHF * Fhv) - Vnp

Where:
PHF = 0.88 for rural, 0.92 for urban (From HCM 2000 Chapter 12)
Fhv = Adjustment factor for heavy vehicles
Fhv = 1 / (1 + Pt (Et-1))
Pt = Proportion of trucks and buses in the traffic stream, expressed as a decimal (e.g., 0.15 for 15%)
Et= Passenger-car equivalents
= 1.1 for level terrain
= 1.5 for rolling terrain
= 7.2 for mountainous terrain

Vnp = Volume adjustment for no passing zones
Vnp = Fnp/0.00776
Fnp = 20% for level 50 % for rolling 80% for Mountainous
(From HCM 2000, Exhibit 12-11)

Step3. Compute segment average speed

The equation used for this update is based on the NCHRP report 387 which is the updated version of the standard BPR equation. We adjusted the *a-value* to fit our system criteria. The following equation was developed based on this information:

$$s = \frac{s_f}{1 + a * x^b}$$

Where
s **= predicted space mean speed**
s_f **=free flow speed**
x **=v/c ratio**
a **= 0.3**
b **= 10**

Signalized Intersection

Step1. Estimate Free Segment Free-Flow Speed

Same equation from the last version of HSAP was used because of the following reason

- Definition of segmentation is not based on the signalized intersection.
- Data availability are limited in order to calculate the control delay
- Field measurements are unavailable

FFS = Posted Speed Limits

Step2. Estimate segment capacity
The following equation from HPMS was used.

Intersection approach capacity = 1,900 * N * Fw * Fhv * PHF * g/C

Where:
N = number of lanes on the segment (one direction)
Fw = adjustment factor for lane width
Fw = 1 + (W-12)/30
W = Lane width (ft)
(From HCM2000, Chapter 16)

Fhv = adjustment factor for heavy vehicles

Fhv = 100 / (100+HV (Et-1)

Where:
HV = percent heavy vehicles
Et = 2.0 passenger car equivalents
(From HCM2000, Chapter 16)

PHF = Peak Hour Factor
= 0.88 for rural conditions, 0.92 for urban conditions
(From HCM 2000, Chapter 10)
g/C = effective green time-to-cycle length ratio
= 0.55 for principal arterials
= 0.45 for minor arterials
= 0.40 for collectors

Step3. Compute segment average speed

The equation used for this update is based on the NCHRP report 387 which is the updated version of the standard BPR equation. We adjusted the *a-value* to fit our system criteria. The following equation was developed based on this information:

$$s = \frac{s_f}{1 + a * x^b}$$

Where

s = **predicted space mean speed**

s_f =**free flow speed**

x =**v/c ratio**

a = **0.5**

b = **10**

LIMITATIONS

The following list of limitation of HSAP.

- Due to the limitation of data, bottlenecks occur at arterials and ramps may not identify using HSAP. (We use the other traffic analysis tools to identify bottlenecks)
- Due to the limitation of time and data, we could not change peak hour spreading method. Although we modified many segments, the maximum volume capacity ratio is still high. (the highest is 2.1)
- Due to the limitation of time, we could not change capacity estimation and speed-flow curves for Mobility Project Prioritization Process (MP3) workbook.