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Considerations for the Development of Work Zone Mobility Performance Measures and Thresholds for Virginia Freeways

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Considerations for the Development of Work Zone Mobility Performance Measures and Thresholds for Virginia Freeways

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Abstract:

The Federal Highway Administration has been encouraging states to improve their monitoring and tracking of the mobility impacts of work zones. The use of mobility performance measures will enable agencies to assess better the contribution of work zones to network congestion; to identify specific projects that are in need of remedial action; and potentially to assess penalties to contractors creating excessive, avoidable negative impacts. Although the Virginia Department of Transportation (VDOT) has defined allowable lane closure hours for the interstate system, VDOT has not defined specific performance measures and thresholds for what constitutes "unacceptable" work zone mobility impacts. Performance measures and thresholds have been developed by a number of other states, so there is a need to determine whether these could be adapted for use by VDOT.

This study explored issues related to a potential work zone mobility performance measurement program for Virginia. The issues investigated included identification of potential performance measures, definition of performance thresholds, and recommendations for data sources for performance measurement calculations. This information was synthesized from information regarding the experiences of selected states and experiences from a series of case studies that used data from Virginia work zones. The review of experiences in selected other states found that delay and queue length were the performance measures used most often by the states studied. The Virginia case studies focused on the use of private sector data to generate mobility performance measures and found that the level of spatial aggregation in rural areas could inhibit the ability to generate accurate performance measures, although granularity was better on urban roads. The level of temporal aggregation was also found to influence performance measures.

The research identified a number of key issues that VDOT should consider as a work zone mobility performance measures program is developed. The report recommends that VDOT develop a pilot program that focuses on urban interstates initially and convene a task group to develop formal policies and procedures for use in the state.

FINAL REPORT

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ABSTRACT

The Federal Highway Administration has been encouraging states to improve their monitoring and tracking of the mobility impacts of work zones. The use of mobility performance measures will enable agencies to assess better the contribution of work zones to network congestion; to identify specific projects that are in need of remedial action; and potentially to assess penalties to contractors creating excessive, avoidable negative impacts. Although the Virginia Department of Transportation (VDOT) has defined allowable lane closure hours for the interstate system, VDOT has not defined specific performance measures and thresholds for what constitutes "unacceptable" work zone mobility impacts. Performance measures and thresholds have been developed by a number of other states, so there is a need to determine whether these could be adapted for use by VDOT.

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INTRODUCTION

The Federal Highway Administration (FHWA) has been encouraging states to improve the monitoring and tracking of the impacts of work zones by creating performance measurement programs that examine a broad range of exposure, safety, and mobility effects.[1] The accurate and consistent tracking of work zone mobility impacts has been particularly challenging, however, as states develop performance measurement programs. The location of permanent sensors may not be appropriate to monitor work zone mobility, and sensors could be taken off line because of construction activities. Having consistent and accurate work zone mobility performance data would allow state departments of transportation (DOTs) to assess better the overall contribution of work zones to network congestion; to identify specific projects that are in need of remedial action; and potentially to assess penalties to contractors creating excessive, avoidable delays. These data could also be useful in the evaluation of contractor requests to work outside predefined allowable work hours.

FHWA annually performs a work zone self assessment review of the Virginia Department of Transportation (VDOT).[2] Two key questions that FHWA has asked VDOT are:

1. Has the agency established measures (e.g., vehicle throughput or queue length) to track work zone congestion and delay?

2. Has the agency established work zone performance guidance that addresses maximum queue lengths, the number of open lanes, maximum traveler delay, etc.?[2]

Although the VDOT operations regions have developed allowable work hours tables that show when lane closures can be installed on major roads, there is increasing pressure to perform work outside the predefined allowable work hours. There is a need to develop acceptable thresholds for work zone mobility impacts so that requests to exceed the allowable work hours can be evaluated fairly and consistently across the state.

Some states have set threshold values for what constitutes "acceptable" work zone mobility impacts. When impacts at a site are expected to exceed these values, additional monitoring and countermeasures may then be put in place to try to mitigate the negative influence of the work zone. Exceeding predefined thresholds may also be used by some states to trigger financial penalties to a contractor. These operational thresholds can also be used to track work zone performance over time for performance measurement purposes.

A major challenge in implementing work zone mobility performance measures has been the availability of traffic condition data. Outside major urban areas, traditional point detector systems such as inductive loops or side fire radar are often located at wide spacings. This makes it unlikely that existing sensors would be available to provide data on many operational metrics used by DOTs. In urban areas, traditional sensor coverage is denser, but sensors are often taken off line during construction. Installing new sensors specifically to monitor work zone mobility is an option, but it is often cost-effective only for long-term, major projects. Even then, construction activities could require that sensors be relocated several times during the course of the project, resulting in additional expenses to the DOT. Given these issues, there is also a need to investigate potential sources of data that could support work zone performance measurement without creating large financial burdens for VDOT.

As VDOT begins to develop a work zone mobility performance measurement program, a number of questions related to how the program should be structured exist. These include:

- What performance measures should be used?
- What threshold values for unacceptable performance should be established?
- What data can be used to support this program?

PURPOSE AND SCOPE

The purpose of this study was to investigate issues related to the development of work zone mobility performance measures for Virginia. The specific objectives of this research were as follows:

- Review work zone mobility performance measures used by selected states.
- Identify mobility performance thresholds used by selected states, and find out how they were determined.
- Identify mobility performance measures that can be reasonably collected in VDOT work zones using existing data sources, and determine performance measures for a sample of problematic sites to identify key issues related to implementation of the performance measures.
- Based on the review of selected states and VDOT data, identify key issues in developing and implementing a work zone mobility performance measurement program.

The scope of this study was restricted to limited access highways, and only mobility performance measures were examined. The focus of the study was project-level performance measures. This study was not intended to develop a work zone performance measure program but rather to identify issues that VDOT must address internally as the program is developed.

METHODS

Four tasks were undertaken to achieve the objectives of the study.

1. Investigate work zone mobility performance measures and thresholds used in selected states.

2. Assess data sources for work zone performance measurement.

3. Perform case studies of VDOT work zone sites.

4. Meet with VDOT's Traffic Engineering Division (TED) to discuss the potential program framework.

Task 1. Investigation of Work Zone Mobility Performance Measures and Thresholds Used in Selected States

Information regarding performance measures and thresholds used in selected states was gathered through a literature review. Performance measures and thresholds used by selected states that were documented in the literature were synthesized, and follow-up information was gathered to determine how the performance thresholds were determined.

Literature Review

Relevant literature on work zone mobility performance measures was identified using the Transportation Research Board Transport Research International Documentation (TRID) database[3] and reviewed. A recent domestic scan[4] had already identified a number of states with performance thresholds for delay, queue length, or capacity, and additional information was located on the American Road and Transportation Builders Association National Work Zone Safety Information Clearinghouse.[5] This information was synthesized to show the range of performance measures and thresholds in use by specific states.

Review of Current State Practices

The review of current state practices included (1) gathering further information from the 12 states identified in the domestic scan regarding how their performance measurement thresholds were developed and how they are used in practice, and (2) investigating the practices of three states near Virginia (i.e., Maryland, North Carolina, and Pennsylvania) that had work zone mobility performance measure programs.

To gather further information from the 12 states, an email was sent to work zone personnel in each of the states (see the Appendix). Information was requested regarding the following:

- data sources used to develop the thresholds
- use of different thresholds for urban/rural areas of the state
- data collection methods for ongoing performance measurement
- proportion of sites monitored and how sites are chosen
- speed at which operational data were obtained (e.g., real time, monthly, quarterly, etc.)
- use of performance measures to address project-specific problems
- use of performance measures to address programmatic issues.

Task 2. Assessment of Data Sources for Work Zone Performance Measurement

Once potential performance measures were reviewed, the next step was to determine what data sources were available to VDOT to support project-level performance measurement. Existing mobility data sources were identified through consultation with VDOT staff. Existing data sources were reviewed, and data streams readily available to VDOT were identified for examination in Task 3. The objective of this task was to identify data sources that could support the program without creating significant additional financial costs to VDOT.

Task 3. Case Studies of VDOT Work Zone Sites

As part of the effort to identify operational performance measures and thresholds, the researchers determined performance measures for a sample of VDOT work zones that had been qualitatively deemed by VDOT field personnel to have poor operational performance, as evidenced by congestion and queuing at the site. Sites were selected to represent a variety of roadway environments so as to illustrate performance across a variety of conditions and consisted of sites where real-time traffic data were available. This served to show where these known, poorly performing work zones fit within operational thresholds developed by selected states. Case studies were selected to represent a variety of geographic regions, traffic volumes, and project durations. Information on the location and duration of the work zones was gathered by consulting with VDOT personnel, and these data were cross-referenced to available operational data (such as INRIX travel time data and VDOT detector data) to determine potential sites.

After viable sites were identified, performance measures for the candidate sites were calculated. These performance measures were then compared to thresholds established by selected states. Any difficulties in calculating specific performance measures or data limitations were noted. Sensitivity analyses on ways of aggregating the data were also performed.

Task 4. Meet with VDOT's Traffic Engineering Division to Discuss Potential Program Framework

The researchers met with staff of VDOT's TED to present the findings of the first three tasks. The meeting was used to discuss tradeoffs between different operational performance measures and thresholds. Issues related to how work zones are monitored, detection needs, and software requirements to support a sustainable program of work zone performance measurement were also discussed. The goal of this task was not to define a final framework but rather to help enumerate additional procedural issues that VDOT's central office and operational regions would need to agree to prior to implementing fully the work zone performance measurement program.

RESULTS

Work Zone Mobility Performance Measures and Thresholds Used in Selected States

Performance Measures

Two recent reports described work zone performance measurement best practices.[1,4] Two work zone mobility potential performance measures that are often discussed are delay and queuing. Delay is often used as a way to represent the additional travel time incurred as a result of work zone operations. Table 1 shows different ways to represent delay as a performance measure. Delay can be summarized in several ways, including the following:

- average delay per vehicle
- average delay per person
- total vehicle-hours of delay
- total person-hours of delay.

In order to calculate all of these delay metrics, the analyst must have at least two pieces of information:

1. average travel time or speed in the work zone
2. a benchmark travel time or speed for comparison purposes.

