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Development of Performance Assessment Guidelines for Virginia's Work Zone Transportation Management Plans

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As America's roadways are becoming more congested and in need of maintenance and repair, management of traffic through work zones is a major issue for state departments of transportation. To assist states with this challenge, in 2004, the Federal Highway Administration (FHWA) published its *Final Rule on Work Zone Safety and Mobility*, which mandated that state DOTs develop transportation management plans (TMPs) for all federally funded roadway construction projects. The Virginia Department of Transportation (VDOT) now requires TMPs for all projects, regardless of funding source. Part of federal and Virginia TMP requirements are to monitor and assess traffic impacts, including a post-construction evaluation of the TMP. Currently, TMPs are not being assessed following individual construction projects, and VDOT does not yet have a formally established process to assess TMP performance throughout its districts and regions. The purpose of this project was to develop a set of guidelines to assist VDOT's work zone personnel and contractors with evaluating TMP performance. The research methodology examines existing literature on work zone evaluation strategies. Thirty state DOTs, as well as personnel within VDOT, were surveyed to explore TMP assessment practices. Finally, two work zone case studies from within the Commonwealth of Virginia were examined. The results of this research effort were used to develop Guidelines for TMP Performance Assessment, with aid and review from a VDOT TMP Performance Assessment Task Group. While these new requirements may add up-front costs to project engineering, VDOT will benefit by having a methodology in place to identify and measure successful strategies to manage safety and mobility impacts from work zones.

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FINAL REPORT

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ABSTRACT

As America's roadways are becoming more congested and in need of maintenance and repair, management of traffic through work zones is a major issue for state departments of transportation. To assist states with this challenge, in 2004, the Federal Highway Administration (FHWA) published its *Final Rule on Work Zone Safety and Mobility*, which mandated that state DOTs develop transportation management plans (TMPs) for all federally funded roadway construction projects. The Virginia Department of Transportation (VDOT) now requires TMPs for all projects, regardless of funding source. Part of federal and Virginia TMP requirements are to monitor and assess traffic impacts, including a post-construction evaluation of the TMP. Currently, TMPs are not being assessed following individual construction projects, and VDOT does not yet have a formally established process to assess TMP performance throughout its districts and regions. The purpose of this project was to develop a set of guidelines to assist VDOT's work zone personnel and contractors with evaluating TMP performance. The research methodology examines existing literature on work zone evaluation strategies. Thirty state DOTs, as well as personnel within VDOT, were surveyed to explore TMP assessment practices. Finally, two work zone case studies from within the Commonwealth of Virginia were examined. The results of this research effort were used to develop Guidelines for TMP Performance Assessment, with aid and review from a VDOT TMP Performance Assessment Task Group. While these new requirements may add up-front costs to project engineering, VDOT will benefit by having a methodology in place to identify and measure successful strategies to manage safety and mobility impacts from work zones.

FINAL REPORT

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INTRODUCTION

Automobile ownership, usage, and vehicle-miles-traveled (VMT) have increased at a much faster rate than highway mileage. At the same time, existing highways are aging and in greater need of maintenance, re-construction, and repair. Agencies and contractors are pressed to complete roadway construction projects as quickly as possible with minimal disruption to motorists while also addressing work zone mobility and safety issues. In 2001, motorists encountered an active work zone 1 out of every 100 miles driven on the National Highway System (NHS), representing over 12 billion hours of vehicle exposure to work zones;[1] this number has likely increased significantly over the past ten years. In 2009, 667 fatalities and over 40,000 injuries resulted from motor vehicle crashes in work zones in the United States.[2] As VMT increases and roadway infrastructure ages, work zones have the potential to become more congested and more dangerous. Sound work zone planning and management are thus essential to ensure the safety and efficiency of our roadway transportation system.

FHWA Work Zone Policy

In order to meet safety and mobility needs during highway maintenance and construction, and to meet the expectations of the traveling public, it is important for state transportation agencies to understand the work zone safety and mobility impacts of projects and take appropriate actions to manage these impacts. In September 2004, the Federal Highway Administration (FHWA) published the *Final Rule on Work Zone Safety and Mobility*[3] (henceforth referred to as the "Final Rule"). The Final Rule updated and broadened the former regulation, "Traffic Safety in Highway and Street Work Zones," and applies to all state and local government projects that receive federal-aid highway funding. Transportation agencies were required to comply with the provisions of the Final Rule by October 12, 2007. Some of the specific requirements[4] are as follows:

- Implement a policy for the systematic consideration and management of work zone impacts on all Federal-aid highway projects. Furthermore, it encourages agencies to implement the policy for non-Federal-aid projects and programs.

- Develop a policy to address work zone impacts throughout the various stages of the project's development and construction. The agency must consider work zone impacts during project development, management of work zone impacts during construction, and assessment of work zone performance after implementation. The agency must also consider communication with the public before and during the project.

- Recognize that state policy may vary based on the characteristics and expected work zone impacts of individual projects or classes of projects.

- Require transportation management plans (TMPs) for all federally funded roadway construction projects. TMPs are encouraged for all projects, even those without federal funding.

Definition of a TMP and Components

A TMP is a set of coordinated transportation management strategies for managing the impacts of a work zone in roadway construction.[4,5] These strategies can include temporary traffic control (TTC), public information (PI) and outreach, or transportation operations (TO) strategies. TTC refers to control strategies, traffic control devices, and project coordination and contracting strategies. PI strategies include awareness strategies for the general public and specifically for motorists. TO strategies typically focus on demand management, corridor or network management, work zone safety management, incident management, and enforcement strategies. Together, a combination of TTC, PI, and TO strategies can be used to manage traffic impacts from a work zone, depending on the size and complexity of the project. A TMP should document the combination of strategies used, the plan for implementing these strategies, and how these strategies will mitigate adverse safety and mobility impacts to traffic.

TMPs need to serve the mobility and safety needs of road users, highway workers, businesses, and the community. The scope, content, and level of detail of a TMP can vary based on the agency's work zone policy and the anticipated impacts of the project. TMP development begins during systems planning and progresses through the design phase of the project. The TMP should identify and assign responsibilities and courses of action, improve public awareness of work zones and impacts, and help maximize project cost-efficiency. Ideally, a TMP should be a written document providing a description of the project, including project background, goals and constraints, a description of the corridor and area, project schedule, and phasing and staging.[4,5]

A TMP should also detail existing and future conditions of the work zone and assess predicted work zone traffic impacts. In conjunction with these predicted impacts, strategies to mitigate the impacts should be selected. Monitoring requirements should also be included[4]. Part of these monitoring requirements should be an evaluation report for the TMP: "the TMP should include reference to the development of an evaluation report upon completion of construction to document lessons learned and provide recommendations on how to improve the TMP process and/or modify guidelines."[5]

The TMP should also contain any contingency plans for activities that should be undertaken to minimize traffic impacts due to unexpected events. Finally, the TMP should include implementation cost estimates for various strategies to avoid under-allocation of funds. Essentially, a TMP is a *more comprehensive* approach to managing work zone impacts.

VDOT's TMP Policy

In 2005, Cottrell[5] developed a set of guidelines for VDOT to use when developing TMPs. Formerly known as "congestion management plans," VDOT has actually been using TMPs since the 1970s. However, Cottrell noted, "In all cases, TMPs were developed on a case-by-case basis without guidelines, processes, or directions on how to proceed." Cottrell developed a systematic procedure to follow in developing plans to lessen the impact of construction projects, especially on limited-access highways. These guidelines were developed from best practices observed in other states, including California, New York, Washington, Illinois, Indiana, and Ohio.

VDOT's TMP Development Guidelines recommend data collection and monitoring of field conditions during construction to compare to predefined performance requirements and predicted work zone impacts. VDOT Regional Traffic Engineers and the contractor should each designate a trained person to implement and monitor the TMP. The TMP should identify the processes that will be used to monitor safety and mobility performance (for example, tracking queue lengths, volumes, travel times, crashes, complaints, etc.). TMP strategy implementation costs should also be tracked and compared to budgeted costs.

The scope, detail, and content of a TMP vary with project complexity; likewise, the level of assessment necessary for a TMP should vary with project complexity. VDOT has three types (or levels) of construction projects[6]. The following project types and are defined in VDOT's TMP Requirements (IIM-LD-241.4):[6]

- *Type A* - no-plan, minimum plan, single phase construction, maintenance projects, utility and permit work; for example, re-paving or adding turn lanes or entrances.

- *Type B* - moderate level of construction activity with the primary traffic impact limited to the roadway containing the work zone; for example, widening of pavement involving lane closures or shifting traffic/detours.

- *Type C* - these types of projects are anticipated to cause sustained and substantial work zone impacts greater than what is considered tolerable based on policy or engineering judgment. These are long-duration construction or maintenance projects (1) on interstates or freeways, (2) in a designated Transportation Management Area (Northern Virginia, Richmond, and Hampton Roads), and (3) that occupy a location for more than three days with continuous lane closures.

Following the completion of construction, the TMP Development Guidelines recommend that a report should be developed containing an evaluation of the TMP. It should contain successes and failures, changes made to the TMP and the results of those changes, public input, actual versus predicted measures, the cost for implementation of the strategies, and suggested improvements. Specifically, the guidelines suggested the following should be included:[5]

- An overall statement reflecting the usefulness of the TMP
- Changes necessary to correct oversights in the TMP
- Changes made to the original plan and their level of success
- Public reaction to the TMP
- The maximum and average delay time encountered during peak and off-peak periods, and delay history over the duration of the project
- Identification of the peak traffic periods
- Frequency of legitimate complaints and the nature of the complaints
- Types and numbers of crashes that occurred during construction
- Types and numbers of safety service patrol assisted incidents
- Level of success and performance log for each implemented strategy of the TMP.
- Suggested improvements or changes for similar future projects.

From the guidelines recommended by Cottrell, VDOT's TMP Policy is outlined in an Instructional and Informational Memorandum (IIM) of TMP Requirements.[6] This directive is applied to all work zone activities regardless of funding source within state right-of-way and on streets and highways within the State Highway System. VDOT's stated goal is "reducing work zone crashes and improving travel time thereby benefitting all citizens of the Commonwealth." Consistent with the FHWA's recommendations, the IIM recommends TTC, PI, and TO strategies, noting that all TTC strategies must be in compliance with the Virginia Work Area Protection Manual (WAPM).[7]

VDOT's TMP Requirements state that Regional Traffic Engineering and Operations should conduct a performance assessment of the TMP including area-wide impacts "during construction as circumstances dictate."[6] A review of the overall effectiveness of the TMP should be completed during the Post-Construction Meeting and included with the Post-Construction Report. Currently, the VDOT TMP Interim/Post-Construction Report is a document that consists of a checklist relating to various work zone activities. Although this requirement and template exists, VDOT's Regional Operations Directors (RODs) have requested assistance with developing better processes and procedures for evaluating TMP performance.

PURPOSE AND SCOPE

The rationale behind TMP performance assessment is to determine if the anticipated work zone impacts and changes desired with the implementation of a TMP actually occur in the field. Currently, VDOT is not performing assessments of individual TMPs because a methodology has not been established. The purpose of this research effort was to develop a set of guidelines with strategies to assess TMP performance. Similar to the process used by Cottrell for creating VDOT's TMP Development Guidelines,[5] this project explored best practices recommended by the FHWA, other state departments of transportation, and VDOT's own districts. In conjunction with these practices, the research team thoroughly examined two case studies of work zones in the Commonwealth to explore current VDOT efforts in assessing TMP performance.

METHODS

To achieve the project purpose, the following tasks were conducted:

1. Perform a literature review.
2. Develop and distribute a survey to other state transportation agencies.
3. Develop and distribute a survey to VDOT work zone coordinators.
4. Perform case studies at two work zones in Virginia.
5. Develop guidelines for assessing TMP performance.

Literature Review

A literature review identified tools and best practices for TMP development, monitoring, and performance assessment. Major areas of the literature review included pre-construction impacts analysis, safety and mobility performance measure development, monitoring and data collection strategies during construction, and post-project evaluation methods. A major guide for identifying best practices came from the FHWA's 2010 Domestic Scan of best practices in work zone data collection, monitoring, and performance assessment from across the nation.[8]

Outside State Transportation Agency Survey

In conjunction with the results of the literature review and the FHWA Domestic Scan, the research team developed a survey for other state transportation agencies. This survey explored other states' methodologies in developing and assessing work zone safety and mobility performance measures, predicting and assessing work zone impacts, monitoring and collecting data, and assessing TMP performance. Over 30 states responded to this survey, including all fifteen featured in the FHWA's Domestic Scan.

VDOT Region Survey

Following the results of the literature review, Domestic Scan, and survey to other state transportation agencies, the research team developed a survey for work zone coordinators in each of VDOT's five regions to examine the extent of VDOT's work zone policies, processes, and procedures. The survey questions again detailed methodologies in developing and assessing work zone safety and mobility performance measures, predicting and assessing work zone impacts, monitoring and collecting data, and assessing TMP performance. The research team received responses from all five regions across the state.

Case Study I: I-81 Pavement Reclamation Project, Augusta County

The first case study explored was the I-81 Full-Depth Pavement Reclamation project in Augusta County. The project TMP and pre-construction impacts analysis were thorough, detailed, and complete, especially for a Type II project. The TMP was provided in a formal document providing project background and then detailing TTC, PI, and TO strategies which were used to mitigate potentially heavy delays. The TMP references the pre-construction impacts analysis, provided as a second document, which thoroughly details the methodology used to predict volumes and delays. These documents provided the research team, as well as VDOT and the contractor, with a set of expectations for how traffic would flow through the work zone and a reference for comparison and TMP evaluation.

Project Background and TMP

In the spring and summer of 2011, VDOT rehabilitated a 3.7 mile, two-lane section of I-81 southbound in Augusta County (just south of the City of Staunton) between Exits 217 and 213. In order to efficiently complete these reconstruction efforts, a TMP was developed to complete a significant portion of the project over five continuous lane closure periods. VDOT Northwestern Regional Operations (NWRO) developed a TMP for the project in conjunction with VDOT's IIM-241,[6] the Virginia *Work Area Protection Manual* (WAPM)[7], and the *Manual on Uniform Traffic Control Devices*.[9] The project involved the closure of one of two southbound lanes along I-81 between MM 217.66 and MM 214.00 and a subsequent detouring of some traffic onto parallel US 11. This work zone was essentially located between two exits – Exit 217 (SR 654) and Exit 213 (US 11). A map of the work zone area is displayed in Figure 1.