Table 1. Potential Delay Performance Measures for Work Zones

Measure (Unit)	Definition	Discussion
Delay per vehicle (hr/veh)	The average excess travel time experienced by each vehicle beyond what would have occurred under some benchmark condition	Shows the average delay each vehicle experienced because of the work zone. This normalized value allows for average experiences to be compared across work zones with different volumes.
Total delay (veh-hr)	The total excess travel time beyond what would occur under a benchmark condition	Shows the total delay caused by the work zone, suitable for direct conversion into total user costs.
Average speed (mph)	The time mean speed of vehicles	Average speed is easy to measure, but the location of data collection can have a significant effect on speeds obtained.
Average travel time (min)	The average time to traverse a given highway segment (can be translated to space mean speed)	Travel time is the basic measure of congestion and reliability and represents segment conditions better than point speeds.

Note: The information in this table was adapted from Ullman, G.L., Lomax, T.J., and Scriba, T., *A Primer on Work Zone Safety and Mobility Performance Measurement*, FHWA-HOP-11-033, Federal Highway Administration, Washington, D.C., 2011, and Margiotta, R., Lomax, T., Hallenbeck, M., Turner, S., Skabardonis A., Ferrell, C., and Eisele, B., *Guide to Effective Freeway Performance Measurement,* NCHRP Web-Only Document 97, National Cooperative Highway Research Program, 2006.

These values are compared to determine whether the work zone has created a negative mobility impact. As a result, the selection of the benchmark travel time/speed is a critical part of the calculation of delay. Common benchmarks for delay and their advantages/disadvantages are shown in Table 2.[1,6] The different benchmarks have tradeoffs in terms of ease of calculation/collection versus their ability to separate work zone impacts and background conditions.

Use of the total vehicle-hours of delay measure requires that consistent traffic volume data be available. The per-person measures also require that data on vehicle occupancy be available.

Queue performance measures to quantify the spatial or temporal extent of stopped/slowed traffic are often sought. Queue length is a popular work zone performance measure since it

Table 2. Advantages and Disadvantages of Different Benchmarks for Delay Calculations for Work Zones

Benchmark	Advantages	Disadvantages
Posted speed limit	Easily defined and understood, often readily available in department of transportation databases, provides constant benchmark for site	Posted speed limit may not be realistically attained during periods of the day with higher volumes, especially on arterial routes; may cause delay attributed to the work zone to appear higher than it actually is; free flow speed may exceed the posted speed limit, so travel at the posted speed may be perceived as a delay by a driver.
Free flow speed	Theoretical upper maximum of travel speed, easily understood, provides constant benchmark for site	Much of the daytime period will be determined to have delay even if there are no readily apparent operational issues; delay attributed to the work zone may appear higher than it actually is.
Historic average speed	Allows for separation of work zone impacts from preconstruction recurring congestion	Benchmark varies by time of day; data availability could be a problem (although data are provided by some private companies).

directly relates to how traffic control devices are set up at a site to provide advance warning. Table 3 summarizes different potential queue performance measures and issues with their application.

Table 3. Potential Queue Performance Measures for Work Zones

Measure (Unit)	Definition	Discussion
Average queue duration (min)	The average duration of a queue	Shows the duration of the queue that was attributable to the work zone. A minimum queue length and a time analysis window will need to be defined.
Average queue length (mi)	The average length of queue created by the work zone	Shows the length of the queue attributable to the work zone. However, defining the *beginning* and *ending* points of a queue can be a challenge. A time analysis window will need to be defined.
Number or percentage of time periods queuing occurred	The proportion of time a queue was present	Some work zones have only occasional queues, whereas others have queues almost daily. It may be difficult to detect and record infrequent queuing unless it is continuously monitored. A time analysis window will need to be defined.
Maximum queue length (mi)	The maximum queue length attributable to the work zone	This can help agencies assess whether advance warning signage is placed far enough in advance to warn approaching motorists adequately. Queue lengths can change rapidly over time and may be at a maximum for only a very short period of time. Queue lengths may differ by lane, depending on the geometrics of the roadway and driver behavior.
Percentage of time work zone queue length exceeded distance threshold	The percentage of time the queue length exceeded a predefined threshold value in miles	Combines queue frequency, length, and duration into a single performance measure. Requires continuous monitoring of traffic conditions. A time analysis window will need to be defined.

Note: The information in this table was adapted from Ullman, G.L., Lomax, T.J., and Scriba, T., *A Primer on Work Zone Safety and Mobility Performance Measurement*, FHWA-HOP-11-033, Federal Highway Administration, Washington, D.C., 2011, and Margiotta, R., Lomax, T., Hallenbeck, M., Turner, S., Skabardonis A., Ferrell, C., and Eisele, B., *Guide to Effective Freeway Performance Measurement,* NCHRP Web-Only Document 97, National Cooperative Highway Research Program, 2006.

Performance Thresholds in Selected States

Thresholds Identified in Recent Domestic Scan

Table 4 summarizes major performance thresholds that were identified during a recent domestic scan of 15 agencies (including 14 state DOTs) entitled *Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation*.[4] In Table 4, *delay performance measures* refer to average delays per vehicle and *queue length measures* refer to the maximum observed queue length.

Twelve of the 14 state DOTs included in the domestic scan (listed in Table 4) had defined a mobility performance measure threshold that was deemed to be acceptable to the DOT. Eight states used delay and 4 used queue length as the major mobility performance measure. The scan report noted that the use of these thresholds varied from agency to agency. For example, the

Table 4. Work Zone Mobility Performance Measures and Thresholds

Agency	Performance Measure	Performance Threshold
California DOT	Delay	0 to 20 min delay depending on location and complexity of project
Florida DOT	Queue length	2-mi maximum queue on interstates or highways with speed > 55 mph
Indiana DOT	Queue length	Queues cannot be present for >6 continuous hours or for more than 12 hr/day; queues > 1.5 mi are not permitted, and queues between 0.5 and 1.5 mi are limited to between 2 hr and 4 hr, depending on length
Maryland DOT	Queue length	Freeways: queues > 2 mi are not acceptable, queues < 1 mi are permitted, and queues between 1 and 1.5 mi are limited to 2 hr
	Delay	Delays < 15 min on arterials
	Level of service (LOS)	LOS requirements are set separately for signalized and unsignalized intersections depending on initial LOS
Michigan DOT	Delay	Delays < 10 min
	Volume/capacity (V/C)	V/C < 0.8
	LOS	Drop in LOS < 2 levels, no LOS worse than D
Missouri DOT	Delay	Delays > 15 min are considered excessive
New Hampshire DOT	Delay	Delays > 10 min undesirable
New Jersey DOT	Delay	Delays < 15 min
Ohio DOT	Queue length	Queues > 1.5 mi are not acceptable
Oregon DOT	Delay	Delays < 10% of the peak travel time
Pennsylvania DOT	Delay	Delays between 15 and 30 min limited to 2 consecutive hours
Wisconsin DOT	Delay	Maximum of 15 min of added delays between major city nodes

Note: The information in this table was adapted from Bourne, J.S., Eng, C., Ullman, G.L., Gomez, D., Zimmerman, B., Scriba, T.A., Lipps, R.D., Markow, D.L., Matthews, K.C., Holstein, D.L., and Stargell, R., *Scan 08-04: Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation,* National Cooperative Highway Research Program, Washington, D.C., 2010.
DOT = department of transportation.

thresholds may be used to assess the impact of basic maintenance-of-traffic (MOT) alternatives during preliminary design, to develop mitigation strategies during final design, or to evaluate mitigation strategy effectiveness during construction.[4] For delay thresholds, 3 states used 15 min, 2 used 10 min, 2 used up to 30 min with some conditions, and 1 used 10 percent of the peak travel times. For queue length thresholds, 2 states used queues greater than 1.5 and 2.0 mi as not permitted. Two states accepted queues between 1 and 1.5 mi for up to 2 hr, and another state accepted queues of 0.75 to 1.5 mi. Two states also included level of service changes as a performance measure.

Threshold Development and Usage by 12 State DOTs Identified in Domestic Scan

As discussed previously, an email was sent to 12 state DOTs covered in the domestic scan,[4] and 6 responded (see the Appendix). For 5 of the 6 responding states, the thresholds were developed by a team; there was no documentation that described why the threshold value was selected. One state stated that its threshold was based on driver tolerance research done several years ago, but a reference was not provided when requested. Four of the 6 responding states applied the thresholds to interstates and freeways only, and 2 of the 6 applied it to all roadways. For 5 responding states, the thresholds applied for both urban and rural roads. One state took into consideration the presence of queuing under normal conditions when evaluating the results. Another state acknowledged that a major metropolitan area was held to a different standard than the rest of the state.

Five of the 6 responding states relied on private sector data sources as opposed to DOT-maintained sensors to calculate their performance measures. Five of the responding states used real-time or close to real-time data to monitor the operational performance. Data from INRIX or SpeedInfo were cited as data sources, and RITIS (Regional Integrated Transportation Information System) was cited as a management tool for querying the INRIX data. One state collected data using field measurements on select projects determined by the region and the construction engineering staff. Four responding states had data on all interstate projects, and 1 collected data on a select number of projects.

Actions taken when the performance threshold values were exceeded also varied among the 6 responding states. If the threshold value was exceeded, 1 state did a performance review, 2 considered adjustments to the traffic control plan, and 2 requested a waiver from the performance thresholds. One state could request a waiver only in the planning stage based on expected queues. One state had the option to consider a waiver. One state indicated that the threshold was a goal and not a firm limit. Three responding states used performance measures to address project-specific problems in the project planning process and to determine if modifications were needed. One state used performance measures to address programmatic issues to evaluate lane closures to see if predicted delays occurred in the field, and another state used them to learn from past experiences to apply to future projects.

Based on the information received from the 6 responding states, it appeared that the primary purpose of the thresholds was to serve as a goal to guide the development of transportation management plans (TMPs) to accommodate the thresholds. More effort seemed to be expended and emphasis placed on the planning phases and development of TMPs than on monitoring and addressing project and program level issues following the start of construction activities.

Thresholds in Nearby States

As discussed previously, since VDOT is particularly interested in the activities of nearby states, the Maryland, North Carolina, and Pennsylvania programs were investigated in greater detail. The three had different performance measures and thresholds. Maryland used a combination of criteria that address freeways (queue length), arterials (delay), and intersections (level of service), as shown in Table 4. North Carolina[7] and Pennsylvania[8] examined only freeways and used queue length/duration and delay, respectively, to assess work zone mobility.

North Carolina developed performance criteria using a combination of queue lengths and queue duration to apply to work zones on interstate and other access-controlled, high-speed freeways.[7] Their performance criteria were:

1. All queues less than 0.75 mi are acceptable for any duration of time.

2. Queues greater than or equal to 0.75 mi and up to 2 mi are acceptable for a duration of up to 2 hr.

3. Queues that exceed 2 mi are unacceptable.

North Carolina regarded a queue as a point at which traffic is either stopped or slowed more than 25 mph below the posted speed limit to the point where traffic has resumed an average speed of 45 mph or greater.[7]

It should be noted that the Pennsylvania threshold provided in the follow-up response had changed from that listed in the domestic scan report (shown in Table 4). PennDOT's current Work Zone Safety and Mobility Policy has three goals, including striving to keep work zone—related additional travel delays less than 20 min when compared to the base condition.

Pennsylvania's threshold goal is applied as follows. If a project is located on a fully controlled, limited access highway such as an interstate, the Pennsylvania Turnpike, or other freeway and the project occupies a location for more than 3 days with either intermittent or continuous lane closures, then:

- Project delays are considered non-significant if additional (project-related) travel time through the project area (including detours) is ≤20 min.

- Project delays are considered significant if additional (project-related) travel time through the project area (including detours) is >20 min for time periods of two or more consecutive hours. These projects require a TMP.

These thresholds are applied statewide. This criterion determines the need for a TMP and is not directly used for operational performance monitoring. Pennsylvania is planning to use INRIX data for monitoring work zones, but how this delay measure will be used to track project-level and programmatic performance is yet to be determined.

Assessment of Data Sources for Work Zone Performance Measurement

Overview

DOTs must consider accuracy and availability of data when developing a work zone performance measurement program. Although it is important that the performance measure selected relate to the mobility issues under scrutiny, the difficulty of obtaining these data elements must also be explicitly considered.

Data can be collected in several ways, and they, along with their data sources, each have their own advantages and disadvantages. Table 5 summarizes some of the advantages and disadvantages of different methods of collecting queue, speed, and travel time data along with their data sources.[9]

Table 5. Advantages and Disadvantages of Selected Methods of Data Collection With Accompanying Data Sources

Data Type	Data Source	Advantages	Disadvantages
Manual measurement of queues	Field observations	Easy to implement	Data are biased since not all field personnel are trained equally and measurements may vary by observer. Increased workload for field personnel. Difficult and costly to attain 24/7 coverage.
	Closed circuit television (CCTV) cameras	If CCTV is already present, this method is cost-effective and easy to implement	Data are biased since not all traffic management center staff are trained equally and measurements may vary by observer. Increased work load for staff. If CCTV not present, setting up portable CCTV can be costly.
Automatic measurement of point speeds	Existing point sensors	Minimal cost and able to do before and after comparisons	Location of devices may not be optimal for work zone assessment purposes; devices may be removed during construction.
	Work zone intelligent transportation systems (Smart Work Zones)	Can control where devices are placed, and minimal additional cost if system installed to provide real-time travel time information or other purposes	Costly to include in a project if not otherwise planned.
	Portable traffic monitoring devices	Commonly used by DOTs	Frequent maintenance of devices is required; costs on long-term projects may be significant.
Automatic measurement of segment travel times	Automatic vehicle location systems	Accurate tracking of speed profiles over duration of congestion	Vehicle fleets to draw data from are limited and will require agreement with vendors who collect these data.
	Automatic vehicle identification	On toll facilities, available sample sizes are high and easily implemented	If not already installed, installation of additional transponder readers will increase costs. Sample size likely to be small on non-toll facilities.
	License plate recognition systems	Available sample sizes are high	Costly to implement.
	Bluetooth readers	Data can be obtained unobtrusively from roadside devices, relatively low cost	Detection range can vary depending on site conditions. Queue difficult to measure without multiple, closely spaced sensors. Construction activities could interfere with system.
	Private sector travel time data	Does not require agency to purchase and maintain the technology, wide coverage area possible	Data can be costly and likely would not be procured for work zone performance measurement alone. Spatial granularity of data could be an impediment to use.

Note: The information in this table was adapted from Ullman, G.L., Lomax, T.J., Ye, F., and Scriba, T., *Work Zone Performance Measures Pilot Test*, FHWA-HOP-11-022, Federal Highway Administration, Washington, D.C., 2011.

Private Sector Data

As noted in the Task 1 results, a number of states identified in the domestic scan report[4] as having model work zone mobility performance measurement programs used private sector travel time data to calculate work zone performance measures. These systems overcome many of the cost and maintenance issues associated with manual or spot data collection methods. Travel time and speed data from these vendors are increasingly being mainstreamed into DOT operations to support performance measurement and real-time traveler information, so they offer a good opportunity to leverage existing resources for work zone performance measurement. For example, the Texas A&M Transportation Institute's *Urban Mobility Report*[10] currently uses INRIX data to quantify congestion in U.S. cities, and VDOT and the Maryland State Highway Administration use INRIX data to provide real-time traveler information on overhead variable message signs.[11,12] Since VDOT has already purchased real-time travel time data from INRIX, this data source could also be used for work zone performance monitoring.

Private sector companies typically create their travel time estimates using global positioning system (GPS) data obtained from commercial fleet management systems and private vehicles using navigation or traveler information smart phone applications. These location data are then processed to estimate travel times on roadways. Several studies have shown that these data are generally accurate on freeways and can be used for real-time traveler information and freeway performance measurement.[13,14] Therefore, the data stream appears to be appropriate for deployment for work zone applications.

Private sector data have been used specifically to generate work zone project-level performance measures in several states. One recent study developed work zone travel time reliability measures for 15 projects in Virginia.[15] The Ohio DOT has also developed a systematic program to track mobility performance measures on a project-level basis using private sector data from INRIX. Figure 1 shows an example of performance measures generated for one project in Ohio (R. Stargell, unpublished data). The performance measure shown is the number of hours where work zone speeds were less than 25 mph. Monthly performance is shown and contrasted to preconstruction performance and speeds observed during the prior calendar year.

Overall, it appears that private sector data can serve as a viable data source for delay measures. Generally, private sector data lend themselves most directly to measuring delay in terms of average delay per vehicle. Accurate volume data from point detectors are often not available at work zones, limiting the ability of a DOT to determine total delay. Depending on the vendor selected, each of the benchmarks listed in Table 2 may be available, so the DOT would need to determine which measure would be most widely accepted by the agency. Performance measures involving total delay or per person measures can be partially fed by the private sector data stream but would require fusion with other data streams to create the final measure.

Although private sector data directly report travel times and speeds, queue lengths are not measured directly. When private sector data are used to develop this measure, queued traffic is typically identified based on when the reported travel speeds drop below a predefined threshold. Thus, selection of this threshold will have a direct impact on the estimated length and duration of

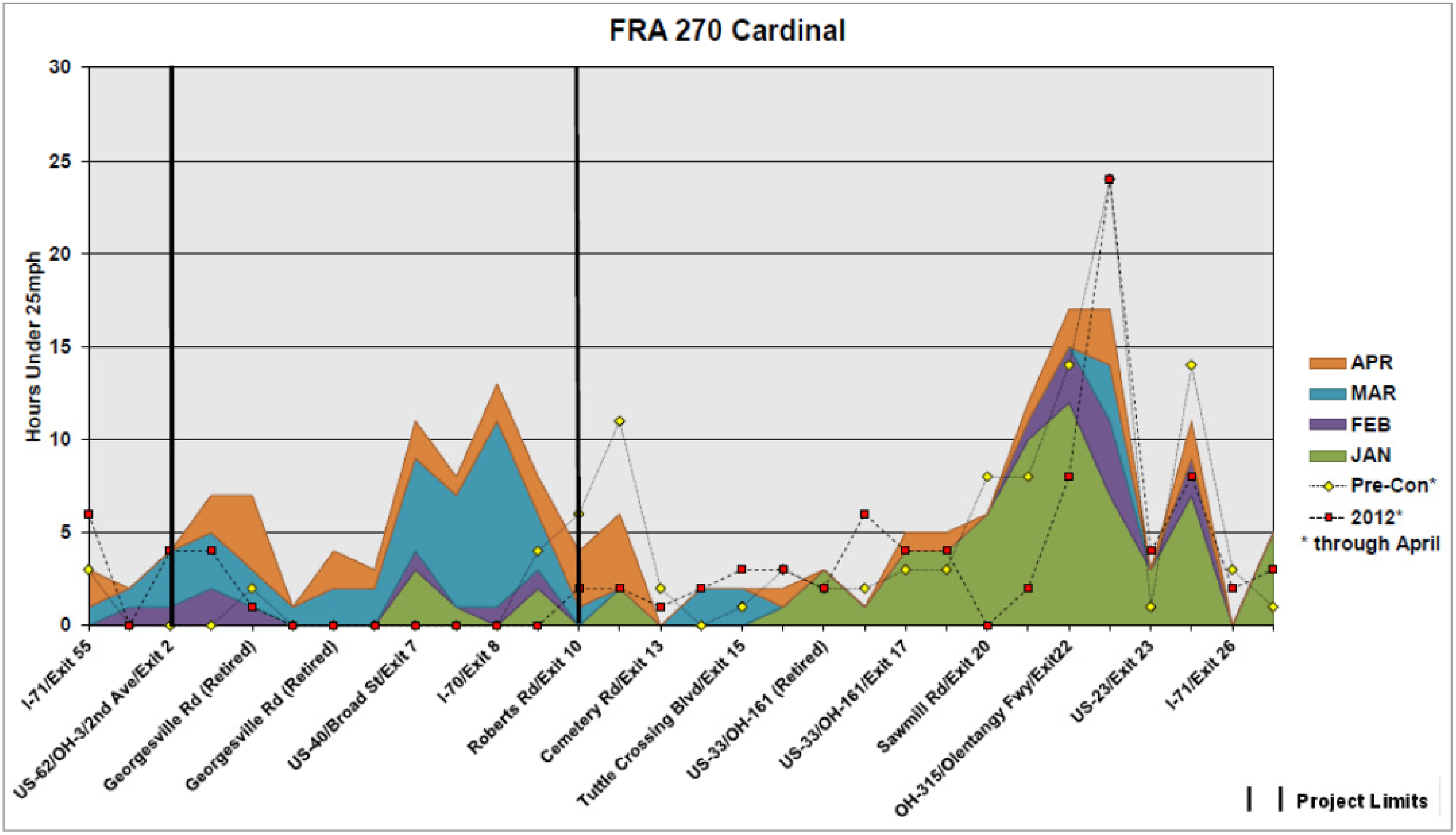

Figure 1. Example of Work Zone Performance Measures From the Ohio Department of Transportation (R. Stargell, unpublished data)

queues. For example, one study in North Carolina defined a queue as being present from when traffic is either stopped or slowed more than 25 mph below the posted speed limit until it has reached an average speed of 45 mph or more.[7] If a DOT used different thresholds, the estimated queue length and duration would change.