Figure 1. I-81 SB Pavement Reclamation Work Zone Area

Along I-81 SB upstream of the work zone, vehicles in the right lane were diverted off of the interstate at Exit 217 and followed signage and flaggers first westbound along SR 654 and then southbound along US 11 before rejoining the traffic stream to I-81 SB at Exit 213. Vehicles in the left lane of I-81 SB upstream of the work zone stayed on I-81 SB along the one open lane through the work zone. Upstream of the work zone, VDOT and the contractor provided limited warning of the right lane detour. This was done intentionally to alleviate late-merge conflicts at the start of the work zone. Upstream trucks were directed to use the left lane to stay on I-81 SB; during peak volume periods, cars were directed to use the right lane.

VDOT underwent an extensive public outreach effort to inform stakeholders, travelers, truckers, and the general public about the project. These efforts included a project website featuring detour maps and traffic alerts; radio notices as far away as Harrisburg, Pennsylvania, Roanoke, and Richmond; meetings at a local high school and with emergency responders and law enforcement; weekly media briefings; and letters to local citizens, General Assembly members, the Virginia Truckers Association, area chambers of commerce, local government official, and the I-81 Corridor Coalition.

Several TO tools and strategies to actively manage traffic were also described in the TMP. These included changeable message signs, cameras, CB Wizards to inform truckers of the work zone, and an advance warning vehicle placed upstream of queues. The message signs would change based upon the level of queuing taking place in and around the work zone.

Pre-Construction Impacts Analysis

VDOT Central Office Traffic Engineering Division (TED), at NWRO's request, developed a microscopic simulation of the I-81 and US 11 corridors using the VISSIM traffic simulation software to identify any queues and the extent of congestion resulting from the I-81 continuous lane closure. Maximum queues were predicted to not exceed 1,500 feet and travel times along both the detour route and I-81 were predicted to not be increased by more than 4 minutes.

Data Collection Methodology

The research team collected extensive traffic data at various locations along I-81 SB and US 11 SB before and during the five continuous construction periods. Volume and classification data were collected along I-81 SB using Wavetronix devices (radar-based traffic sensors) at four locations: upstream of the work zone, at the start of the work zone past the beginning of Type II channelizing devices, within the work zone, and past the work zone. Volume and classification data were collected along US 11 SB via pneumatic tubes at five locations: upstream of the detour segment, three locations along the detour segment, and the ramp to I-81 SB at Exit 213. The Wavetronix devices were deployed on Friday afternoons prior to the start of construction and usually recorded data until the following Tuesday or Wednesday. Figure 2 displays the setup of Wavetronix devices along the side of the freeway. The pneumatic tubes recorded data continuously throughout the week.

Figure 2. Setup of Wavetronix Device Along I-81

Baseline and during-construction travel time data were collected using the floating-car method. Travel times were collected for three different weekday peak-hour (4 P.M. – 6 P.M.) periods during construction and one baseline weekday peak-hour period. During data collection, two probe vehicles traveled along I-81 SB through the work zone, while one probe vehicle exited I-81 SB at Exit 217 to use the detour route. Travel times were measured between Exit 222 upstream of the work zone and Exit 213 at the end of the work zone (a 9.1 mile link). Recorded project impacts are discussed in the “Results and Discussions” section.

Case Study II: Gilmerton Bridge Replacement Project Phase I, City of Chesapeake

The second case study explored was Phase I of the Gilmerton Bridge replacement project along Military Highway (US 13/US 460) in the City of Chesapeake. While this project is not expected to be complete until 2014, the first phase of bridge replacement involved a reduction of the highway to one lane in each direction along with a suggested detour route along I-64. Unlike the I-81 Pavement Reclamation project, this project did not feature an extensive TMP, as project plans were developed prior to FHWA Final Rule implementation.

Project Background and TMP

The existing Gilmerton Bridge was built in 1938 and has reached the end of its 70-year life span; in addition, the bridge currently provides very low clearance for waterborne vessels and thus requires frequent drawbridge openings, resulting in frequent delays to motorists. The bridge is currently being replaced by a new span that will provide a 35-foot closed clearance. The research team studied the traffic control plan for the Phase One of the bridge replacement. During Phase One of the project, expected to continue until late 2012, motorists are limited to one lane in each direction and shifted to the westbound lanes (north side) of the bridge during this Phase. The replacement bridge will take approximately three years to build while remaining open to vehicular traffic, albeit with one lane in each direction. Although construction of the span will take a long period of time, the project team coordinated the construction schedule and traffic control to significantly lessen the impact on the motoring public.

As opposed to the I-81 Pavement Reclamation project, the Gilmerton Bridge replacement project does not have an extensive TMP document describing TTC, PI, and TO strategies. This is likely due to the project being developed prior to the establishment of the Final Rule[3] and TMP requirements.[3,6] The TMP Task Force team noted that while project managers are supposed to be updating these “Pre-TMP” projects, many are not updated due to time, budget, or personnel constraints. The TMP for the Gilmerton Bridge replacement project consists of the maintenance-of-traffic CAD sheets in the project blueprints. These sheets display and describe the TTC setup according to the MUTCD. PI and TO strategies were not explicitly documented, although project personnel explained many of these to the research team.

Since the start of construction in November 2009, Military Highway has been reduced to one lane in each direction in the work zone area, which is between Canal Drive on the east side of the bridge and I-464 on the west side of the bridge. On the west side of the bridge between I-464 and the bridge, US 460 enters and exits the highway via an interchange. Figure 3 displays

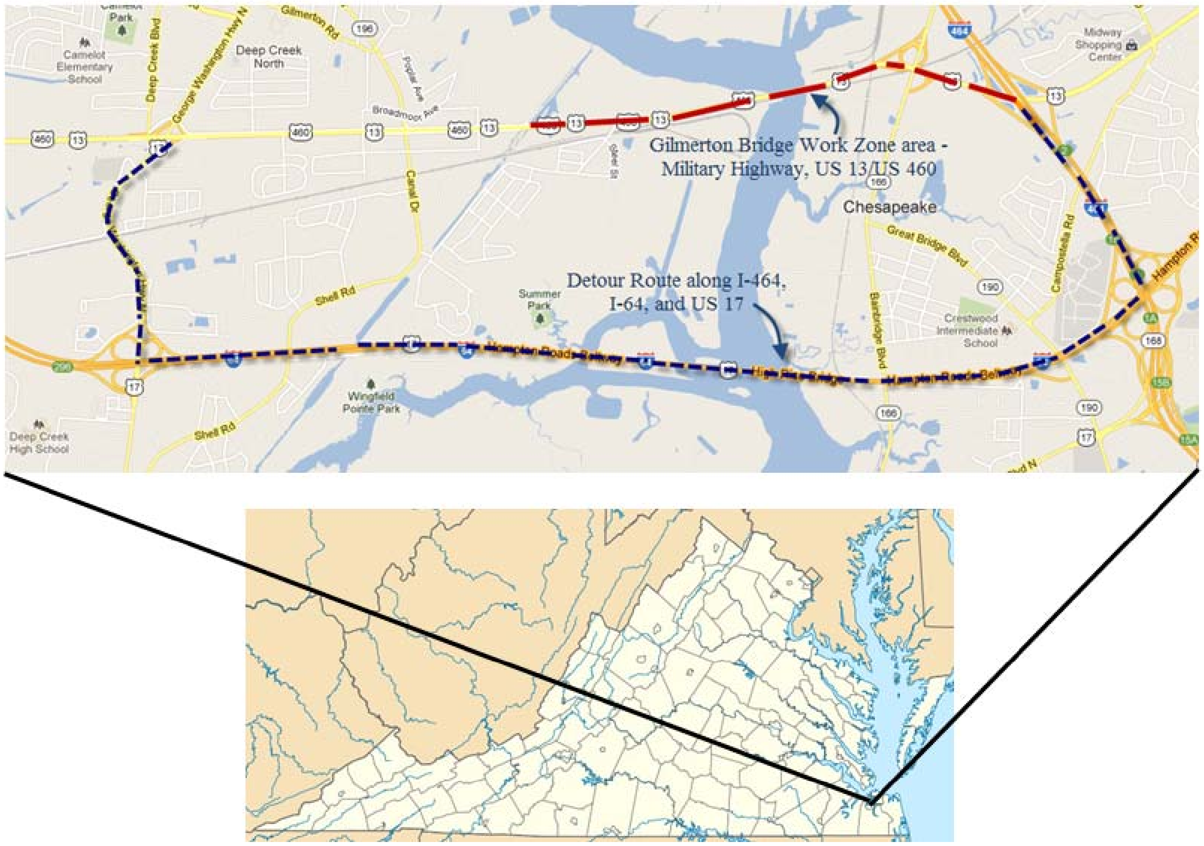

Figure 3. Gilmerton Bridge Replacement Work Zone Area

a map of the work zone area. This map includes the suggested detour for vehicles in either direction, which requires use of I-464, I-64, and US 17 (George Washington Highway). All three of these detour facilities are two lanes in each direction, with I-64 and I-464 being freeways.

VDOT Hampton Roads District Public Affairs underwent several initiatives to alert motorists of the work zone and alternate routes. These include news releases, emails to database subscribers, highlighted project closures in the District's weekly lane closure forecast, and traffic "sponsorships" on local radio stations. Beginning in September 2011, the bridge has been completely closed to traffic on Sunday nights through Thursday nights from 8 P.M. to 5 A.M. to expedite construction; these closures will continue through Summer 2012 until Phase Two of the project is implemented. VDOT ran public service announcements on cable television to not only inform motorists of these closures but also explain the benefits of the project.

Pre-Construction Impacts Assessment

The Hampton Roads Planning District Commission (HRPDC) used the regional planning model and QuickZone to predict impacts resulting from the proposed lane closures on Gilmerton Bridge.[11] From their results, it was anticipated that the capacity of the single lane would not be able to accommodate the predicted demand, resulting in substantial delays during the peak hour periods. The QuickZone output suggested significant increases in travel times (at least 20 minutes during weekday periods and upwards of one hour in both directions on Friday peak periods). Queues were also expected to exceed over 3,000 feet in both directions during peak periods. This study did not take into account any volume changes along Military Highway that may have resulted from public awareness of construction and alternate routes. The traffic impacts of this project could be dramatically different from predicted impacts if volumes over the bridge were to change.

Data Collection Methodology

The research team met with project staff and determined that mobility impacts were not to the magnitude predicted by the HRPDC study. Queues and delays on both approaches to the work zone were evident but not to the extent of the pre-construction impacts analysis. The research team chose to examine volumes through the work zone and travel times along both Military Highway and the detour route as measures of work zone traffic impacts.

VDOT has multiple sources of volume data for examining work zone data; the research team sought to determine which sources could provide volume data for this particular work zone. As opposed to setting up Wavetronix devices for this project, which were not available at the time, or hiring a contractor to collect data, the research team decided to explore VDOT's archived volume data. TED has a continuous count station along Military Highway adjacent to the Gilmerton Bridge that could accurately provide volumes traveling in both directions through the work zone both prior to and during construction.

Travel time runs were conducted in both directions along Military Highway and the detour route, using GPS devices to track travel times. The links along Military Highway (and the detour route) between the Military Highway/US 17 intersection and the Military Highway/I-464 interchange were chosen as appropriate indicators of travel time through the work zone area. The travel time runs were two days in October 2011 using four probe vehicles.

To help verify travel time data, the research team explored VDOT's access to archived Inrix travel time data. Inrix is a vendor that collects traffic data and sells it to transportation agencies; for the Hampton Roads area, VDOT has purchased access to travel time data from the past several years taken from fleet vehicles traveling on various links. Travel time data are available for many interstates and arterials as well.[12] A challenge exists in processing this travel time data, however: archived data are provided as 5-minute average speeds for various traffic message channels (TMCs), or links. These links are often very short in nature – many less than a mile in length. In order to compute travel times along a desired stretch of highway, the desired TMCs comprising this stretch must first be identified using GIS or Google Earth, and the TMC lengths must also be obtained. Travel times along an individual TMC can be computed by dividing the link length by the average speed; average travel times along an overall link can be estimated by summing average travel times along individual TMCs for a given time period. For this project, the research team was able to identify a set of TMCs for an approximately 4.0 mile stretch of Military Highway around the Gilmerton Bridge work zone between US 17 and I-464 in which travel time data could be analyzed.

Development of Guidelines for Assessing TMP Performance

Utilizing the findings from the previous tasks, the research team developed a set of guidelines for assessing TMP performance. This task was undertaken with the assistance of a Task Group consisting of VDOT work zone managers and coordinators. Task Group member are shown in Appendix A. Two types of guidelines were developed: 1) guidelines for assessing individual project TMPs and 2) guidelines for assessing TMPs at the agency level.

RESULTS AND DISCUSSION

Literature Review

The literature review suggested that TMP performance assessment is not simply a post-construction process but rather a process that occurs over the life cycle of a project and begins during project development, as noted by the Final Rule.[3] For large-scale and potentially disruptive projects, initial traffic impacts should be predicted and subsequent performance measures should be developed prior to construction. During construction, traffic impacts should be monitored and data should be collected to be compared to performance measures or thresholds. Finally, a post-construction assessment should tie in data showing work zone impacts and performance measures, as well as changes made, lessons learned, and applications to future work zones. The literature review explored best practices for each of these processes.

A major guide and source of information for this project came from the FHWA's National Cooperative Highway Research Program (NCHRP), which conducted a Domestic Scan of fifteen U.S. state transportation agencies in 2010. This Domestic Scan[8] provided numerous examples of best practices in the areas of work zone impacts analysis, performance measure development, data collection methodologies, and use of data/performance measures for improving work zone safety and mobility. The Domestic Scan also provided recommendations for state transportation agencies to improve each of these areas. Many of these best practices and recommendations, combined with other literature findings, were included as part of the research team's survey to state DOTs and VDOT districts.

Performance Measure Development

In order to assess the effectiveness of a TMP in regards to work zone safety and mobility, performance measures must be defined and used. Performance measures are "sets of defined, outcome-based conditions or response times that are used to evaluate success."[13] The Domestic Scan notes that agencies which "have clearly established performance measures tend to effectively track those measures and consider them through the project development process."[8] Agencies use performance measures to specify what they seek to achieve, to communicate goals and objectives in a transparent way, and to document and assess the effectiveness of policies, practices, and procedures. Performance measure development should be an iterative process involving all stakeholders associated with a project or policy. Performance measures must be specific, measureable, and achievable. Performance measures for TMP assessment should focus on safety and mobility impacts to traffic in the work zone area.