Another concern about the use of private sector data to assess queue length relates to the way in which speed/travel time data are reported by the vendor. Many vendors report travel times and speeds using Traffic Message Channel (TMC) links. TMCs were defined by mapping companies as a consistent way to report traveler information on digital mapping devices.[16] TMCs have been typically defined as homogeneous segments between major interchanges or intersections. If a queue is defined as when a TMC falls below a certain speed threshold, this will cause the entire TMC to be categorized as either queued or not queued.

The interaction of the TMC length and the speed threshold plays an important role when private sector data are used to estimate queue length. TMC lengths can vary considerably depending on roadway functional class and setting. Urban TMCs are often very short, allowing more precision in the estimation of queue lengths. In rural areas, however, TMCs can be much longer, which can obscure the impact of the work zone in a local area. This can be a problem, particularly in work zones since project boundaries or impacts may not align well with the TMCs. One study of 15 work zones found that, on average, an additional 1.8 mi of non–work zone roadway was included in the TMCs that contained the work zone.[15] To illustrate the impact of this spatial mismatch, an 8-mi-long TMC that has a 2-mi work zone in the middle of it can be considered. In this case, the private sector data might never detect any localized queuing at the work zone since impacts would be "washed out" by the conditions on the other 6 mi of the TMC.

Case Studies of VDOT Work Zone Sites

Selection of Data Source

Based on the review of performance measures in use in other selected states and the assessment of data sources, private sector travel time data from INRIX were selected for further evaluation as a data source for work zone performance measures in Virginia. This was done for several reasons.

1. The INRIX data are used by a number of states identified as leaders in work zone performance measurement.

2. VDOT has already purchased statewide real-time INRIX data. This minimizes the costs to implement a work zone performance measurement program. Statewide coverage is available, and no field equipment needs to be deployed. This provides the maximum flexibility for the program moving forward.

3. The data quality of the INRIX data has been validated by VDOT on freeways. An ongoing project by the Virginia Center for Transportation Innovation and Research

(VCTIR) has shown that data quality on freeways is within bounds deemed acceptable by VDOT.[14]

4. The INRIX data can be used to develop both delay and queuing performance measures.

Selection of Case Studies

Four case studies from Virginia were conducted to illustrate the abilities, limitations, and key tradeoffs that must be made when private sector data are used to develop project-level delay and queue length estimates. The Regional Integrated Transportation Information System (RITIS) developed by the University of Maryland[17] was used to acquire real-time INRIX data for four work zone sites in Virginia with a range of traffic and site characteristics. Information from VDOT was used to identify study locations, define the time periods when the work zone was active, and identify specific work zone activities that were occurring. In all four cases, field observations noted that queuing and congestion were present during the work activities.

Although all four case studies involved interstate work zones, each had traits that could pose a challenge when private sector data are used. The four case studies evaluated were:

1. *I-81 Northbound, Milepost (MP) 191-200.* This site involved a lane closure in a rural, mountainous area of the state. This site was used to illustrate whether performance measures could be generated under lower volume conditions during overnight hours in rural areas.

2. *I-95 Southbound, MP 74-84.* This site was located in an urban downtown area with densely spaced interchanges, but construction occurred overnight, when private sector data are often more limited. Two of three lanes were closed.

3. *I-95 Southbound, MP 158-161.* This case study examined a 1-day project occurring during overnight hours in a suburban area and served to illustrate whether short-term work zone impacts could be captured accurately. Two of three lanes were closed at this site.

4. *I-81 Southbound, MP 118-140, and U.S. Route 460/11.* This case study involved a full freeway closure in a rural area and a subsequent detour onto a parallel arterial route. It served to illustrate whether impacts attributable to the work zone could be captured on surrounding facilities.

Data Collection and Performance Measure Calculation

First, information on the spatial extent and duration of the work zones was collected for each site from VDOT project summaries. Specific information acquired included the location of the work zone, time when the work zone was active, nature of the work zone, and traffic volumes. Dates and times when lane closures or detours were present were also noted. Since the focus of this study was project-level performance measures, data for 1 day in which congestion was present at each site were reviewed to illustrate some tradeoffs and issues that VDOT must confront when calculating performance measures using private sector data.

Next, speed and travel time data were acquired based on the project information. The two metrics selected for investigation were average delay per vehicle and queue length. INRIX data were downloaded using the RITIS Massive Raw Data Downloader based on each site's location and the time when work zone impacts were observed. For the purposes of the work zone impact analysis, it is important to download data that extend farther than the work zone limits in order to capture any impacts that may extend past the advance warning area. For example, if the work zone limits were MP 50 to 60, data were initially queried for at least MP 45 to 70 to ensure that the full extent of congestion and queuing was collected. Data were then aggregated using both 1-hr and 5-min intervals to compare and contrast the impacts of temporal aggregation on the resulting performance measures.

The procedure for performance measure calculation was as follows:

1. *The maximum spatial extent of the queuing and congestion was determined.* Historic speeds at the site when no work zone was present were provided by INRIX as a benchmark to compare against real-time data while the work zone was active. For each TMC and each time interval, the historic average speed was compared to the real-time speed when the work zone was present. If real-time speeds were less than 90 percent of what was observed historically on that TMC at that time of day, the researchers assumed that the TMC was impacted by the work zone. To be conservative, if a TMC was determined to be affected by the work zone at any given interval, the TMC was retained throughout the analysis period. Any TMCs that never dropped below this threshold were assumed not to be impacted by the work zone and were removed from further analysis.

2. *The TMCs were examined to determine whether traffic was queued.* RITIS uses a threshold of 60 percent of the historic average speed to determine bottleneck locations,[18] and this threshold was adopted as the threshold for determining queued traffic. If a TMC speed dropped below 60 percent of the historic average speed, it was marked as queued. The lengths of the contiguous TMCs falling below this threshold during each time interval were summed to determine the queue length. The duration when any link was marked as queued was used to determine the overall queue duration at the work zone. The use of the historic data benchmark allows for the separation of work zone impacts from preexisting recurring congestion at the site.

3. *To determine the delay caused by the work zone, the sum of the historic travel times across contiguous impacted TMCs was subtracted from the observed travel time during work zone operations on those same TMCs.* This provides a measure of the average delay per vehicle created by the work zone. This represented instantaneous delay in the work zone.

The performance measures were then compared across sites to help illustrate variations in the quality of performance measures that could be generated from private sector data.

Case Study Results

Case Study 1: I-81 Northbound, MP 191-200

This case study was a work zone on I-81 Northbound from MP 195 to 197 in Rockbridge County, Virginia. The right lane of a two-lane directional segment was closed as part of ongoing work on a truck climbing lane project. The section was located in a rural area and had a grade of approximately +2.9 percent. The 2012 directional annual average daily traffic (AADT) was approximately 20,000 veh/day.[19] This work zone project began in February 2009 and had an estimated completion date in late 2013, but this case study focused on data from June 9, 2012. Although the work zone was present only from MP 195 to 197, the INRIX data revealed traffic impacts that extended from MP 191 to 200.

Figure 2 shows the average delay between MP 191 and 200 between 7:00 P.M. and 11:30 P.M. using both 1-hr and 5-min aggregation intervals. Figure 2 shows that there was a marked difference in the performance measures calculated depending on the aggregation interval used. Using a 1-hr interval served to dampen variation in the data at this site. The maximum delay was 20.56 min using the 1-hr interval and 31.52 min using the 5-min summary interval. This difference could create significant impacts, depending on how the performance measures are being used at the project level. If they are being used to assess penalties to contractors or determine compliance with work zone performance measures, an hourly aggregation interval would be less likely to detect subhourly intervals where the contractor exceeds allowable thresholds. Thus, although an hourly aggregation interval may reduce the analytical workload for the development of monthly or annual programmatic work zone performance measures, it may be very conservative if it is being used to assess real-time contractor compliance with operational targets.

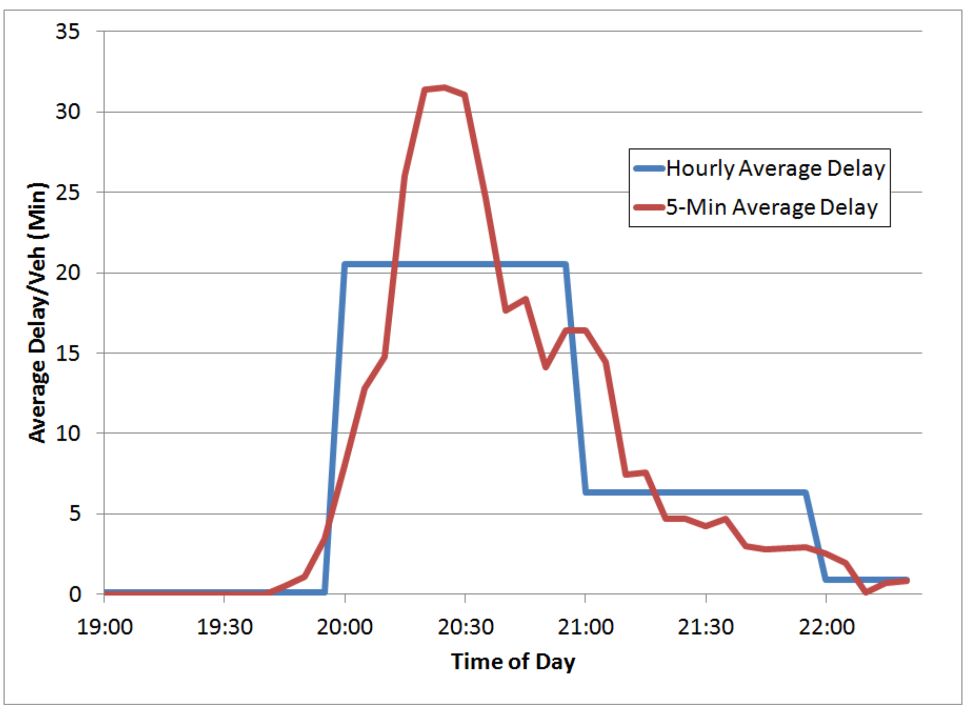

Figure 2. Average Delay for Case Study 1 on June 9, 2012, Between 7:00 P.M. and 11:30 P.M.

Figure 3 shows the queue length estimated at this site using the private sector data. The queuing diagram exhibits far less variation than the delay figure attributable to the influence of the TMC size. In this case, the 9.3-mi analysis length was composed of only four TMCs, which ranged in length from 0.58 to 5.04 mi. Since each of these TMCs was identified as either queued or not queued based on the speed threshold noted earlier, this produced a queuing figure that resembled a step function with very sudden changes. In this case, long TMCs (such as the 5.04-mi section) create impediments to using private sector data for queuing performance measures in rural areas. These issues are not present in the delay calculations at this site, however. This indicates that queue measures should be viewed with caution in rural areas because of the influence of average TMC size on the queue length estimates.

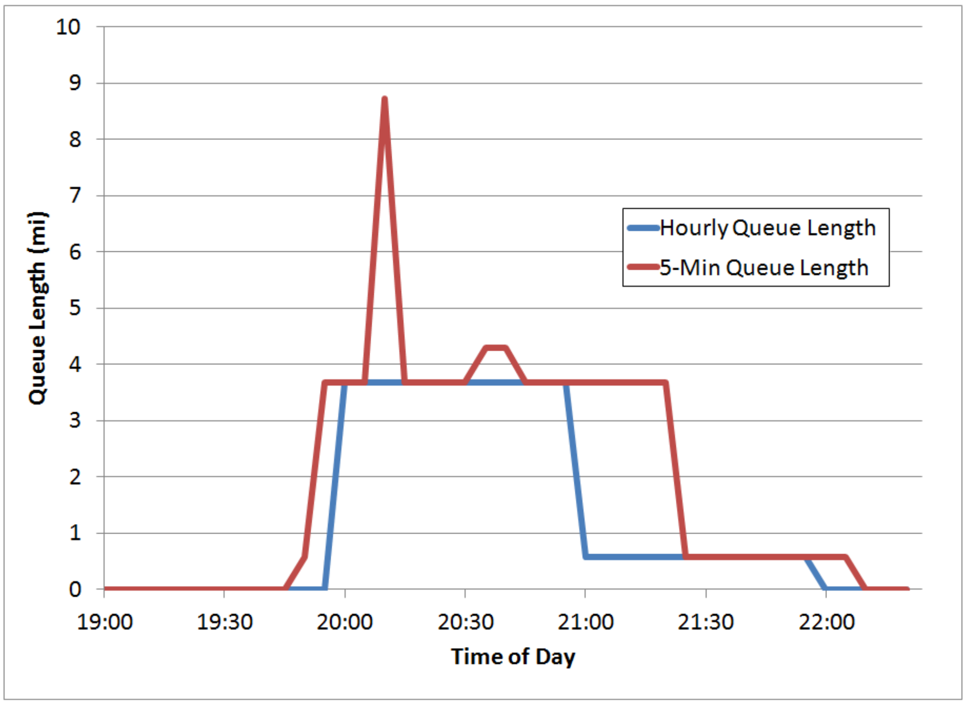

Figure 3. Queue Length for Case Study 1 on June 19, 2012, Between 7:00 P.M. and 11:30 P.M.

Case Study 2: I-95 Southbound, MP 74-84

This case study involved closure of two of three southbound lanes on I-95 in downtown Richmond, Virginia, on Sunday through Thursday evenings from 8 P.M. to 6 A.M. between September 20, 2012, and October 5, 2012. I-95 was reduced to one travel lane in each direction between the Lombardy Street Bridge (MP 77) and Laburnum Avenue (MP 79). Although drivers were advised to follow posted detour routes, significant congestion was still observed on I-95. The 2012 AADT at this location was approximately 65,000 veh/day.[19] Based on the INRIX data, the work zone impacts extended from MP 74 to 84.

Figures 4 and 5 show the results of the delay and queue performance measure calculations at this site on September, 30, 2012, between 8 P.M. and midnight. Figure 4 shows the delay performance measure calculations for the site for the 1-hr and 5-min aggregation intervals. In this case, there are smaller differences between the two aggregation intervals than in Case Study 1, but the hourly aggregation interval still served to dampen the impact of the

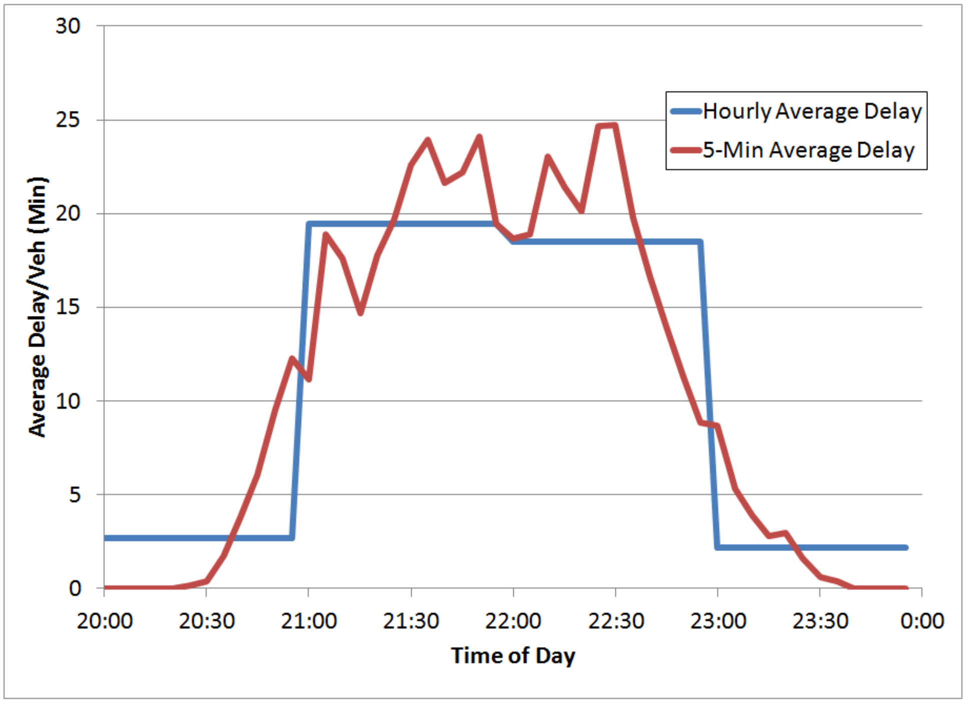

Figure 4. Average Delay for Case Study 2 on September 30, 2012, Between 8 P.M. and Midnight

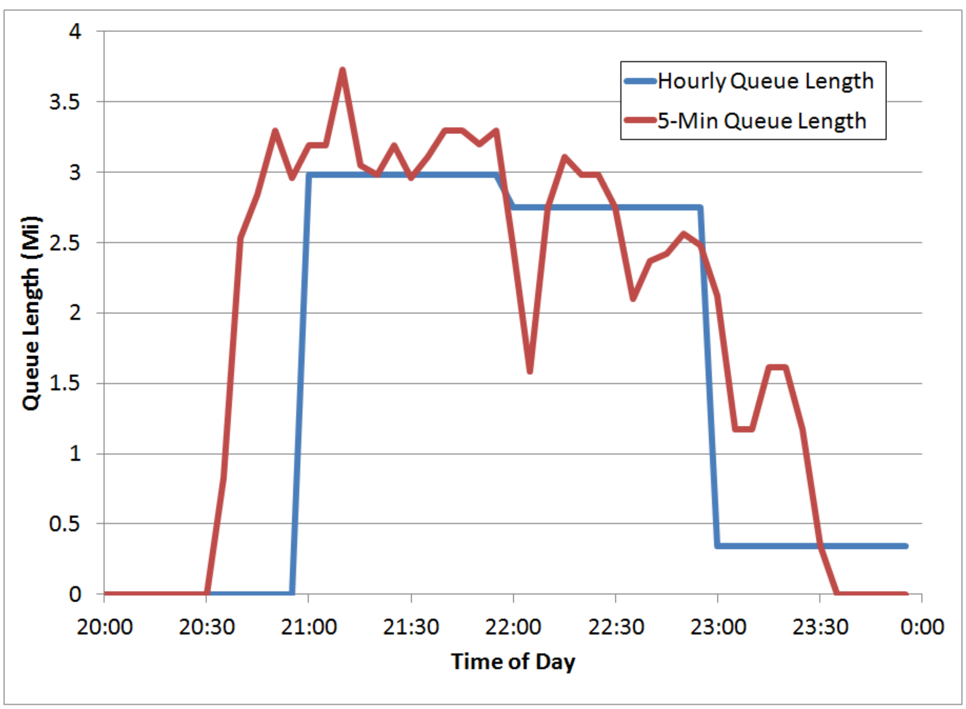

Figure 5. Queue Length for Case Study 2 on September 30, 2012, Between 8 P.M. and Midnight

work zone peaks. It also failed to capture the onset and dissipation of congestion at the site as accurately since the start and end of congestion both happened approximately midway through the hour.

Figure 5 shows the queuing profile for the site and serves as a contrast to Case Study 1. The total analysis length of this site was similar to that of Case Study 1 (9.3 mi for Case Study 1 vs. 9.6 mi for Case Study 2), but many more TMCs were present for Case Study 2. A total of 4 TMCs were available for Case Study 1 vs. 17 TMCs for Case Study 2. The 17 TMCs for Case Study 2 ranged in length from 0.08 to 1.89 mi. The shorter mean TMC length for Case Study 2 is representative of what is often seen in urban areas where TMCs have been created based on complex, closely spaced interchanges. This granularity, in turn, permits much more accurate estimates of queue length to be developed in comparison to more rural cases with longer TMCs. The 5-min aggregation interval still reflects changing queues more rapidly, as well as the subhourly variation, but differences between 1-hr and 5-min results were generally not as large as in Case Study 1.

Case Study 3: I-95 Southbound, MP 158-161

This case study examined a short-term work zone on I-95 Southbound in Prince William County, Virginia. At 9 P.M. on February 17, 2012, VDOT removed a 30-ft-tall cantilevered sign structure located on southbound I-95 at the interchange with the Prince William Parkway in Woodbridge, Virginia. The 2012 directional AADT of this section of road was approximately 80,000 veh/day.[19] Two of three lanes were closed, but motorists could avoid delays by using the parallel high-occupancy vehicle (HOV) lanes. The INRIX data showed that the area impacted by the work zone extended for approximately 3.5 mi from MP 158 to 161.

This case study served to examine whether performance measures could be determined for a one-time, short-term work zone that occurred during overnight hours. Real-time data were available for this site, and measured impacts were corroborated by field observations. Figure 6 shows the delay measurements at the site. Generally speaking, this site showed greater consistency between the 5-min and 1-hr aggregation intervals than in the other case studies. In general, the 5-min results were within ±5 min of the 1-hr averages. Once again, the 5-min intervals showed more variability in results.

Figure 7 shows the queues at the site. Since this was an urban area, TMC sizes were relatively short. The 3.56-mi analysis length was composed of five TMCs with lengths between 0.36 and 1.42 mi. Similar to the delay calculations, the results were relatively similar between the 5-min and 1-hr aggregation intervals. The small average TMC length also allowed for reasonably detailed queue length estimates to be generated. Estimated queue length durations were longer for the 1-hr aggregation interval, however, since the onset and dissipation of congestion were not captured to as great a temporal resolution as the 5-min aggregation interval.