Safety performance is difficult to quantify outside of actual events. Crashes and injuries to workers are the generally accepted measure, as well as “legitimate” complaints from users. A survey of user-perceived safety of a work zone could also be conducted but would be more difficult to quantify. Some states, such as New Hampshire, use emergency vehicle dispatch frequency as a safety performance measure; other states, such as Oregon and New York, have quantitative work zone inspection scores that “grade” work zone safety.[8] The Domestic Scan notes that most safety performance measures used by agencies tend to be at the agency or program level rather than the individual project level.[8] Depending on the duration of a project, safety can be evaluated during construction or post-construction. For example, if a project lasts for several months, crash rate can be assessed monthly and compared to a crash rate based on 3 years of crash data prior to the start of the project. Ohio DOT often uses comparisons of crash frequencies at specific locations during projects to identifying trends, hotspots, and underlying causes.[8]

Mobility performance measures provide indications of how easy or difficult travel is along a corridor or in a region.[14] Roadway mobility can be quantified in numerous ways through a variety of data collection techniques. The Domestic Scan suggests that mobility performance is typically measured at the project level in contrast to safety performance.[8] Mobility performance measures can quantify not only how efficiently vehicles are moving through a corridor but also how variable this movement is.

Quiroga[15] discussed three types of mobility measures and the strengths of each. The first types are *Highway Capacity Manual* (HCM) measures – computed measures derived from other data such as volume to capacity (V/C) ratio and level of service (LOS). These values can be “somewhat abstract to the traveling public” and “difficult to use for long-range planning because concepts such as capacity and speed-flow relationships change over time.” HCM measures are usually easier and more relevant for localized analyses rather than area-wide analyses.
The second type of measure, queuing-related measures, includes queue length, duration of queuing, and lane occupancy. While the authors suggest that queues can best reflect the traveling public’s perception of congestion, measuring queues can be difficult and site- and time-specific. However, the FHWA recently developed a Primer on Work Zone Performance Measurement[16], which details methodologies for measuring queues or estimating queue lengths from spot speed data. Queue length measurement is important from a safety perspective as well so that drivers can be alerted to downstream congestion.

Quiroga’s preferred method of mobility performance measures are travel-time based measures, such as vehicle travel time, speed, and delay.[15] These are easy to understand to both professionals and the public, flexible, and applicable across modes. Travel-time measures can be applied to specific locations, corridors, or regions. Perhaps most importantly (especially to decision-makers), travel-time based measures translate easily into costs. Travel time data can be collected either through vehicle techniques such as the “floating car method” or roadside techniques using sensors. Roadside techniques are becoming more popular and preferable today, such as utilizing Bluetooth sensors that track how long it takes a vehicle to move from one sensor to the next. Inrix is an example of a vendor that sells travel time data to agencies; a significant amount of travel time data for links within the Commonwealth of Virginia is now available to VDOT.

Pre-Construction Impacts Analysis

Transportation agencies typically conduct analyses to predict impacts such as queue length and delay resulting from highway construction projects. This impacts analysis is used to determine the allowable extent of lane closures, including how many lanes can be closed and for how long they can be closed. The Domestic Scan noted that it is optimal to consider work zone impacts as early in the project development process as possible. TMPs are developed from the work zone impacts assessment and should serve as a dynamic guide that can change based on the actual observed impacts during construction.[8] A variety of tools exist to predict work zone impacts. Smadi and Baker[17] conducted a study of several traffic analysis tools examining how accurately they can predict work zone conditions, taking into account cost and practicality of each tool. They describe three types of analysis tools:

1. Sketch planning tools provide general estimates of travel demand and operations at the project level. These tools are usually the simplest, most cost-effective, and least time-consuming. However, they lack some of the features and capabilities of more complex tools. Examples of sketch planning tools include QuickZone, QUEWZ, and CA4PRS. Sketch planning tools include spreadsheet-based queue analysis tools,[8] of which many states have created their own.

2. Analytical tools are software programs utilizing the *Highway Capacity Manual* methodologies and formulas. These tools are best suited to isolated facilities, as their output is unable to account for network performance.

3. Simulation analysis tools provide the highest levels of detail but are also the most time-consuming and costly. These tools can range from microscopic tools, such as VISSIM, Dynasim, and CORSIM, which model the dynamic and stochastic behavior of individual vehicles, to macroscopic tools, such as Synchro, which model vehicle movements in platoons using speed/volume and demand/capacity relationships.

Monitoring and Data Collection Strategies During Construction

The FHWA specifically states that "work zone performance assessment is not intended to require agencies to embark on a large data collection, storage, and analysis effort . . . the goal is to improve work zone safety and mobility by making effective use of the available data and information sources."[18] These sources could include project logs, field observations, crash records, operations data from traffic management centers (TMCs) and ITS, enforcement, or public input. The Domestic Scan notes that "in terms of monitoring during project implementation, the activity of both safety and mobility performance measures is much more of a sampling activity at the project level, with emphasis placed on those work zones where impacts are expected to be most significant."[8] Data collection techniques and equipment used should vary based on performance goals, the budget, the geometry of the work zone, and the availability of permanent data collection infrastructure. Data that are collected should be tied to performance measures, and performance measures should be developed based upon the availability of certain data.

The most common source of safety data are crash reports. Crash reports are usually collected by local law enforcement; project logs can keep track of these as well.[8,13] A major issue with safety data collection is the lag time between the time of a crash and when that crash data actually becomes available.[8] Additional sources of safety data include inspection reports, service patrol calls, TMC incidents, and complaints. Many states are committed to collecting up-to-date safety data in work zones. Ohio DOT collects crash data from major projects approximately every two weeks; agency personnel manually code police crash reports into a database to allow for near real-time safety tracking. New York State DOT has "probably the most formalized process" for collecting safety data, as all types of work zone traffic crashes and worker accident data are gathered by project staff and entered into a database for trend analyses.[8] When agencies such as Michigan DOT gather supplemental crash data, they use a specific form to ensure data consistency and collection quality.[8] More states are moving toward electronic coding of crashes.[8]

Sources of mobility data for work zones include both manual and electronic methods. Manual methods include visual inspection or manual sampling. Michigan DOT has a specific mobility data collection form to sample peak-period traffic.[8] Electronic sources include detectors for speed/volume/occupancy monitoring such as loop detectors or Wavetronix radar-based data collection devices. The Domestic scan notes that manual/visual inspections remain popular as "smart" work zones can be expensive; however, New Hampshire DOT is finding value in ITS deployments and tracks a number of mobility-related measures via portable ITS devices that look like orange barrels in work zones.[8] These ITS "Smart Barrels" can be used to collect volume and speed data, as well as estimate queue length.[19] Many states also rely on TMCs to help manage work zones and track mobility impacts such as queue lengths. In areas where TMCs are not available, third-party data sources are making it easier to obtain mobility data in work zones. Private sector travel-time data can significantly expand an agency's ability to monitor work zone mobility; however, issues exist with linking private-sector travel time links to work zone extents.[12] Integrating data from an archived private-sector travel time database can also require significant expertise and time. Finally, many state agencies, such as California DOT (Caltrans), the Illinois Tollway Authority, and Missouri DOT are reaching out to the general public using customer surveys to assess mobility impacts. For example, Missouri DOT has a website with a "Tracker" tool for assessing how it delivers services and products to its customers; measures include percentage of work zones meeting expectations for traffic flow and visibility and a nine-question survey for non-technical MoDOT personnel and the general public.[8]

The Domestic Scan's overarching finding from successful states was that support from upper management for collecting and analyzing data is critical. The Scan notes that not all agencies explicitly address or require data/performance measurement monitoring as part of a TMP; many agencies rely on project staff (as opposed to the contractor) for monitoring impacts.[8] Many agencies still face challenges in connecting data collection and performance measures; that is, data availability often affects which performance measures that agency chooses to use. Generally, agencies with solid work zone safety and mobility data management systems tend to make better use of their data. Electronic database systems are becoming more popular as a tool to quickly store and analyze data. Electronic crash data significantly speed up the availability of safety data; for example, in Indiana, 86 percent of safety data is available within 5 days.[8] Many agencies, such as Maryland State Highway Administration (SHA) have also found development of an electronic database system to track and approve current/future lane closures very useful.[8]

Updating TMPs/Work Zones During Construction

Once performance measures have been established and data are collected from work zones, what are transportation agencies doing with these data in relation to the TMP and predicted work zone impacts? The Domestic Scan found specific examples of agencies that use safety and mobility data to identify deficiencies or gaps in their approach to project delivery and make improvements. A common way in which agencies use work zone mobility data is to establish acceptable times of day when one or more travel lanes can be closed for work activities. Ohio DOT makes regular changes to design standards, specifications, and other documents based on work zone data. For example, by comparing during-construction safety data with pre-construction data, agency personnel were able to locate a “problem spot” for median egress from a work zone for large vehicles and altered their standards to provide greater sight distance for these vehicles. Access to real-time data correlates to an agency’s ability to modify or update work zones in a timely manner.[8] At the same time, a lack of timely data prevents agencies from responding more quickly to work zone conditions.

The Domestic Scan notes that not all agencies have gone through a full policy and process review cycle as required by the Final Rule.[3,8] Not all agencies have fully explored the availability and usefulness of data available for work zone safety and mobility improvement due to a number of reasons, such as a lack of expertise, time, and funding. While a lack of resources is an issue for many agencies, the Scan suggests that more can be done with available data. The Scan recommends that agencies constantly improve how data are analyzed and continuously improve processes and procedures.[8]

Post-Project Evaluation

Post-construction, agencies should incorporate lessons learned for use in future projects. For example, Michigan DOT has documented implementing changes addressing lessons learned from prior projects on new projects and these changes have been estimated to reduce crashes.[8] Michigan also tracks results of lane closures closely and records when predicted impacts do not correspond to actual impacts.[8] Currently, few states conduct post-project evaluations for individual construction projects. New York State DOT conducts regional traffic control inspections for a “representative sample” of work zones and assigns a score from 0 to 5 to various work zone traffic control components. Traffic control components scoring lower than “3” require a follow-up report to be submitted.[20] Similarly, Illinois DOT conducts a work zone traffic control project review every other year (alternating with years to perform *process* reviews). This review involves a “random selection of projects” sampled for drive-through inspection.[21] After both of these states conduct their regional/district work zone sample inspections, follow-up meetings are held to discuss lessons learned.

For individual projects, Illinois DOT has TMP performance assessment guidelines for safety and mobility.[21] A safety performance assessment is required if a fatal crash occurs within the project limits and summarizes crash information, any changes made to traffic control as a result, and/or recommendations to change IDOT's standards or policies. Mobility performance assessments are only required for significant, long-term projects. IDOT requires the Resident Engineer to submit a Work Zone TMP Summary Report summarizing TMP strategies including changes made, successes and failures, descriptions of traffic operations due to the work zone, and any recommendations for changes to IDOT standards or policies.[21]

The FHWA released a guide on Work Zone Impacts Assessment[18] designed to help transportation agencies develop and/or update their own policies, processes, and procedures for assessing and managing the work zone impacts of road projects throughout different program delivery stages. Work zone impacts assessment is a process that begins during Systems Planning and continues throughout the entire project. The FHWA guide includes discussions on conducting performance assessments for developing recommendations on improving work zone policies, processes, and procedures and incorporating work zone impacts assessment and management in maintenance and operations.[18]

Outside State Transportation Agency Survey

The research team received responses from representatives of 33 state transportation agencies, including all 15 states who participated in the Domestic Scan. Some responses were quite detailed and included attached TMP-related files for the research team to use; other responses were not completed fully. The following sections summarize responses to various segments of the survey. The full survey can be found in Appendix C.

Safety Impacts of Work Zones

A large number of states establish safety performance measures at the agency/program level, while some establish safety performance measures at the individual project level. Many states also evaluate safety performance measures in addition to establishing them. The most popular safety performance measure was number of crashes; many states also used crash rate (which incorporates the number of crashes). Worker injuries, complaints, and a subjective rating of safety were also used by several states. All states who responded use crash records to collect safety data; other popular methods of collecting safety data include visual inspection/inspection reports and project logs.

Mobility Impacts of Work Zones

Approximately the same number of states said that they establish mobility performance measures at the agency level as states who said that they establish mobility performance measures at the individual project level (16 at the agency level; 15 at the project level). This is contrary to the findings of Domestic Scan which suggested that mobility performance measurement was much more common at the individual project level. Some states (Michigan, Missouri, Montana, New Hampshire, Oregon, and Washington) said that they establish mobility performance measures on both levels. Four states (Michigan, Missouri, Montana, and New Hampshire) said that they establish safety and mobility performance measures on both levels. Nearly two-thirds (20) of the states who responded said that they evaluate mobility performance measures as a part of their overall TMP evaluation.

Figure 4 displays mobility performance measures used by agencies. The responses suggest that “maximums” may be more popular than “averages” but also suggest that there is no agreed-upon “best” mobility performance measure.

Similarly, the survey results suggested that there is no consensus as to the “best” ways to collect mobility data. Eleven states use project logs; 20 use field observations (all who responded); 10 use count stations; 9 use travel time data; and 4 use other sources such as public feedback or ITS. This is consistent with the Domestic Scan’s assertion that (manual) field observations are the most common (and, likely, the least expensive) source of work zone mobility data. Oregon DOT noted that they are just beginning to introduce “Smart Work Zone” traffic management systems to measure work zone traffic operations and report real-time information and warnings to motorists; these systems will be limited to large, long-term projects.

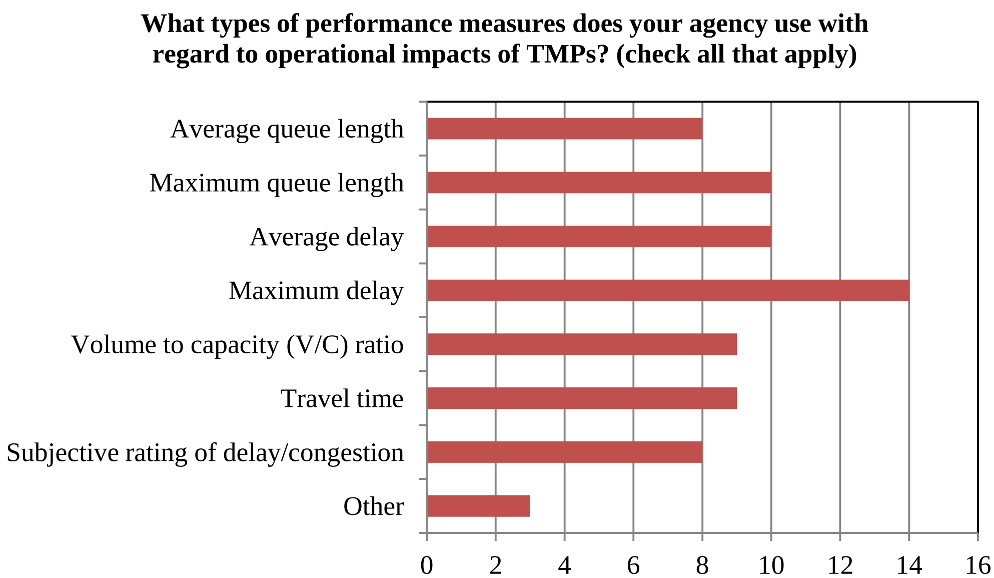

Figure 4. Mobility Performance Measures Used by State DOTs

Work Zone Impacts Assessment

Nearly all states who responded use software tools to predict work zone impacts. Some software tools, such as *Highway Capacity Manual*-based software and spreadsheets, as well as Synchro, QuickZone, VISSIM, and CORSIM, were more popular than other tools, such as QUEWZ or Dynasim. Most states said that the complexity of tools used depends on the complexity of the project; however, some states said that the complexity of the project does not affect the type of impacts assessment tool used.

Similar to mobility performance measure responses, there was no overwhelming consensus among state agencies in regards to which software-produced measures were most important for assessing work zone impacts. Results were fairly evenly split over travel times/delays and average/maximum queue lengths.

The final question in this section of the survey asked states to rate how satisfied they are with their work zone impacts assessment tools. Figure 5 displays states' responses.

Agencies were allowed to make comments in response to this question. One state noted that the "current software is inaccurate, difficult, and time-consuming to use . . . training seems to be unavailable." To alleviate these shortcomings, that state developed their own sketch planning spreadsheets. Some states noted that they were generally satisfied with results but have seen over-estimates of queues and road user costs, especially from QUEWZ. One state commented that their issue with software tools was "gaining consistency statewide with using the software." Oregon DOT, who use their own web-based software known as the Work Zone Traffic Analysis (WZTA) Tool as opposed to the software tools that were listed in the survey, was one of the few states who "strongly agreed" that they are satisfied with their traffic analysis software. They noted that a recent study of their software's benefit-cost ratio suggested a ratio of 9.31:1 over five years (dollars spent in development/maintenance/operation versus savings related to reduced delay).

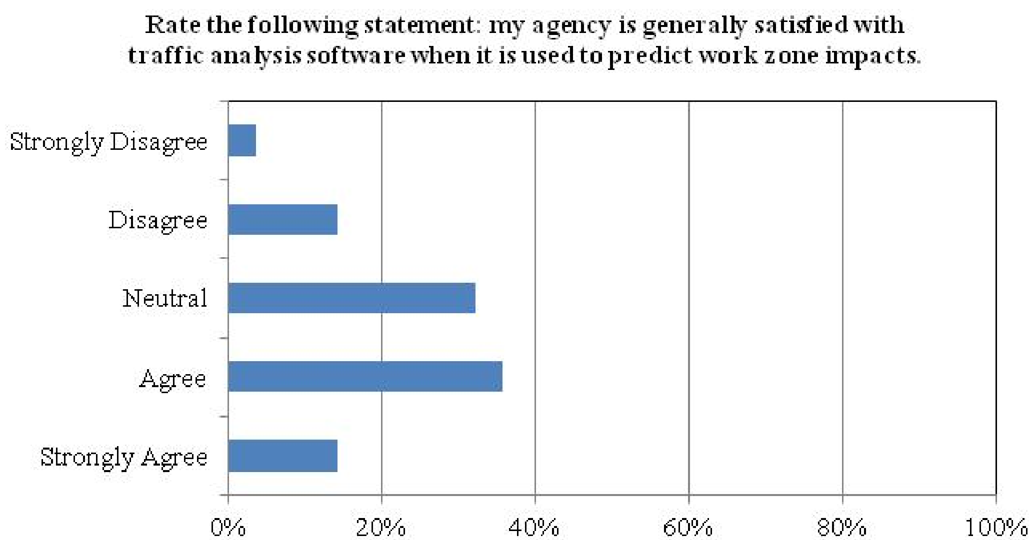

Figure 5. Agency Satisfaction with Software Tools for Predicting Work Zone Impacts

Monitoring Work Zones

More than one-third of states surveyed stated that they check field conditions against software-predicted impacts; more than one-third of states surveyed said that they check field conditions against predefined performance thresholds. Four states (Michigan, Missouri, New Mexico, and Oregon) said that they do both. More than half of states that collect data said that the data are used to update and revise TMPs during construction. Slightly more than half of states said that data collected during construction are also used to update agency policies and procedures post-construction.

Work Zone Information Dissemination

In regards to tools used to disseminate information to motorists and agency personnel about work zone conditions, nearly all states mentioned 511 systems and/or changeable message signs. Many also mentioned press releases, social media such as Twitter, web sites, and media outlets such as TV and radio stations.

States were asked whether they assess the effectiveness of their public awareness/motorist information strategies; nearly two-thirds said that they do not. This could be due to a lack of methodology to assess PI strategies. Of states that said they do assess public information strategies, they did so through surveys or by assessing changes in travel patterns. Texas DOT mentioned that districts are asked to review TTC, TO, and PI strategies for all projects annually and forward results to the Traffic Operations Division. They noted that the review is a discussion of the strengths and weaknesses of the strategies used and that there are "no formal performance measures" used.

Additional Questions

States were asked what their biggest barriers to sound post-construction work zone impacts assessment were. A lack of personnel (manpower) was an overwhelming response from states as to why post-construction assessment of work zone strategies and impacts is not completed more thoroughly. Data and funding were also common responses. A few states noted an issue of consistency; that is, states have not established methods or performance measures for post-construction assessment.

Finally, states were asked if their agency currently has guidelines for assessing TMP performance. Nineteen states said they had some sort of guidelines for assessing TMP performance, while 11 said that they do not. The extent of these guidelines varies. Some mentioned that their guidelines are limited or in their infancy, such as a process review every 2 years. One state mentioned that they had a policy but extremely limited manpower to do the work. New York State has developed a work zone inspection program which has been modified and updated over the years. They stated that "the most successful method is having an extremely experienced design/review team that fulfills the function on ALL regional projects." NYSDOT has a fairly rigorous post-construction inspection report form which "grades" a project. NYSDOT, Wisconsin, and Illinois provided copies of their TMP policies. Wisconsin's TMP policy describes a process for assessing the "quality, performance, and effectiveness of the TMP in achieving project objectives," stressing that TMP strategies need to be linked to performance measures. Performance measures can vary for different projects, and new measures may need to be developed to evaluate the effectiveness of new strategies. Performance data should be documented in a post-construction report containing the following:

- an overall statement reflecting the usefulness of the TMP
- changes made to correct oversights in the TMP
- changes made to the original TMP and how successful those changes were
- public reaction to the TMP (i.e., using surveys)
- average delay time, queue length, etc., during construction
- frequency and nature of complaints as well as how these complaints were resolved
- crashes/incidents during construction and how they were resolved
- recommendations or suggestions for future projects
- highlights of the most successful areas of the TMP.

This language is very similar to the language described in Chapter 1 from VDOT's TMP policy.[6] The most thorough post-construction report from another state was provided by the California DOT (Caltrans) for a project involving the closure of two lanes on a major freeway in Los Angeles County[22] This report summarized TMP strategies used such as message signs and detours; the report goes on to evaluate the effectiveness of the TMP using travel time and volume data for both the mainline and detour routes. Caltrans provided a list of "lessons learned" at the end of the report for future TMP development.

VDOT Region Survey

Following the survey to state transportation agencies across the country, the research team developed a similar survey for VDOT work zone coordinators. The research team received four responses each from Northern Virginia (NOVA) and Northwest Regions, two responses from Central Region, and one response each from Southeast Region and Southwest Region. Although eleven respondents "started" the survey, only six responded to the majority of the questions. This is a very small sample size of VDOT personnel, and it is unknown whether the responses of these personnel are reflecting the general practices of their entire district/region or simply their specific experiences. All five regions are accounted for from these six respondents. The following sections summarize results from the survey to regional work zone coordinators. The full survey can be found in Appendix D.

Performance Measures

All respondents used number of crashes as a safety performance measure. Number of complaints, worker injuries, a subjective rating of safety, and SSP/police response time were also mentioned as safety performance measures. The most commonly cited mobility performance measures (in decreasing order) were travel times and maximum queue length, average queue length and average delay, and maximum delay and volume to capacity ratio. Other cited measures include a subjective rating of congestion, incident clearance time, and bicycle/pedestrian mobility during closures. As expected, the safety and mobility performance measures used by various VDOT districts are overwhelmingly "highly dependent" upon available data according to those surveyed.

Work Zone Impacts Assessment

VDOT personnel, including inspectors, traffic engineering, and work zone personnel, are all part of the responsible parties for work zone impacts assessment in all districts. Multiple respondents also stated that the contractor has some responsibilities as well. To assess and/or predict work zone impacts prior to construction, the responses varied between utilizing 1) the VDOT Allowable Work Hours Tool developed by VCTIR, 2) hourly traffic volumes (seasonally adjusted AADT or pre-construction counts), 3) geometry and driving patterns, 4) traffic mix, and 5) accident data.

Tools used to predict impacts varied across and within regions. Three respondents said that they have and use spreadsheet tools to predict impacts. Four respondents said that they have and use software tools to predict impacts. Figure 6 displays which software tools are most popular among the respondents.

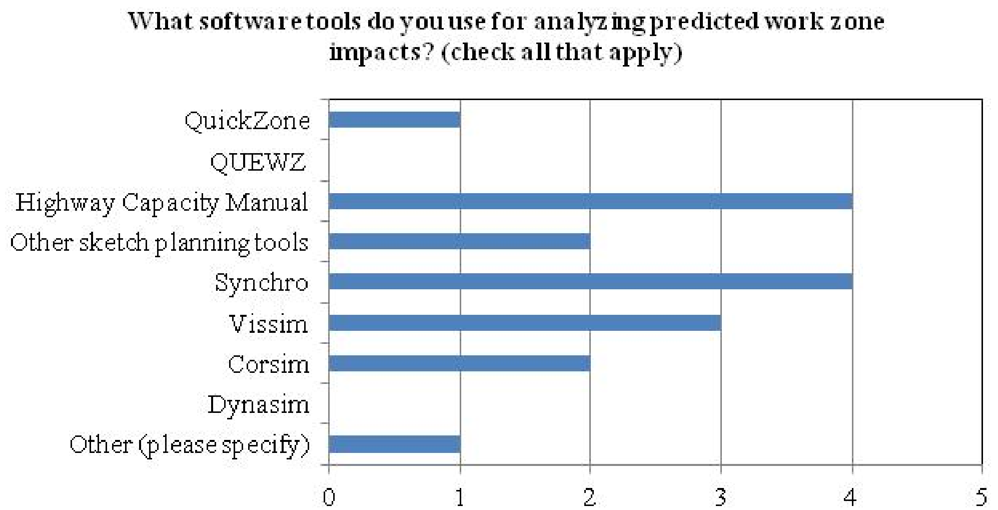

Figure 6. VDOT Work Zone Coordinators' Preferences for Work Zone Software Tools

Other Pre-Construction Information

The research team also asked the work zone coordinators about various usages of Domestic Scan-recommended best practices prior to construction. They were asked if they ever incorporated performance measures into contract language (i.e., using performance-based specifications as opposed to method-based specifications); four respondents indicated "yes." Also asked was whether or not Road User Cost (RUC) information was incorporated into agency cost analyses. Again, responses varied. Five respondents from stated that they do incorporate RUC information. One respondent explained that RUC information is used to set incentives/disincentives when applicable and needed to complete a critical phase of work where traffic is most impacted.

Additional questions were posed about maintenance-of-traffic (MOT) alternatives analysis prior to construction. Five respondents from said that they do compare traffic alternatives during project development. One respondent commented that for Megaprojects, a formal alternatives analysis occurs only on major short-term or long-term closures. All respondents indicated using a permitted lane closure chart.

The Domestic Scan also recommends that certain practices be avoided. One of these is lane rental provisions, in which a contractor can pay additional fees to close lanes during normally-non-permitted time periods even if adverse impacts to traffic are anticipated. Only one respondent said that their region/district allows for lane rental provisions.

Data Collection and Monitoring

Three respondents stated that they require work zone performance monitoring in TMPs. When asked who was responsible for monitoring work zones, answers varied. One respondent stated that VDOT specifications require a designated work zone safety person on contractor staff. Another respondent stated that “contractors are expected to, but don’t do a very good job, so we end up doing it.” Multiple responses listed VDOT staff or inspectors, which could be an outside consultant.

For sources of safety data, all respondents stated that field observations were used. Police crash reports, customer surveys/complaints, crash reports from work zone personnel, and fire/rescue dispatch frequency were also cited. There was no predominant source of mobility data. TMCs were the most popular response, followed by travel time data, count stations, and project logs. Four respondents from three regions said they monitor travel time or queue lengths in the field and compare them to predicted impacts and/or predefined performance thresholds.

In regards to best practices recommended by the *Domestic Scan*, three respondents indicated ability to access to real-time work zone data from cameras and data supplied by the Traffic Operations Center. They also mentioned utilizing electronic data collection. These data includes traffic volumes (on some major projects) and speeds. Only two respondents stated that they have an electronic system for entering crashes. Three stated that they have database management systems for lane closures and traffic performance. Two also stated that they have a crash analysis database. Three respondents said that they use customer surveys for assessing work zones. These can take the form of “customer awareness surveys.” TMCs play a major role in work zone monitoring, using existing cameras to monitor congestion (where they are available) and coordinate/report lane closures. TMCs also coordinate Highway Advisory Radio and Safety Service Patrol.

Updating/Revising TMPs and Agency Policies

The survey asked if monitoring and performance results are used to make changes to TMPs during construction. Four respondents said that they do. For example, based on traffic monitoring, a location adjustment was made to a merge taper and sign spacing for a project along I-295 southbound over I-64. In Northern Virginia, “constant changes to traffic operations” are made “to optimize traffic flow while maintaining safety for all modes of travel”; this occurs around the I-495 HOT Lanes, the Dulles Rail Metro project, BRAC, and the I-95 fourth lane widening.