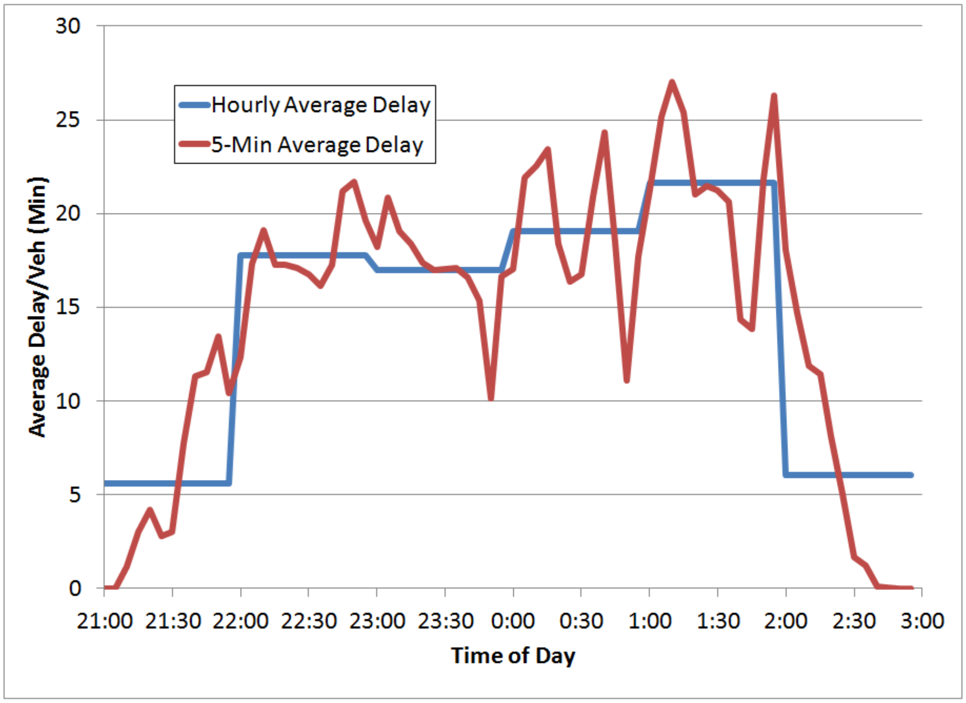

Figure 6. Average Delay for Case Study 3 on February 17, 2012, Between 9 P.M. and 3 A.M.

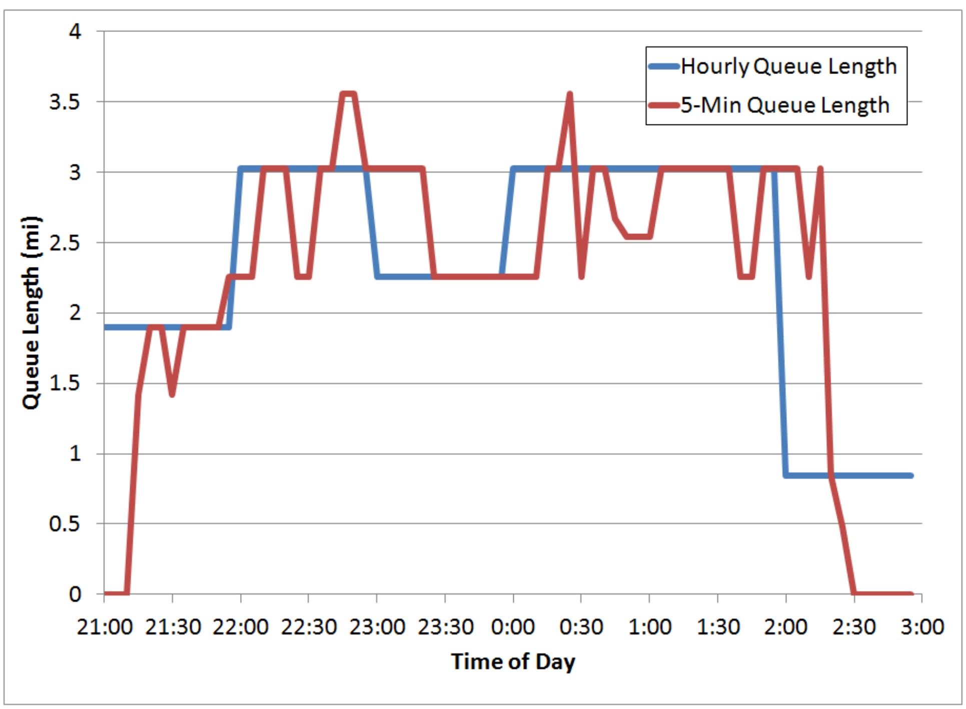

Figure 7. Queue Length for Case Study 3 on February 17, 2012, Between 9 P.M. and 3 A.M.

Case Study 4: I-81 Southbound, MP 118-140, and U.S. 11/460

This case study involved construction of a new truck climbing lane on I-81 Southbound between Salem and Christiansburg, Virginia. This project began in 2010 and was completed in late 2013. The work zone was located on an existing two-lane directional segment with a +3.7 percent grade sustained for 2.2 mi and a 2012 directional AADT of 25,000 veh/day.[19] On July 18, 2012, a full interstate closure was conducted because of blasting operations on I-81. Traffic was detoured onto U.S. 11/460 at I-81 Exit 132 and back onto I-81 at Exit 118. The detour route had a 2012 AADT (without detour traffic) of approximately 18,000 for both directions of travel combined.[19] The detour route was a four-lane divided arterial that transitioned into a two-lane rural road.

On the day studied, the detour was implemented between 10:30 A.M. and 1:00 P.M. A right-lane closure was also in place on westbound Route 11/460 during the detour. The INRIX data showed work zone impacts extended for approximately 8 mi from MP 132 to 140 on I-81 and throughout the length of the detour route. This case study served to illustrate how the private sector data can be used to assess systemwide impacts of work zones on parallel facilities and issues related to the use of the data on arterial roads.

Figures 8 and 9 show the delay and queuing impacts on I-81 as a result of the freeway closure. The section of road monitored was 16.8 mi long and consisted of six TMCs. The TMCs ranged in length from 0.17 to 8.64 mi. Figure 8 shows that using a 1-hr aggregation interval masks many subhourly variations, sometimes causing an underreporting or over-reporting of delay by almost 15 min/veh. The onset and dissipation of congestion are also not captured adequately. Figure 9 shows the estimated queue. The maximum queue is significantly lower using the 1-hr interval, and the duration of queuing is also underestimated by approximately 1 hr. In this case, the TMC located closest to the diversion point was 4.42 mi long. As a result, the initial queue quickly changed from 0 to 4.42 mi. The relatively coarse spatial granularity on the section of rural interstate makes the queuing estimates less reliable than what was seen in Case Studies 2 and 3.

Figures 10 and 11 show conditions along the arterial detour route during the freeway closure. The detour route was 10.73 mi long and composed of only two TMCs, which were 4.35 and 6.38 mi long. Figure 10 shows the delay on the detour route. The figure shows that the hourly aggregation significantly deviated from the 5-min aggregation during the onset and dissipation of congestion. When the data in Figure 10 are combined with the data from Figure 8 along with vehicular volume information, it should be possible to determine a combined user delay impact for the entire work zone. Figure 11 shows the estimated queue. Given that only two TMCs were available over the entire 10.73-mi detour route, the estimated queues are very coarse and cannot be assumed to show the spatial extents of queuing reliably. There is also a significant difference in the estimated queue duration of about 1 hr between the 1-hr and 5-min aggregation intervals. Again, use of the hourly data causes the averages to be much lower than when shorter durations are used.

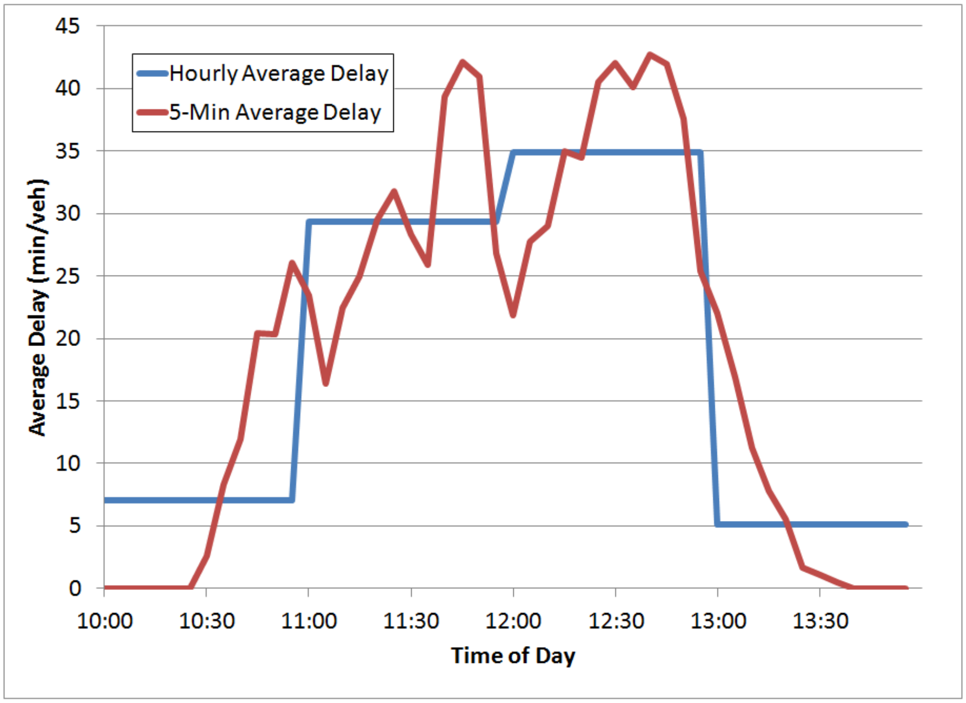

Figure 8. Average Delay on I-81 for Case Study 4 on July 18, 2012, Between 10 A.M. and 2 P.M.