When asked if they use performance results to make changes to work zone policies, three respondents said “yes.” Changes could include hours of operation, acceptable configurations, and coordination between projects. When asked if they use performance results to make changes to design standards, only one respondent said “yes”; this referred to changing sign spacing due to roadway geometry. One respondent stated that this is not a district responsibility but rather a headquarters responsibility. When asked if they used performance results to make changes to values for capacity used in analysis, three respondents said “yes.” One example mentioned was multiple-lane ramp lane closure time. Another respondent referred to the I-495 HOT Lanes project, in which the highly congested and dynamic environment is constantly having data collected on it so that staff “has a better understanding of the capacity to move traffic.”

Additional Input

The final question to VDOT regions asked what their biggest barriers or constraints to doing more with work zone data were. A lack of personnel was mentioned by multiple respondents. One respondent mentioned limited real-time data or non-user-friendly data. In regard to simply being able to collect work zone data, one respondent from Northern Virginia mentioned that available right-of-way on an over-capacity system and finances also constrain the ability to collect more data.

Summary

Table 1 summarizes best practices targeted in this survey and the number of respondents from within VDOT who stated that they had used or were familiar with each practice. Many of the responses seemed to reflect the unique nature of each construction project – different constraints and resources exist for individual highway construction projects. Some projects are not impactful enough to require extensive procedures or manpower to develop and monitor the TMP; other projects require significant data collection efforts and technologies to soundly monitor the TMP.

Table 1. VDOT Usage of Work Zone “Best Practices” from Survey Results

Practice	No. of Respondents
Performance-based specs for contracts	4
Incorporating Road User Costs (RUCs) into agency cost analyses	5
Comparing maintenance-of-traffic alternatives during project development	5
Permitted lane closure charts	5
Requiring work zone performance monitoring in TMPs	3
Comparing mobility data to predicted impacts	5
Comparing mobility data to predefined performance thresholds	4
Electronic data collection	3
Electronic crash entry database	2
Electronic lane closure database	3
Customer surveys for assessing work zones	3
Using monitoring/performance results to make changes to TMP during construction	4
Using performance results to make changes to work zone policies	3
Using performance results to make changes to design standards	1
Using performance results to make changes to values for capacity used in analysis	3

VDOT uses many of the recommended "best practices" set forth in the Domestic Scan, at least for select projects. These practices include heavy TMC involvement, incorporation of Road User Costs (RUCs) into agency cost analyses, and use of database management systems including electronic crash entry. Multiple regions have also used data collected from projects to update TMPs, change design standards or agency policies, or update values used in capacity analysis to better understand traffic flow through work zones.

Case Study I: I-81 Pavement Reclamation Project, Augusta County

This section documents observed impacts during construction. These impacts are compared to both pre-construction baseline data and TED's predicted impacts. In addition, VDOT's and the contractor's implementation of the TMP and changes made to the TMP are detailed.

Observed Impacts

The research team met with the project's two main traffic control coordinators, the contractor's work zone traffic control coordinator and VDOT's work zone safety coordinator. Discussed were concerns and questions with the TMP and monitoring/performance measurement practices. During construction periods, the coordinators monitored queues and volumes approaching the work zone from the SR 654 bridge over I-81 and via an advance warning vehicle placed upstream of queues. Traffic control strategies such as message signs and flagging were altered based on the coordinators' judgment. Perhaps the most noticeable impact was that queues were minimal upstream of the work zone due to a very high percentage of car traffic utilizing the detour during peak volume periods. During the 24-hour construction periods, at no point did queues extend to the "emergency detour" threshold of Exit 220. Within the work zone, some delays were experienced both along I-81 within the single lane through the work zone, as heavy truck traffic often slowed in close proximity to construction vehicles, and along the detour, where flaggers could not provide completely continuous flow to all detouring vehicles. These delays, which often occurred past the divide for the work zone, were measured in terms of travel times through the work zone. Figure 7 shows slow-moving traffic within the work zone adjacent to intense construction activity.

Changes to TMP During Construction

Both coordinators echoed the idea that a TMP is a living document and a constant work in progress. One can only account for so much in a TMP and traffic control plan; unforeseen issues arise that must be adjusted during the project. These issues and changes were not explicitly documented, however; rather, the contractor and traffic control coordinators relied on their judgment and knowledge. During the first week of construction, the coordinators estimated that there were "far more on-the-fly changes" to traffic control strategies in comparison to a typical construction project (T. Christianson, personal communication). One change made to the TMP involved the wording of upstream message signs. For lighter volumes, a message of "Trucks use left lane / right lane exits" was used, alerting motorists of the detour and "allowing" cars to stay on I-81 SB. For heavier volumes, when it was necessary to move more traffic to the detour route, the message was changed to "Trucks use left lane / cars use right lane."

Figure 7. Slow-Moving Traffic Through I-81 Work Zone Adjacent to Construction Activity

The coordinators aggressively managed traffic in the work zone to minimize delays and make best use of the available interstate and detour capacity. If the route through the work zone (left lane) became slow, the coordinators would instruct the TOC to change the upstream message signs to shift car traffic onto the detour route. If a truck failed to merge into the left lane along I-81 and instead was forced onto the detour route, the coordinators would instruct flaggers to not "stop" the truck at intersections, which could create a shock wave of slow vehicles behind it. There were no queue length or data "thresholds" for the decisions made by the coordinators – the work zone traffic coordinators "just used [their] gut[s]" (T. Christianson, personal communication).

Measured Impacts

VDOT and its contractors set a goal of zero crashes for all projects. Crash data are collected by law enforcement and entered into a shared database maintained by the DMV. Both law enforcement and VDOT have access to this database, which uses standardized FR300 crash entry forms. These forms can make notes of the condition of a crash location, such as it being in a work zone. During the continuous closure periods, there were five crashes in the work zone, including one DUI. The only other safety performance factor of note for this project was complaints, which are directed to VDOT's call center. Substantive complaints are passed along to the work zone safety coordinator; during the continuous closure period, there were less than five complaints in regards to traffic control.

As mentioned, at no point did queues extend to Exit 220 during 24 hour lane closures, even during the PM peak volume periods. Queues were monitored by the contractor's work zone traffic control coordinator and VDOT's work zone safety coordinator via visual inspection and by using a roving “advance warning vehicle” placed upstream of queues. Changes in queue lengths resulted in changes to the traffic control at the coordinators’ judgment. Queue lengths were not explicitly recorded for analysis.

Traffic data collected from roadside sensors recorded 15-minute flow rates at locations upstream of the work zone and within the work zone. Data suggest that equivalent hourly flow rates upstream of the work zone (in the advance warning area) during peak periods were often in excess of 1,500 vehicles per hour per lane (vphpl) and approached 2,000 vphpl. As some of this volume was forced to detour, within the transition area, the maximum 15-minute flow rates were less than 1,500 vphpl and usually less than 1,300 vphpl. Within the work zone (the activity area), the maximum 15-minute flow rate was 1,180 vphpl, and most flow rates were usually less than 1,100 vphpl or even 1,000 vphpl. This suggests that the capacity of the work zone is less than peak-hour volumes upstream on I-81 SB. Figure 8 shows fluctuations in daily flow rate within the work zone for two Saturdays during construction and for one Saturday prior to construction; peak flows outside of construction periods are more than double the peak flows during construction. Figure 9 shows weekday hourly volumes for select weekdays during construction at the start of the work zone. The flow rates suggest that the capacity of the work zone was much less than the capacity of a typical single lane of rural freeway.

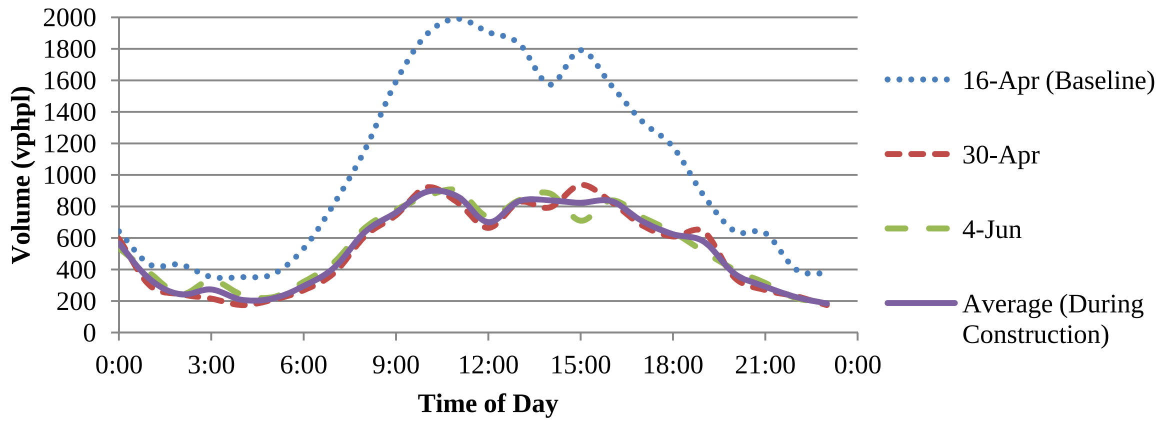

Figure 8. Hourly Volumes Along I-81 Within Work Zone for Select Saturdays During Construction

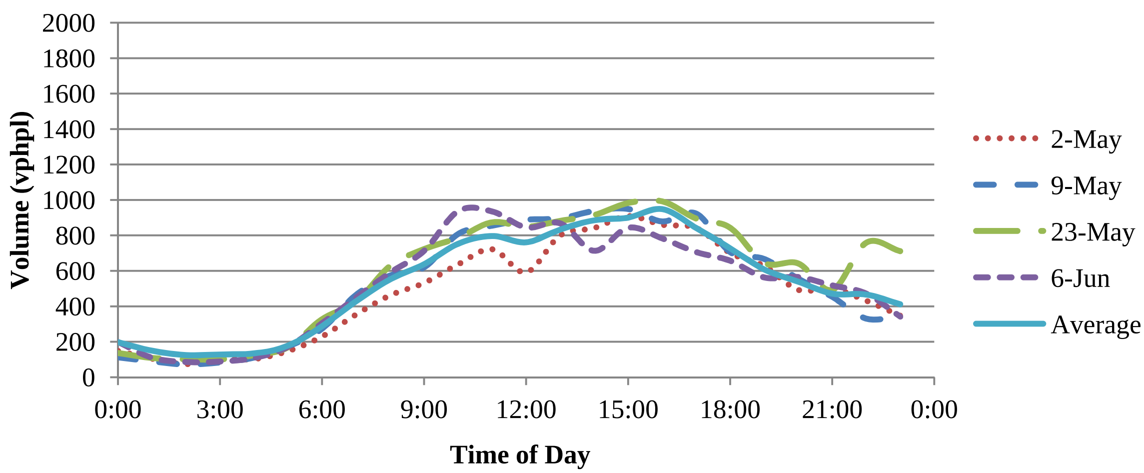

Figure 9. Hourly Volumes Along I-81 at the Beginning of the Work Zone for Select Weekdays During Construction

TED was fairly accurate with predictions of daily volumes in the work zone area. Figure 10 compares actual average weekday daily volumes with TED predictions. The most noticeable difference is the daily volume within the work zone, as much more traffic used Exit 217 (and thus did not travel through the work zone) than expected. Part of the discrepancies in TED's predictions stem from their assumption that some local traffic would not use I-81 at all in this area and instead use parallel US 11 upstream of the detour segment. This did not occur, as shown by the "I-81 SB Upstream of WZ/Detour" and "US 11 SB Prior to SR 654" volumes on the graph in Figure 10. Figure 11 displays average hourly weekday volumes along US 11 within the detour segment, showing the large increase in volumes due to vehicles utilizing the detour route.

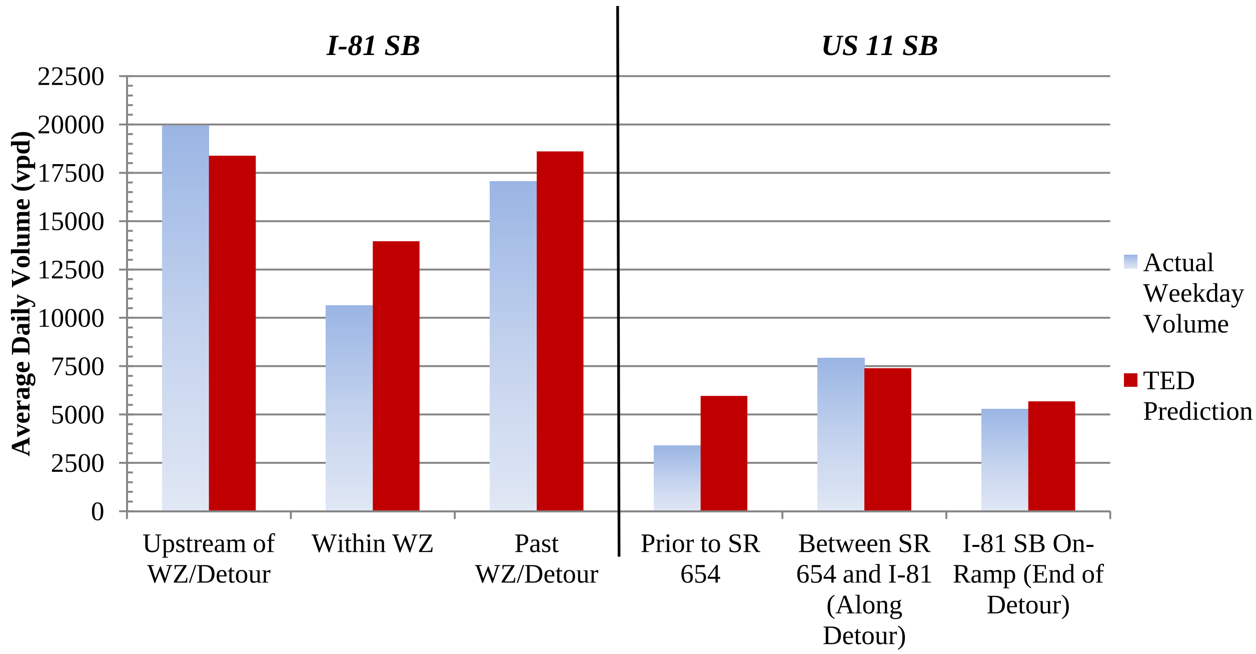

Figure 10. Average Weekday Daily Volumes During Construction Periods

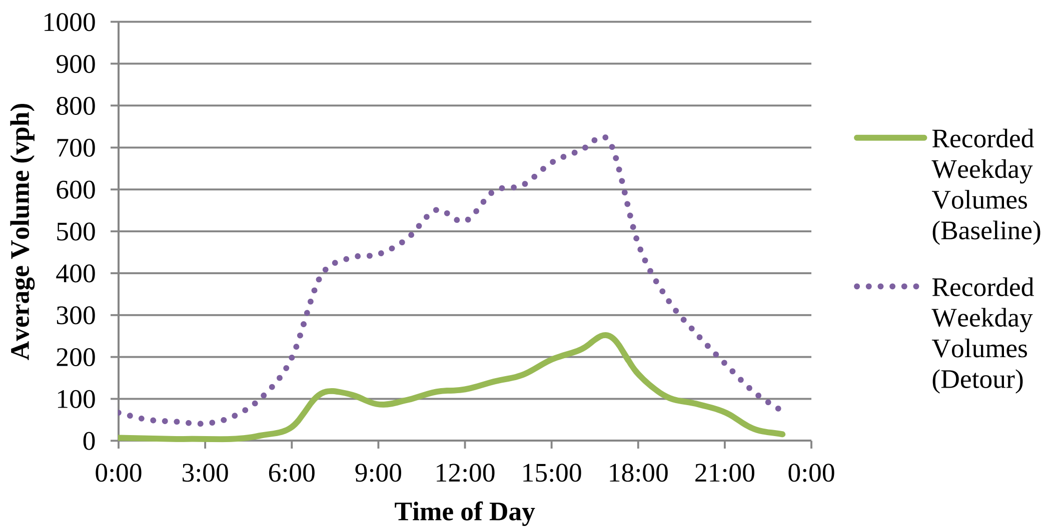

Figure 11. Average Weekday Hourly Volumes Along US 11 Within Detour Segment

I-81 SB is a notorious corridor for heavy truck volumes. Along I-81 SB in this region, data confirmed that an average of nearly 30 percent of vehicular traffic is truck traffic, with much higher percentages during overnight periods (often between 50 percent and 60 percent trucks). VDOT and the contractor were very successful in keeping truck traffic along I-81 SB while forcing cars to detour when necessary. While much of the truck traffic is typically confined to the right lane (the pavement damage to the right lane of I-81 SB due to truck volume provoked this construction project), data showed that during construction periods, truck volumes in the left lane were much higher upstream of the work zone, even at MM 220.1. Figure 12 displays average heavy vehicle percentages in each lane both in advance of and just approaching the work zone during construction and outside of construction hours. These figures suggest that many truckers were aware of the upcoming work zone and detour in advance of the work zone.

Nearly 90 percent of heavy trucks, defined as vehicles measured to be longer than 50 feet, stayed on I-81 SB through the work zone. Within the work zone, the traffic stream had a much higher composition of heavy vehicles than typical I-81 traffic, as expected. On weekdays, the makeup of the traffic stream within the work zone was 40 percent heavy trucks. Out of the overall traffic stream, over 45 percent of all cars and nearly 40 percent of all vehicles traveling along I-81 SB upstream of the work zone exited at Exit 217, a majority of which were utilizing the detour. This was much higher than VDOT's conservative estimate that only an additional 10 percent of traffic would use the detour route (in addition to the 13 percent typical local traffic that exits at Exit 217).

Table 2 displays a summary of average travel times through the work zone area from the test vehicle runs. Baseline travel times along the 9.1-mile link from Exit 222 to Exit 213 averaged 7 min 57 sec. During construction, peak-hour travel times for vehicles remaining on I-81 averaged 11 min 13 sec. while the detour travel time averaged 12 min 38 sec. Thus, on average, the work zone delayed travelers staying on I-81 3 min 16 sec and delayed travelers

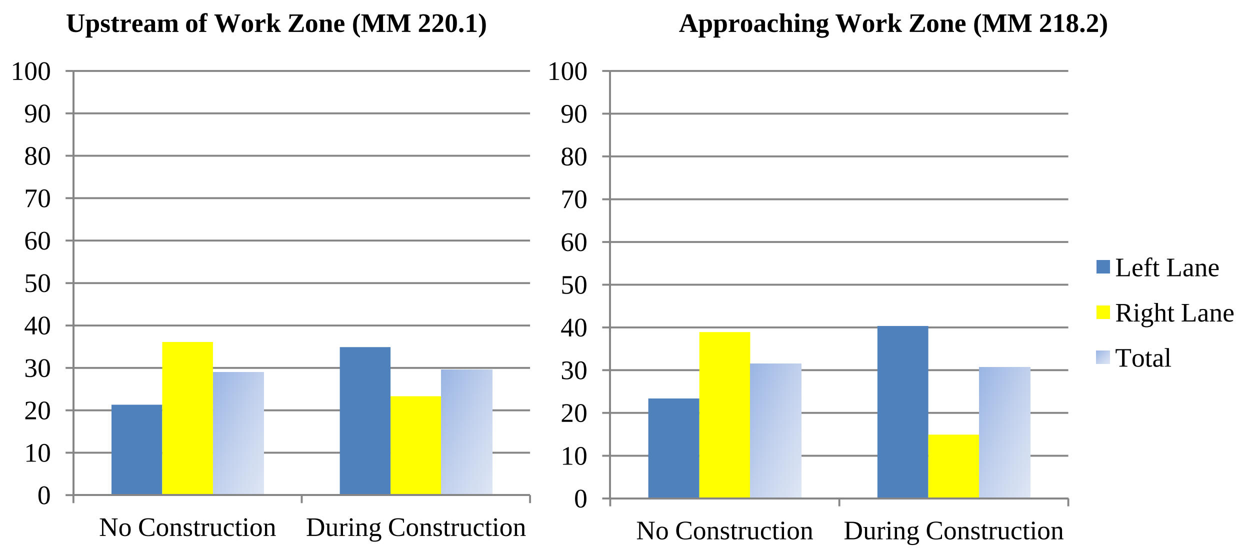

Figure 12. I-81 SB Heavy Vehicle Percentages Upstream and Approaching the Work Zone

Table 2. Average Recorded Travel Times Through the I-81 Work Zone Area

Route	Baseline		During Construction		Difference	
	Travel Time (sec)	Travel Time (min)	Travel Time (sec)	Travel Time (min)	sec	min
I-81 Work Zone	477	8.0	673	11.2	196	3.3
Detour Route	624	10.4	758	12.6	134	2.2

using the detour 4 min 41 sec. During construction, there was much variability in travel times along both routes, which can be attributed to the heavy truck traffic through the work zone. At the start of the construction period and during incidents and rolling road blocks, travel times were longer as noted by the work zone coordinators.

Effectiveness of TMP and Lessons Learned

VDOT's work zone safety coordinator for this project provided several "lessons learned" from the project that VDOT can use in the future (F. Wright, personal communication). By being proactive with traffic control, traffic can be actively managed, as the work zone coordinators realized through their forced detour strategy. VDOT personnel suggested that flaggers can be as good, if not better than signals at moving traffic, especially because they can assist motorists with questions. They stressed the need for having an incident manager and local wrecker available on site during critical times in case of a crash or incident. Cameras in the work zone area were essential for monitoring queues. VDOT personnel also suggested that it would have been ideal to have more changeable message signs upstream of the work zone with additional spacing to allow increased lane changes. Overall, traffic management did not add significant costs to the project; installation and tear-down, work orders for additional signs, and flaggers were costs cited (F. Wright, personal communication).

The extensive PI campaign implemented for the project was an important element of the TMP, helping to alert motorists of the work zone. It is not possible to determine the direct impact of the PI campaign on the observed changes in flow but it is assumed to have contributed. As supported by data showing vehicle classifications upstream of the work zone, within the work zone, and along the detour route, truckers were generally quite aware of the work zone and VDOT's/the contractor's desire to have trucks remain on I-81. Trucks were moving into the left lane in advance of the work zone even with limited signage, suggesting that they may have been aware of the work zone via communication with other truckers, media outlets such as the CB Wizard, and/or radio ads. Additionally, overall daily and hourly volumes upstream of the work zone and through the work zone were somewhat lower than baseline volumes although not as low as predicted by TED indicating a possibility that motorists had been made aware of the work zone and altered their routes.

TED conducted an extensive pre-construction impacts analysis, which allowed VDOT and the contractor to anticipate work zone impacts and actively manage traffic. The analysis did overestimate some work zone impacts, such as the volume of vehicles within the work zone. The analysis also did not take into account the reduced capacity of the work zone, which slowed traffic moving through the work zone at the activity area. This reduced capacity necessitated use of the forced detour. The research team conducted a study using VISSIM simulations (based on TED's model) to compare the observed field impacts to several scenarios with different control parameters.[23] This study showed that the forced detour traffic control scheme employed by VDOT and the contractor reduced travel times and queues in comparison to a traffic control strategy that employed no detour or only suggested a detour (but kept one lane closed through the work zone). The simulation results indicated that the forced detour strategy be documented by VDOT and used in similar work zone scenarios in the future.[23]

Neither VDOT nor the contractor documented changes made to the TMP or submitted a written post-construction lessons learned report. Ultimately, however, this project provided an example of an innovative traffic monitoring and control strategy that could be used in future work zones. This project also provided a thorough, detailed example of a TMP and pre-construction impacts analysis report. These reports provide documentation that could be used for future work zone traffic control strategies. The research team asserts that a post-construction evaluation would be a valuable supplement to the TMP and impacts analysis by addressing oversights, changes, and lessons learned.

Case Study II: Gilmerton Bridge Replacement Project Phase I, City of Chesapeake

This section documents observed and recorded impacts during Phase I of the Gilmerton Bridge replacement project. These impacts are compared to available pre-construction baseline data and the Hampton Roads Planning District Commission's (HRPDC) predicted impacts. VDOT's and the contractor's implementation of the TMP are also detailed.

Predicted Impacts

The HRPDC used the regional planning model to predict impacts resulting from the proposed lane closures on Gilmerton Bridge. Gilmerton Bridge carried approximately 35,000 vehicles per day (both directions combined) prior to construction. With all four lanes open, the bridge has a V/C ratio of 0.94, which is approaching capacity. Although some traffic was predicted to divert during the lane closures, a reduction of 2 lanes to 1 lane in each direction yields a predicted V/C ratio of 1.58 during the closure. Therefore, a further evaluation of traffic impacts was required.

The HRPDC used QuickZone (recommended by the FHWA as the appropriate tool for a project of this scope) to analyze a single lane closure in each direction along the bridge. From their results, it was anticipated that the capacity of the single lane would not be able to accommodate the predicted demand, resulting in substantial delays during the peak hour periods.

In the eastbound direction during weekday peak periods, queues were expected to be less than 1,400 feet; during Friday peak periods, queues were predicted be greater than 3,000 feet. On weekdays, travel times across the bridge were predicted to increase from just over 2 minutes to between 10 and 15 minutes during the morning peak and between 20 and 25 minutes during the evening peak. During the Friday afternoon peak periods, travel times were expected to be greater than 50 minutes.

In the westbound direction during weekday peak periods, queues were expected to be between 1,400 and 1,800 feet; during Friday peak periods, queues were predicted be greater than 3,500 feet. On weekdays, travel times across the bridge were predicted to increase from just over 2 minutes to between 15 and 20 minutes during the morning peak and around 30 minutes during the evening peak. During the Friday afternoon peak periods, travel times were expected to be greater than 60 minutes.

In addition to impacts on Military Highway, the HRPDC notes that diversion of traffic could result in an increase of traffic on the I-64 High Rise Bridge. Existing traffic currently already results in congestion of varying degrees on the High Rise Bridge, which had a V/C ratio of 0.98 in 2006. Using HCS+ software, it was predicted that the volume along I-64 would increase by 3,500 vpd from 79,849 vpd to 83,349 vpd. This results in a V/C ratio above 1.0 and a reduction in LOS along I-64 from E to F.

Importantly, the HRPDC study does not take into account any volume changes along Military Highway that may result from public awareness of construction and alternate routes. In addition, HRPDC noted that no consideration was given to account for traffic signal timing optimization on the city surface streets as they are maintained by others.

Observed Impacts

VDOT, the contractor, and the research team all found that delays predicted by HRPDC were not occurring in the field. The research team also found that the major source of delays through the work zone can be mainly attributed to drawbridge openings, not work zone activities. During peak hours (6:30-9:30 A.M., 3:30-6:30 P.M.), the bridge is not required to open for recreational or commercial vessels. However, the bridge must open at any time for vessels carrying flammable gases/hazardous materials upon arrival. In addition, if a commercial cargo vessel (including tugs and tugs with tows) gives two hours notice, the bridge will open for it upon arrival. During off-peak hours, the drawbridge opens on signal on the half-hour every half hour. These bridge openings can last ten minutes or longer and significantly affect the flow of traffic, taking several minutes or even tens of minutes to clear the queue. Outside of drawbridge opening events, however, queues on both approaches to the work zone are short, and traffic proceeds through the work zone slowly but steadily.

Volume Impacts

The 2010 *Highway Capacity Manual*[10] estimates the capacity of a two-lane highway as 3,200 passenger cars per hour (pc/h) in both directions, with a maximum of 1,700 pc/h in one direction. This is under base conditions (lane width greater than or equal to 12 feet, clear shoulders wider than or equal to 6 feet, no no-passing zones, all passenger cars, level terrain, no impediments to through traffic). For the two-lane segment of the Gilmerton Bridge work zone, while adequate lane width is maintained, there are no shoulders and no passing is allowed. In addition, construction activities take place directly adjacent to traffic. Thus, it can be estimated that the peak flow rate through the work zone in one direction should be less than 1,700 pc/h.

Prior to construction, peak-hour volumes in both directions along Military Highway were much greater than the capacity of a single lane (as two lanes were provided in each direction). The research team examined volume data from July 2008 – the most recent archived data available prior to the start of construction in November 2009 – and averaged hourly volumes for weekdays (Tuesdays-Thursdays). In the northbound (eastbound) direction, volumes exceeded 2,100 vph during the A.M. peak and approached 1,700 vph during the P.M. peak; in the southbound (westbound) direction, volumes exceeded 1,700 vph during the P.M. peak.
The research team analyzed volume data from two-week periods in August 2010, February 2011, and August 2011 and compared these data with volume data prior to construction (July 2008) to gauge if volumes changed along Military Highway. Considering "weekdays" as Tuesdays through Thursdays, it was found that peak-hour and average daily volumes are much lower since the initiation of construction. Figure 13 displays average weekday hourly volumes in the northbound direction through the work zone; Figure 14 displays average weekday hourly volumes in the southbound direction. Figure 15 displays average weekday daily traffic in both directions along Military Highway for each 2-week period examined. The highest average peak-hour volumes occurred in the southbound direction in August 2010, in which approximately 1,400 vph were recorded on average across a two-week period from 4 P.M. to 5 P.M. In 2011, no peak-hour volumes in either direction averaged greater than 1,300 vph for the selected time periods.