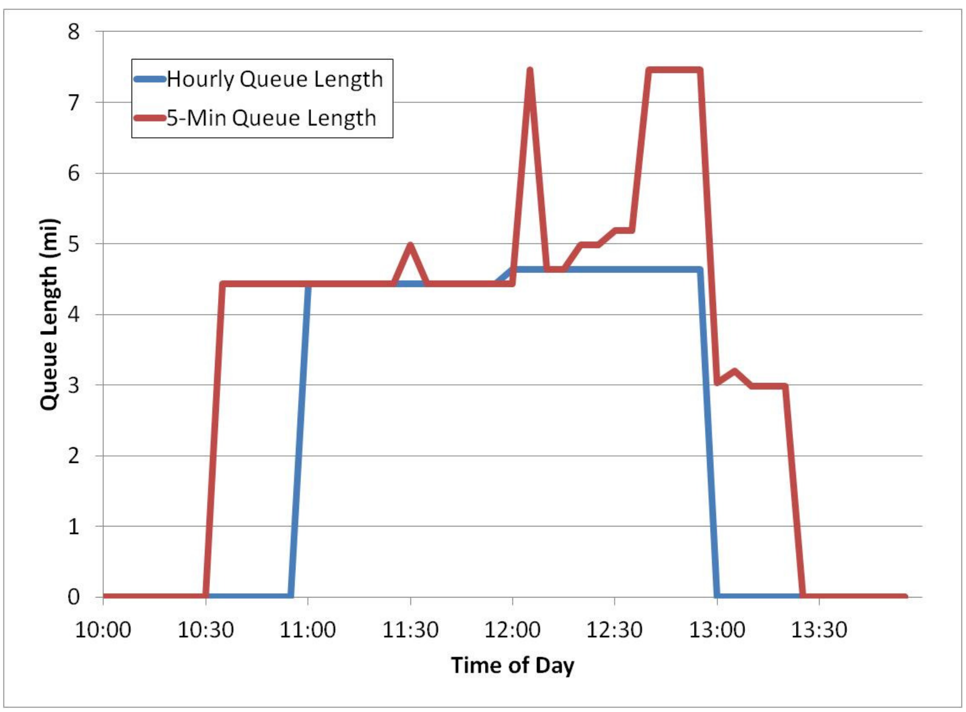

Figure 9. Queue Length on I-81 for Case Study 4 on July 18, 2012, Between 10 A.M. and 2 P.M.

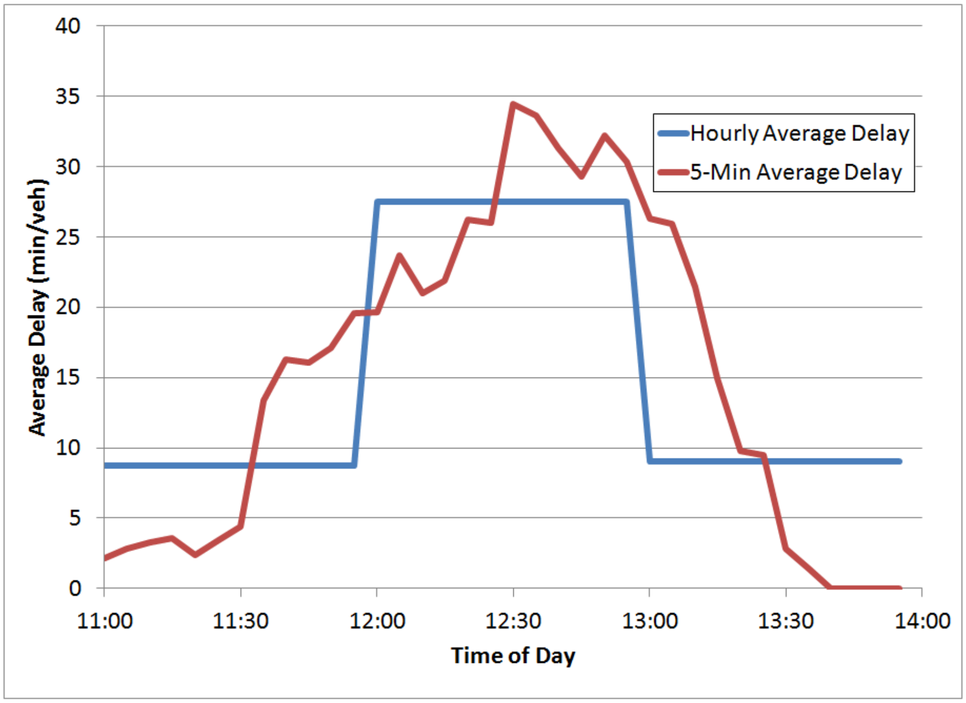

Figure 10. Average Delay on U.S. 11/460 for Case Study 4 on July 18, 2012, Between 11 A.M. and 2 P.M.

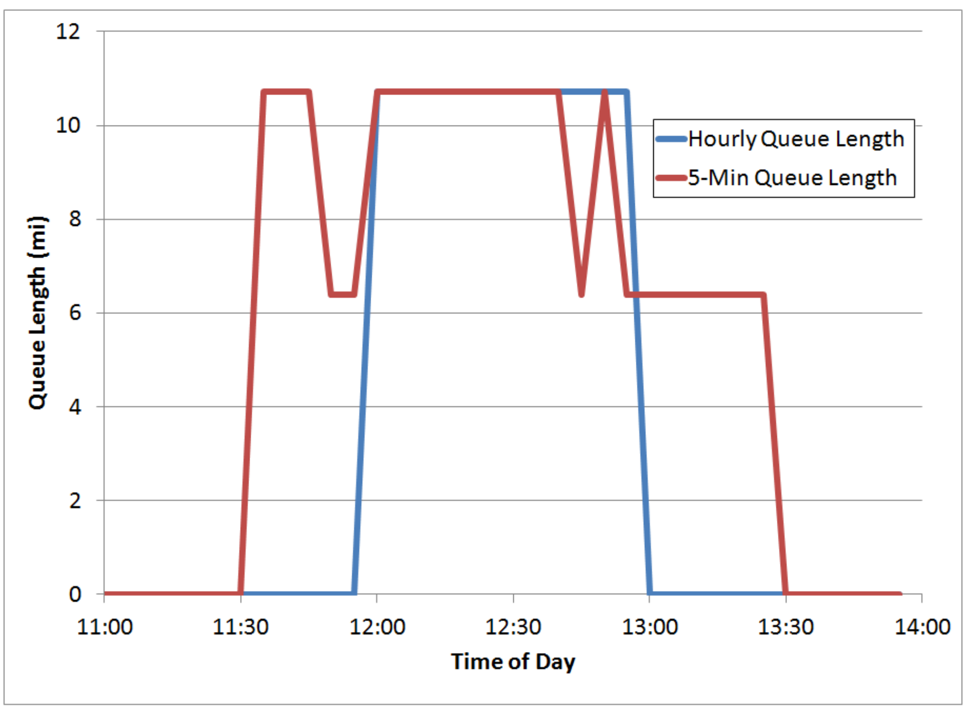

Figure 11. Queue Length on U.S. 11/460 for Case Study 4 on July 18, 2012, Between 11 A.M. and 2 P.M.

Although this case study showed that it is possible to generate systemwide estimates of work zone mobility impacts, it also showed some of the difficulties that can arise as a result of long aggregation intervals and large TMC lengths. The hourly data significantly underestimated the duration of queuing on both the mainline and arterial route, and the large TMC lengths on these rural sections also made estimates of queue length inherently imprecise. These queue length measures would not appear to be suitable for project-level performance measurement, particularly if contractor performance would be subject to penalties or remedial actions.

Threshold Comparison

The delays and queue lengths generated in each case study were compared to the thresholds in use by the 12 states identified in the domestic scan.[4] Table 6 shows whether the delays and queue lengths in each of the four sites passed the threshold of each DOT. Case Studies 1 and 2 passed the California and Pennsylvania threshold values, but the delay or queue lengths did not in all other cases. This serves to show that although some of the threshold values used by selected states are laudable goals, they may be difficult to achieve in practice in Virginia, even during night work. As VDOT sets thresholds, care should be taken that they are not set to unrealistically low values.

For this analysis, if a TMC speed dropped below 60 percent of the historic average speed, it was marked as queued. Information on how a queue is determined is not available from Indiana, Maryland, and Ohio. North Carolina regards a queue as a point at which traffic is either stopped or slowed more than 25 mph below the posted speed limit to the point where traffic has resumed an average speed of 45 mph or greater.[7] How the queue is defined by each DOT may impact how the four sites analyzed compare to the queue thresholds of the other DOTs. Likewise, the benchmark speed or travel time used for delay calculations may differ from what was evaluated in the case studies, so results could differ if delay was calculated using different benchmark speeds.

DISCUSSION

This study reviewed practices in selected states to identify key decisions that VDOT should make while moving forward with work zone performance measures. Possible performance measures were then examined using four case studies of actual VDOT work zones, and issues with applying private sector data sources to this problem were examined. Some key features that VDOT should consider when developing a work zone performance measurement program are discussed here. Given the breadth of impacts of a work zone performance measure program, it is the intent of this report to identify issues that need further discussion rather than to provide specific recommendations for how the VDOT program would be constructed at this point. This report will serve as a resource to a future group designing a work zone mobility performance measures program.

Table 6. Comparison of Virginia Case Study Performance Measures to Thresholds Developed by Selected States

State	Relevant Performance Measurement Threshold	Va. Case Study 1: I-64/I-81	Va. Case Study 2: I-95/I-64	Va. Case Study 3: I-95	Va. Case Study 4: I-81 and U.S. 11/460
Maximum Queue Length (mi)		8.72	3.73	3.56	7.46 (I-81), 10.73 (detour)
Maximum Delay (min)		20.56	19.47	21.64	42.08 (mainline), 34.45 (detour)
California	0-min delay for most freeway projects <15-min delay if aggressive TMP is being used <30-min delay on complex projects	Pass (complex project)	Pass (complex project)	Fail	Fail
Indiana	Queues cannot be present > 6 continuous hr or 12 hr total per day 0.5 mi < queues < 1.0 mi limited to 4 continuous hr 1.0 mi < queues < 1.5 mi limited to 2 continuous hr Queues > 1.5 mi not permitted	Fail	Fail	Fail	Fail
Maryland	Queues < 1.0 mi acceptable on freeways 1.0 < queues < 1.5 mi limited to 2 hr on freeways Queues > 2.0 mi not acceptable on freeways	Fail	Fail	Fail	Fail
Michigan	Delays < 10 min	Fail	Fail	Fail	Fail
Missouri	Delays > 15 min considered excessive	Fail	Fail	Fail	Fail
New Hampshire	0 < delays < 5 min acceptable 5 < delays < 10 min not preferable Delays > 10 min undesirable; field staff will consider suspending work	Fail	Fail	Fail	Fail
New Jersey	Delay < 15 min	Fail	Fail	Fail	Fail
Ohio	Queues < 0.75 mi acceptable 0.75 < queues < 1.5 mi limited to 2 hr Queues > 1.5 mi not acceptable	Fail	Fail	Fail	Fail
Pennsylvania	Delays < 15 min acceptable 15 min < delays < 30 min limited to 2 consecutive hr	Pass (delay did not exceed 30 min for 2 hr)	Pass (delay did not exceed 30 min for 2 hr)	Fail	Fail
North Carolina	Upstream queues exceeding 2 mi for any length of time not acceptable	Fail	Fail	Fail	Fail

TMP = Transportation Management Plan
This table contrasts the results of the Virginia case studies with the state thresholds reported in Bourne, J.S., Eng, C., Ullman, G.L., Gomez, D., Zimmerman, B., Scriba, T.A., Lipps, R.D., Markow, D.L., Matthews, K.C., Holstein, D.L., and Stargell, R., *Scan 08-04: Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation,* National Cooperative Highway Research Program, Washington, D.C., 2010.