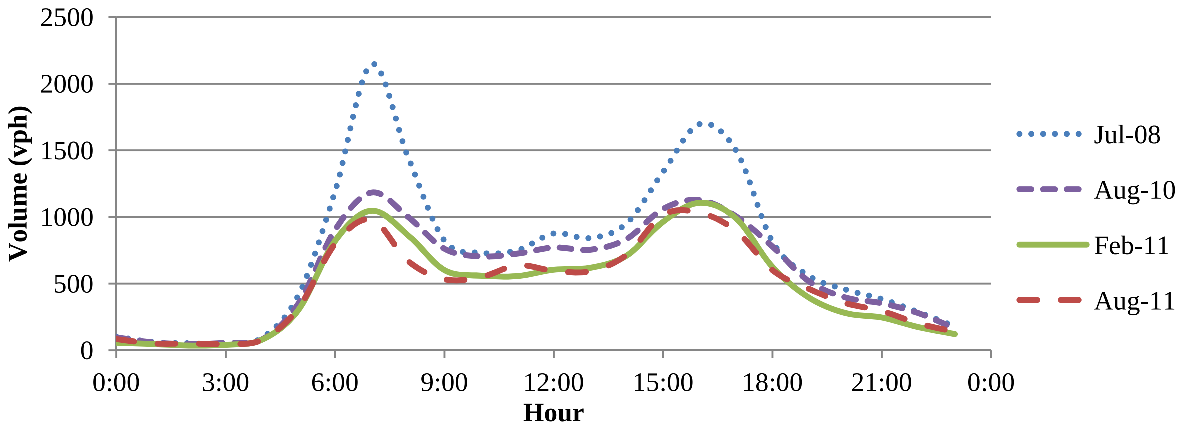

Figure 13. Average Weekday Hourly Volumes Along Military Highway NB at Gilmerton Bridge Work Zone

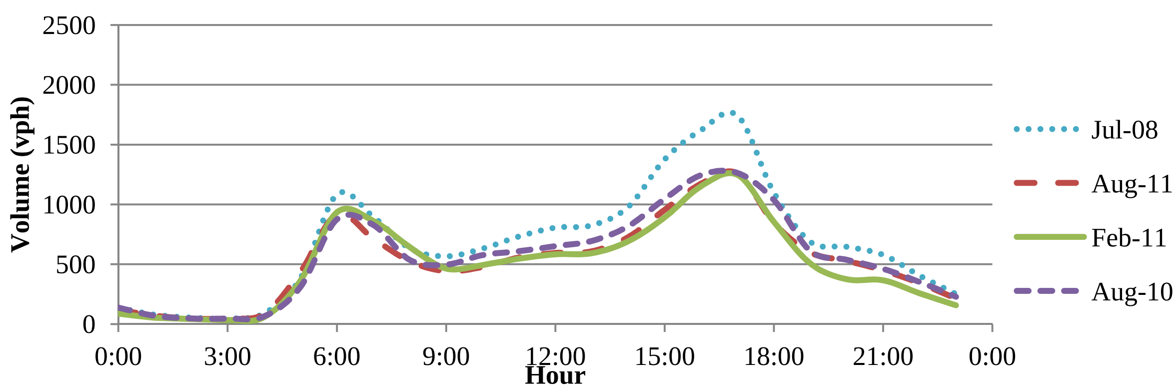

Figure 14. Average Weekday Hourly Volumes Along Military Highway SB at Gilmerton Bridge Work Zone

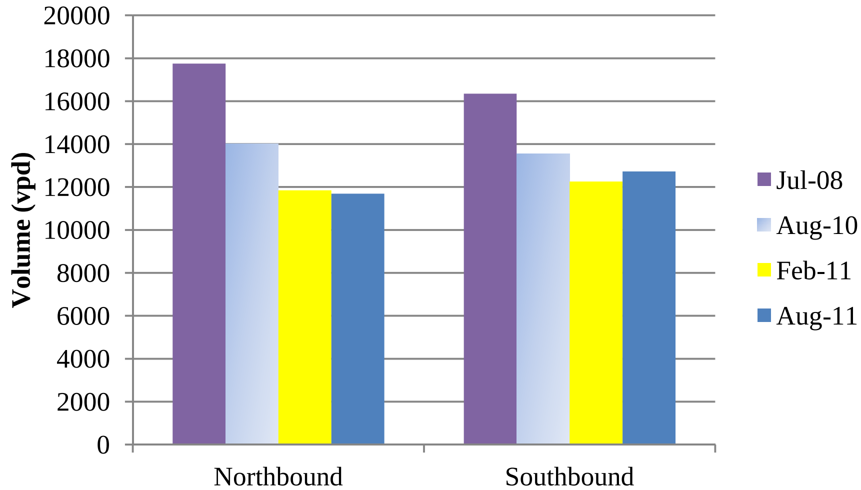

Figure 15. Average Weekday Daily Traffic Counts Along Military Highway at Gilmerton Bridge

In response to this long-term work zone, some motorists appear to be avoiding Military Highway through the work zone area. One lane through the work zone in each direction is not enough to handle the volume that existed along Military Highway prior to construction. Due to time and data constraints, the project team could not examine volume trends on I-64 or other parallel facilities such as the Downtown Tunnel. However, the project team was able to examine travel along both Military Highway and the I-64 High Rise Bridge detour through travel time runs.

Travel Time Impacts

Travel time runs through the work zone during Phase I of the project were conducted on October 11th and 12th, 2011. As the Gilmerton Bridge work zone has been in place since 2009, the project team was unable to conduct travel time runs through the work zone to gauge baseline times. Table 3 summarizes the results of travel time runs through the work zone in 2011. By noting times of drawbridge openings, the researchers were able to separate out travel time runs during drawbridge openings from normal conditions. In the northbound direction, average travel times through the work zone were less than travel times along the detour route, even with runs during drawbridge openings included. In the southbound direction, average travel times through the work zone were less than travel times along the detour route when only considering runs outside of drawbridge openings. If runs including drawbridge openings are included, average travel times during the October 11 P.M. peak hour were greater along Military Highway SB than along the detour route, and average travel times during the October 12 A.M. peak hour were approximately the same along Military Highway as along the detour route.

The travel time data suggest that the drawbridge openings have a much greater impact on travel time through the work zone than the work zone setup itself. During the P.M. peak hour on October 11, extensive delays were experienced that can be attributed to a drawbridge opening at 5 P.M. that lasted for ten minutes but took much longer for queues to clear. During the P.M. peak hour on October 12, travel times were much quicker through the work zone as there were no drawbridge openings. Upon examining volumes from the continuous count station through the work zone for both days, hourly flows are very similar for both P.M. peak hours; however, there are multiple 15-munute flow rates that are much lower on October 11 – corresponding to drawbridge events.

Using the methodology previously described, Inrix data were examined to gauge differences in travel times along Military Highway before and during construction. By adding average travel times (derived from average speeds) across consecutive TMCs in one direction for a time period, average travel times for an entire link can be estimated. Average travel times were examined for A.M. and P.M. peak periods for a one-week period in September 2009 (prior to construction) and for one-week periods in February 2010 and August 2010 (during construction). While travel times in all time periods were undoubtedly affected by drawbridge openings, the only noticeable differences in travel times before and during construction appear to be in the southbound direction during the P.M. peak hour. Travel times through the four-mile work zone link during this time period appear to be taking approximately two minutes longer than travel times along Military Highway prior to construction. Once again, travel time data suggest that drawbridge openings have a much greater impact on travel times than the work zone itself.

Table 3. Summary of Travel Times Along Military Highway and the Detour Route

Route	Measure	10/11/2011	10/12/2011		
		P.M. Peak (min)	A.M. Peak (min)	Mid-day (min)	P.M. Peak (min)
Military Highway NB	Avg. Travel Time	6:40	10:09	7:46	6:02
	Standard Deviation	2:26	5:56	3:18	0:46
	Avg. Travel Time (No Drawbridge)	5:48	7:56	5:55	6:02
	Standard Deviation	0:48	3:20	1:20	0:46
Detour NB	Avg. Travel Time	16:30	11:52	11:37	11:46
	Standard Deviation	2:31	0:33	0:34	0:54
Military Highway SB	Avg. Travel Time	15:08	8:45	7:22	5:41
	Standard Deviation	6:30	4:28	3:34	0:33
	Avg. Travel Time (No Drawbridge)	11:45	6:04	6:11	5:41
	Standard Deviation	1:57	0:55	2:09	0:33
Detour SB	Avg. Travel Time	9:35	8:46	8:36	8:14
	Standard Deviation	1:23	1:28	1:49	0:31

Effectiveness of TMP/Lessons Learned

Although the HRPDC predicted extensive queues and delays through the Gilmerton Bridge work zone, the project team and contractor attested to minimal delays outside of drawbridge openings. The most noticeable queuing and travel time impacts are in the southbound direction during the P.M. peak hour (as verified by the contractor), but these delays are not more than a few minutes for travelers not encountering a drawbridge opening. A major reason for the reduction in queuing and delays appears to be a decrease in volume along Military Highway since the start of construction. Peak hourly flows and daily flows are much lower during construction in comparison to pre-construction counts. This could be attributed to increased motorist awareness of the work zone, whether by familiarity with the area or from public outreach employed by VDOT.

As this project is in an urban location, it provides a much greater opportunity than the I-81 project for VDOT to use existing data sources. VDOT has a continuous count station within the work zone area collecting volume and classification data in both directions. Additionally, VDOT has an archive of private-sector travel time data that, with some time and expertise committed, can provide reliable estimates of work zone mobility.

DEVELOPMENT OF GUIDELINES FOR ASSESSING TMP PERFORMANCE

Based on the results of the literature review, surveys, and case studies, the research team developed an initial set of recommendations for TMP guidelines and presented them to a Task Group for review. After several draft iterations the research team developed a formal set of guidelines for TMP performance assessment. These guidelines were submitted to the Task Group for further review. Additional input was provided by work zone personnel throughout the Commonwealth, as well as Traffic Engineering personnel and members of the Traffic and Safety Research Advisory Committee (TASRAC) at VCTIR. The final guidelines are presented in Appendix B. Included with these guidelines is a newly developed Post-Construction TMP Performance Assessment Report Form. These guidelines and report form are considered the primary product of this research project and are being submitted to VDOT for streamlined implementation.

Overview of Guidelines

The VDOT TMP Performance Assessment Guidelines are divided into two main components: (1) guidelines for assessing the effectiveness of individual project TMPs, including the Post-Construction Report Form and (2) guidelines for assessing TMPs at the agency level over a given time period.

Guidelines for Assessing Individual Project TMPs

The requirements for individual TMP Performance Assessments will be standardized by project type (A, B, or C). Requirements for assessing TMPs include pre-construction performance measure development and impacts analysis, during-construction monitoring and data collection, and a post-construction evaluation. For a given project type, specific tasks must be conducted. Performance measures must be established and tied to data that will be collected, such as queue lengths and travel times. Crash data must be collected and analyzed for all projects. As described in VDOT's TMP Requirements (IIM-LD-241.4),[6] changes to the TMP (defined as any modification to the TMP that requires a seal from a licensed professional engineer) must be documented; other modifications to the TMP are also recommended to be documented. Figure 16 displays a flow chart of the specific TMP performance assessment requirements based on project type. Further detail on requirements for each step in the TMP Performance Assessment process can be found in Appendix B.

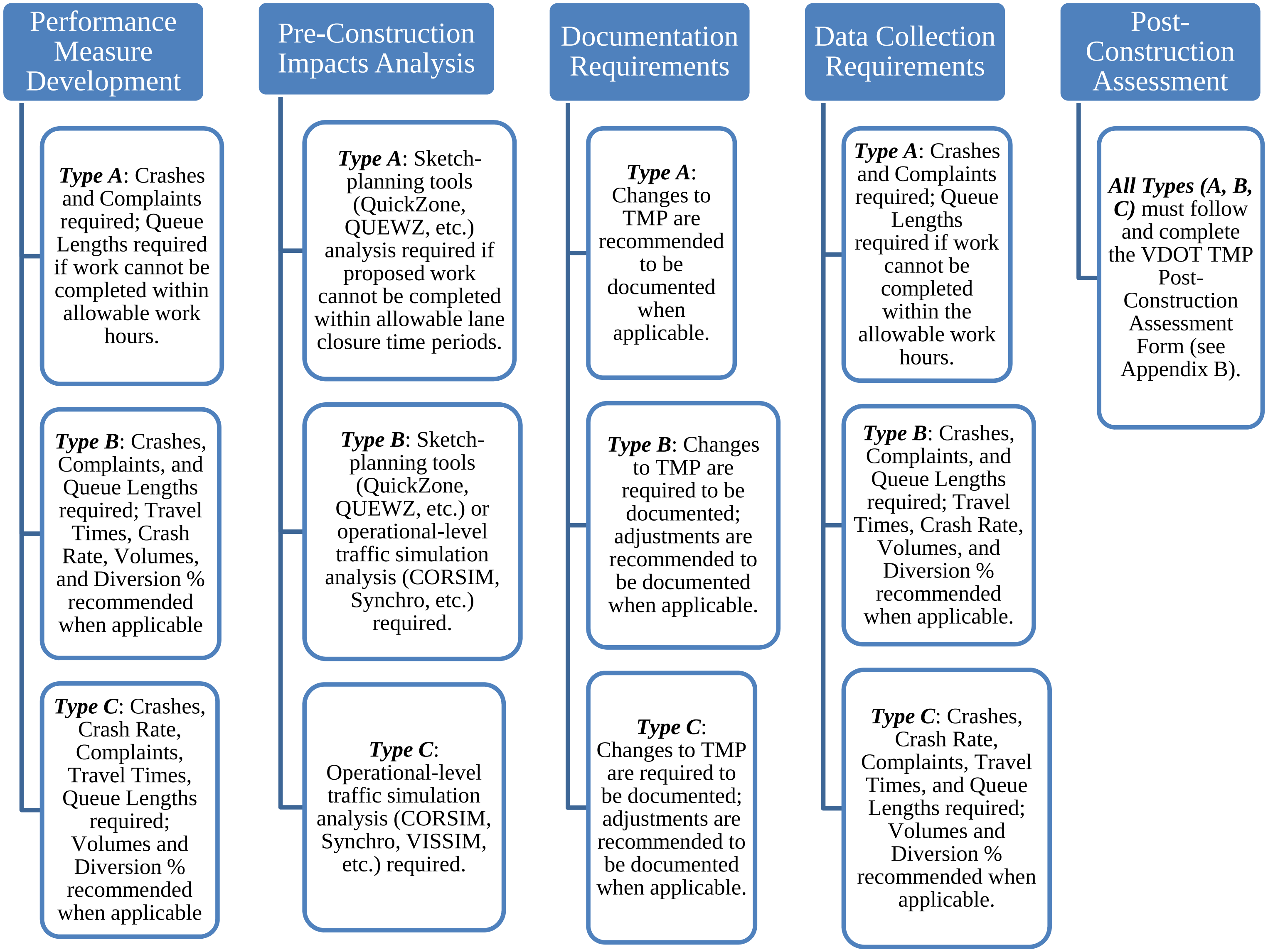

Figure 16. TMP Performance Assessment Requirements Flow Chart

Following completion of construction, all projects will be evaluated using a newly developed Post-Construction TMP Assessment Report Form, provided with the proposed Guidelines in Appendix B. This form was developed using an example form provided by Rhode Island DOT for assessing TMPs, with input from the TMP Task Group. In addition to providing background information on the project, this Report Form contains the following comment fields, taken from VDOT's TMP Requirements[6] (the complexity of the responses and quantitative analysis in this Report should correspond with the complexity of the TMP):.