Selection of Performance Measures

Delay and queue length/duration were the most common performance measures used by the selected states examined. If VDOT decides to embark on a statewide work zone mobility performance measurement program, it appears that private sector data are the only data source that can currently be used broadly to achieve this goal without incurring additional costs. Private sector travel time data were used to determine two commonly used work zone performance measures: delay and queue length. Delay could generally be calculated easily from the datasets used. Historic average speeds were available for preconstruction conditions, which allowed calculation relative to that baseline measure. Alternatively, posted speed limits or other thresholds could be easily used.

Discussions with VDOT's TED showed that queue length was considered to be a preferred measure for work zone performance, but queue length was a more problematic measure for the private sector data. First, a speed threshold had to be set below which traffic on the link was determined to be queued. Thus, the amount of queuing determined will be sensitive to the threshold value selected by the DOT. Second, a more significant issue is the influence of TMC length granularity on the determination of queue length and queue duration. The Virginia case studies serve to illustrate the large variability in TMC size that can exist in rural vs. urban facilities. The rural facilities of Case Studies 1 and 4 had mean TMC lengths of 2.3 and 5.4 mi, whereas the urban/suburban work zones of Case Studies 2 and 3 had average TMC lengths of 0.56 and 0.71 mi. Thus, using private sector data to define queue lengths should be viewed with caution, especially in rural areas. This concern is heightened for project-level performance measures where there could be project cost implications if queues were not measured correctly. Manual measurement of queues is likely to be extremely costly, and dense point sensor spacings are unlikely to be viable if all interstate work zones are to be examined. Thus, it appears that limited application of private sector data in urban work zones may be the most viable short method to estimate work zone queues in the short term.

Spatial Aggregation Impacts

The spatial granularity at which the data are reported should be closely considered when defining a work zone performance measurement program that relies on private sector data. TMCs are typically defined based on the locations of intersections or interchanges. Since work zones may occur at the midpoint of TMCs, long TMCs could mask the impact of the work zone by including a significant amount of non–work zone travel data. Given the differences in rural and urban TMC lengths, it currently appears that urban sites could be most effectively monitored using the private sector data. Analysts should closely examine the TMC sizes before proceeding with performance measure calculations, especially in rural locations.

Temporal Aggregation Impacts

Another issue that could impact performance measure outputs is the level of temporal aggregation. This is especially important for project-level assessments that could be used to ask contractors to make changes to their traffic control plans or to assess performance penalties. As the time over which performance measures are created increases, the severity of congestion tends to be masked. For example, if VDOT is interested in the amount of time delay exceeds 15 min at a work zone, a 1-hr aggregation interval will result in fewer violations than if the performance measures are calculated every 5 min. Further, it is more likely that there could be significant traffic volume changes over a 1-hr period than a 5-min period. Since average delay values are likely to be the most readily available performance measure, 1-hr aggregation intervals could create issues where data are incorrectly weighted across very different flow regimes. Thus, VDOT should carefully consider and specify the time over which any performance measures are aggregated.

Threshold Setting

The four Virginia case studies generally showed that the performance thresholds used in selected states may be difficult to attain on high-volume roadways in Virginia, even if work is conducted at night. As a result, VDOT may not be able to adopt thresholds used in other states directly, although they may be used as a starting point for discussion. It also appears likely that different thresholds may be required for urban and rural parts of the state or by region. Consensus on thresholds should be reached in consultation with the regions. Methods and benchmarks for calculating thresholds should be clearly defined to ensure consistency across the regions.

Another issue to be considered when setting thresholds is the difference between project-specific thresholds and corridor-level thresholds. For example, a 20-min delay may be deemed acceptable on a single project. If there is a major corridor project with multiple work zones along a single roadway, it is possible that a traveler could encounter a series of these 20-min delays. The combined effect of these 20-min delays may result in an overall trip time that is deemed unacceptable. Thus, there may be a need to set separate thresholds to address when drivers would pass through multiple work zones in a short distance.

Program Development and Ongoing Management

As the program is developed, VDOT must consider how the performance measures and thresholds will be used within the larger work zone program. For example, if modeling results indicate that delay or queuing thresholds will be exceeded in the TCP design stage, corrective actions to mitigate the congestion could be required. Likewise, the process to be used to address concerns related to ongoing projects that are found to exceed performance thresholds should be defined. Roles and responsibilities for who conducts the performance measurement work, how violations of work zone thresholds are handled, and lines of reporting need to be defined. Discussion with VDOT’s TED revealed that requests for exceptions to current allowable work hours are not handled consistently between regions and sometimes there is no traffic engineering review of requests. Future work to standardize the processes associated with these requests will be an essential component of the program.

In addition, VDOT will need to have a computerized system that can perform project monitoring automatically if private sector data are to be mainstreamed into work zone performance measurement. In this study, the RITIS software developed by the University of Maryland was used. Several vendors are making software modifications that can fuse together DOT work zone records and probe vehicle records to generate performance measure figures and charts in an automated manner. Provision of these tools will help enhance and expand the use of this data stream for mobility measurement in work zones.

Future Developments

It should be emphasized that the findings of this research represent current conditions as of the writing of this report. Private sector companies are continually refining their methodologies and attempting to improve their products. Future developments may allow for further sub-segmentation of TMCs or other improvements that could remove some of the current limitations of using private sector data in rural areas. As VDOT develops its program, it should be prepared to reevaluate decisions regularly to support changes in any private sector data that are used.

CONCLUSIONS

- *Delay and queue length/duration are the most commonly used performance measures in certain selected states examined in this study.* Both of these performance measures capture important facets of work zone impacts. Delay relates directly to how travelers perceive the mobility impact of the work zone, and queue length and duration provide information to a DOT on whether traffic control provides sufficient advance warning of congestion to drivers.

- *Private sector data can be used to assess work zone delays on freeways, but spatial granularity of the TMC links can create problems when they are used to estimate queue lengths, especially in rural areas.* Since queue lengths are determined by whether a TMC drops below a speed threshold, that performance measure may not be accurate when private sector data are used in rural areas.

- *The temporal aggregation interval can influence whether a work zone is determined to exceed a delay/queue threshold.* DOTs should specify a standard aggregation interval in any program developed. Tradeoffs between responsiveness and analytical effort need to be weighed in defining the aggregation interval.

- *Based on the Virginia case studies evaluated, performance thresholds used in certain selected states examined may not be appropriate in general for use in Virginia, particularly for high-volume, urban facilities.* Existing performance thresholds were often exceeded in the four Virginia case studies evaluated, indicating the need to determine values specific to Virginia. It is possible that different thresholds will need to be set based on local tolerance for delay. Although the likelihood of exceeding thresholds is greater on high-volume urban roads, thresholds were also exceeded in Case Studies 1 and 4, which occurred on rural routes.

RECOMMENDATIONS

1. *VDOT's TED should develop a pilot work zone performance measurement program using the INRIX data that focus on urban freeways.* VCTIR staff would support this effort. Initial efforts should focus on monitoring impacts in urban freeway work zones where TMCs would support the estimation of both delay and queue length. The existing RITIS software could be used to conduct this performance measurement in a cost-effective way since VDOT already has access to these data.

2. *VDOT's TED should create a task group including staff from VDOT's regional operations, VDOT's Operations Division, the TED, and VCTIR to develop a policy on work zone mobility performance measurement. The task group should determine an allowable threshold for the performance measures selected in Recommendation 1 and develop a process for using the threshold to support work zone mobility decisions.* This threshold may vary by region or project type. A process for how these thresholds will be applied should be created. This would include how they would be used during TMP development, as well as actions that would be taken if a work zone was found to exceed the proposed threshold. Roles and responsibilities in the process should be defined and standardized to the maximum degree possible.

BENEFITS AND IMPLEMENTATION PROSPECTS

This study reviewed current best practices in work zone mobility performance measurement and identified key considerations in using private sector travel time data to support this program. The information contained in this report will be used to help guide VDOT's TED and operational regions as they develop a work zone mobility performance measure program and performance thresholds for implementation by VDOT. Given the number of stakeholders that will need to be involved in this process, VDOT's TED indicated that the development of the actual program would need to occur outside the research conducted in this work. VDOT's TED has indicated that VCTIR staff will be involved as the work zone performance measure program is developed and implemented.

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APPENDIX

EMAIL REQUESTING INFORMATION FROM 12 STATE DOTS

VDOT is looking into developing work zone operational performance thresholds (such as delay per vehicle, queue length, and duration of queue). From the Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation report by the NCHRP scan team, we learned of your performance measures.

I am requesting that you answer the questions below and email me your responses by Friday, August 10, 2012.

Thank you. We look forward to hearing from you. If you have questions, please contact me.

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Work Zone Operational Performance Thresholds

1. The scan team report provided the acceptable mobility/operational performance measurement threshold of various states in a table (Table 2.1 in the report http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_08-04.pdf). Please provide a copy of your agency's document that describes your work zone operational performance measurement threshold.

2. How was your threshold developed? If there is a study or documentation to support it, please provide a copy.

3. Do the thresholds apply to work zones on all roadways? If not, under what conditions do the thresholds apply?

4. Did you consider different thresholds for urban/rural areas of the state? If yes, please explain the differences and how they were defined.

5. How are data collected to monitor the operational performance? Are new sensors/monitoring systems deployed or are only existing sensors used? If yes, who is responsible for deploying new sensors, the contractor or your agency?

6. What proportion of sites is monitored? How are sites selected for monitoring if all sites are not monitored?

7. How rapidly is operational data obtained? Is it real-time?

8. What actions are taken if the thresholds are exceeded? How are the thresholds enforced? Who authorizes these actions?

9. Are there times or ways where the threshold can be waived? If yes, please explain the waiver process including who can waive the threshold.

10. How are performance measures used to address project-specific problems?

11. How are performance measures used to address programmatic issues?

Reminder, when possible, please attached documents or provides links to information on websites.