- Provide a statement reflecting the overall usefulness of the TMP.
- Summarize/describe all changes necessary to correct oversights in the TMP.
- Summarize/describe all changes made to the original plan and their level of success.
- Summarize/describe public reaction to the TMP, including frequency of legitimate complaints and the nature of the complaints.
- Summarize travel times encountered during peak periods, if required, using a table and questions provided.
- Summarize queues encountered during peak periods, if required, using a table and questions provided.
- Summarize/identify the peak traffic periods and any discrepancies in these periods from pre-construction impacts assessment.
- Summarize the number, severity, and types of crashes that occurred during construction.
- Summarize types and number of safety service patrol responses (when applicable).
- Summarize/describe the most successful and least successful strategies from the TMP.
- Summarize/describe any suggested TMP improvements or changes for future similar projects.

Guidelines for Assessing TMPs at the Agency Level

Section 630.1008(e) of the Final Rule[3] requires agencies to perform a process review of TMPs at least every 2 years. This review "may include the evaluation of work zone data statewide and/or randomly selected projects." An overall review of TMP processes should address the following questions:

- Which management strategies have proven to be either more or less effective in improving the safety and mobility of work zones?

- Are there combinations of strategies that seem to work well?

- Should TMP policies, processes, procedures, standards, and/or costs be adjusted based on what has been observed or measured?

- Are the best decisions in planning, designing, implementing, monitoring and assessing work zones being made?

In 2009, VDOT Central Office personnel conducted a Work Zone Safety Program Process Review as required by the Final Rule. This process review was led by the Work Zone Safety Team of the Traffic Engineering Office and included the review by others from the Location and Design, Scheduling and Contract, and Operations divisions of VDOT, Regional Traffic Engineering personnel, and FHWA Virginia Division personnel. The Process Review consisted of the following elements:

- Survey of field personnel on the use of Transportation Management Plans

- Work Zone Team review of select construction projects in the Eastern, Central, and Northwestern Regions and interviews with project and district personnel

- Review and evaluation of work zone crash data from the previous two years

- Review of other activities of the Work Zone Safety Team.

Following the results of this Process Review, the VDOT project team recommended that a similar Process Review take place at least every two years alternating between regions so that within four years, all regions of the state have been examined. This Process Review is incorporated into the TMP Performance Assessment Guidelines shown in Appendix B.

CONCLUSIONS

Ultimately, the TMP Performance Assessment Guidelines provided from this research are a starting point for VDOT to explicitly document traffic impacts from work zones and use these findings to further improve work zone safety and mobility. In conjunction with the TMP Performance Assessment Guidelines developed in this project, the following major conclusions:

- *TMP performance assessment is a process that occurs over the life-cycle of a project.* This process must include tasks that occur before and during construction as well as post-construction. Constant changes need to be made to a TMP during construction that cannot possibly be accounted for prior to construction.

- *VDOT implements many recommended practices for TMP performance assessment, but not yet on a consistent basis across the state or across projects.* The research team identified many recommended "best practices" for the various stages of TMP performance assessment from the FHWA, other state agencies, and VDOT regions and districts. VDOT implements many of these identified best practices, such as electronic data collection and database usage. However, there exists a lack of consistency across VDOT regions for various practices. This situation results from the lack of a formalized process or practice for use throughout VDOT to assess TMPs, as well as a lack of manpower, funding, and resources in certain cases.

- *VDOT and its contractors are using innovative traffic control strategies for managing work zones, in addition to extensive public information campaigns and transportation operations/demand management strategies*. For example, the I-81 Pavement Reclamation project implemented an innovative forced detour traffic control strategy that, through data collection, analysis, and simulation, can be verified to be more effective than traditional detour strategies.

- *Full-scale TMPs, while required for all construction projects since Final Rule implementation, are still not being produced or updated for some VDOT projects that were developed prior to the Final Rule* (but not yet funded at the time of Final Rule implementation).

- *VDOT contractors and personnel make changes to TMPs and traffic control plans in response to observed impacts; however, documentation of these changes and effectiveness of strategies is still minimal.*

- *Most VDOT and contractor personnel are not currently completing written post-construction assessments of TMPs*. Those who are completing these assessments may not be currently submitting these completed assessments to the State Traffic Engineer. As a result of this, the Task Group developed a standardized post-construction form based on Rhode Island DOT's assessment methodology and reflecting VDOT's TMP Policy.

- *Various options exist for conducting many of the tasks in the proposed TMP Performance Assessment Guidelines.* These tasks range from pre-construction performance measure selection and impacts analysis, during-construction data collection and monitoring, and post-construction assessment. VDOT has in-house expertise and data collection resources that could allow TMP performance assessment to be conducted by VDOT personnel.

- *VDOT does have a process in place to assess TMP performance at the agency level, but it is not yet being completed on a consistent basis*. This process review involves surveying field personnel on their use of TMPs, a review of construction projects in select regions, a review and evaluation of work zone crash data, and a review of additional work zone data.

RECOMMENDATIONS

1. *VDOT should implement the proposed TMP Performance Assessment Guidelines for all roadway construction projects.* By having a formalized process to assess TMP strategies, VDOT will foster innovation in traffic control strategies, such as the unique traffic control strategy used in the I-81 Pavement Reclamation project. The processes established in these Guidelines should allow for continuous improvement in traffic impacts mitigation strategies, reduced safety and mobility impacts, and cost savings to contractors, VDOT, and roadway users.

2. *VDOT work zone personnel should keep the extent of the TMP performance assessment in line with the complexity of the TMP.* TMP performance assessment must take into account performance measures which are established prior to construction and can be tied to data available for collection during construction. The performance assessment should analyze collected data from the project in relation to the established performance measures and pre-construction impacts analysis.

3. *VDOT needs to assign responsibility for conducting TMP performance assessments to a specific role or position.* This could be completed in-house or contracted out to a consultant. Data collection and monitoring requirements should not be added to contract specifications, although the contractor will ideally provide input to VDOT personnel to assist in the TMP performance assessment. VDOT has expertise and resources available, such as VCTIR.

4. *VDOT should review completed performance assessments of individual TMPs periodically.* VDOT should use these analyses to update or tweak the TMP Performance Assessment form questions and/or requirements.

5. *The state-level TMP process review proposed by these Guidelines should also assess the effectiveness of the Guidelines.* This process review should take place every two years and examine a selection of projects from at least half the regions of the Commonwealth. Ideally, this process review will be able to combine the results of many completed TMP Performance Assessments, providing VDOT with a list of lessons learned and successful strategies to employ in future work zones. This process review can also be used to assess whether the requirements in the Guidelines have resulted in safety and mobility benefits across the Commonwealth.

BENEFITS AND IMPLEMENTATION PROSPECTS

Assessing and managing impacts of work zones through the use of TMPs has a variety of potential benefits[8]. Safety and mobility benefits are possible due to improved traffic flow and include the potential for significant road user cost savings for the public; agencies are able to increase customer satisfaction and improve public relations; and TMP assessment facilitates innovation and continuous improvement in the strategies used to mitigate work zone impacts. TMP assessment allows for a transportation agency to systematically build off of “lessons learned” from prior work zones to continuously improve work zone performance.

The proposed TMP Performance Assessment Guidelines in Appendix B should be implemented in an Instructional and Informational Memorandum (IIM) by VDOT and required for all TMP Types. VDOT work zone personnel should assist with carrying out the requirements of the guidelines, including completing the Post-Construction Assessment Form. The results of these assessments should be incorporated into the state-level TMP process review, which should take place at least every two years.

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- the TMP Performance Assessment Task Group
- VDOT Central Office personnel who championed the project: Paul Kelley and David Rush.

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APPENDIX A

TMP PERFORMANCE ASSESSMENT TASK GROUP MEMBERS

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APPENDIX B

GUIDELINES FOR ASSESSING TRANSPORTATION MANAGEMENT PLANS AND VDOT TMP PERFORMANCE ASSESSMENT FORM

INTRODUCTION AND BACKGROUND

In 2004, the FHWA published the *Final Rule on Work Zone Safety and Mobility*[1] which applies to all state and local government projects that receive federal-aid highway funding. The Rule requires that states develop a policy to address work zone impacts through the various stages of a project's development and construction and required Transportation Management Plans (TMPs) for all federally funded projects. States were required to be in compliance with the Rule by October 12, 2007. The Virginia Department of Transportation (VDOT) met this requirement by establishing a TMP policy with a set of guidelines for TMP development.[2]

According to the rule, a TMP should detail existing and future conditions of a work zone and assess predicted work zone impacts. In conjunction with these predicted impacts, work zone impacts management strategies should be selected. Monitoring of the work zone is necessary; part of VDOT's monitoring requirements[2] is an evaluation report for the TMP, which, upon completion of construction, should document lessons learned and provide recommendations on how to improve the TMP process. The guidelines in this report will detail strategies to measure work zone traffic performance, predict traffic impacts, monitor and collect data during construction, and use the data and performance measures to evaluate the effectiveness of TMPs.

GENERAL GUIDANCE

A TMP is a living document that changes over the life-cycle of a project. Prior to construction, impacts can be predicted and used to develop appropriate traffic mitigation strategies. Adjustments to the plan will need to be made during construction to account for conditions that have changed or predictions that simply do not match actual conditions. The ability to make these adjustments is dependent on monitoring and data collection activities within the work zone. Furthermore, documentation of the changes made and the reasons for the changes essential for lessons learned to be applied to future TMPs.

The scope, detail, and content of a TMP will vary with project complexity; likewise, the level of assessment necessary for a TMP should vary with project complexity. VDOT has five project management categories that fit within three types (or levels) of construction projects.[2] Each project management category is defined as follows:

- Category I – No-plan projects, small, simple and short-duration projects
- Category II – Minimum-plan projects, relatively simple, single-season construction projects

- Category III – Multi-season construction projects of medium complexity

- Category IV – Very large, complex, multi-season projects (generally >$100M)

- Category V – Major projects and multi-contract projects where seamless interaction among contractors is necessary.

Project Types and Associated Project Management Categories

The following project types and project management categories are defined in VDOT's TMP Requirements (IIM-LD-241.4):[2]

Type A (Project Management Categories I and II)

- Typical Projects: No-Plan, Minimum Plan, Single Phase Construction, Maintenance Projects, Utility and Permitted Work

- Project Type: Simple project – widening of pavement or adding turn lanes or entrances. Sequence consists of temporary lane closures and flagging operations with no shifting of traffic onto temporary pavement and with two-way traffic operation maintained at all times or at new construction locations with no existing traffic.

Type B (Project Management Categories III & IV)

- Typical Projects: Moderate level of construction activity with the primary traffic impact limited to the roadway containing the work zone.

- Project Type: Moderately complex project – pavement widening or bridges for additional through lanes and pavement rehabilitation. Sequence consists of lane closures to one or both directions with shifting traffic that may include temporary pavement or detours for the duration of the work. If detour routes are used they typically will remain in place 24 hours per day for the duration of the work. Project will be constructed over several phases and may include bridge replacements or new bridges, new interchanges, modifying existing interchanges or a new construction location with existing traffic crossing the construction area.

Type C (Project Management Category V)

- These types of projects are anticipated to cause sustained and substantial work zone impacts greater than what is considered tolerable based on policy or engineering judgment. They should be identified early in the design process in cooperation with the FHWA.

- Typical Projects: Long duration construction or maintenance projects on interstate and freeway projects that occupy a location for more than three days with intermittent or continuous lane closures within the following Transportation Management Areas; Northern

Virginia (including the counties of Arlington, Fairfax, Loudoun, Prince William, Spotsylvania and Stafford), Richmond (including the City of Richmond, Chesterfield and Henrico Counties), and Hampton Roads (including the Cities of Chesapeake, Hampton, Newport News, Norfolk, Portsmouth, and Virginia Beach as well as James City and York Counties). Also include interstate and principal arterial roadways with complex multi-phase construction, high accident rates, full closures, or multiple work zones (two or more) within two miles of each other.

- Project Type: Complex project – adding additional thru lanes, bridge rehabilitation, interchange construction and reconstruction. Sequence consists of lane closures with several traffic shifts that may include temporary pavement or detours for the duration of the work. Impact of work zone on traffic operations extends beyond the work zone and affects alternate and/or detour routes. Multi-phase construction – bridge replacements or new bridges. Rebuilding interchanges with additional ramps or extensive modification to existing ramps.

GUIDELINES FOR ASSESSING INDIVIDUAL PROJECT TMPs

The guidelines set forth herein for assessing individual project types (A,B,C) include matrices for various aspects of project development relating to TMP assessment. These matrices will show tasks that are required, recommended "when applicable" (based on engineering judgment), or not required.

The guidelines are divided into stages of project development that have a direct relation to TMP performance assessment. Pre-construction guidelines focus on tasks relating to performance measure selection and work zone impacts assessment. During-construction guidelines provide recommendations for monitoring and data collection techniques. The post-construction guidelines include a post-construction assessment report that documents lessons learned based on established performance measures and collected data.

Pre-Construction

1. Performance Measure Selection

Performance measures are essential to work zone assessments and are used as a quantitative way to evaluate successes and failures. Performance measures must be specific, measureable, and achievable; performance measures for TMP assessment should focus on safety and mobility impacts. These measures must be tied to available data and therefore consideration must be given to data availability during project planning.

Safety Performance Measure Requirements:

- For all projects, the number of crashes and the number of safety related complaints from motorists should be used to assess the relative safety of the work zone.

- For more complex, long-term projects, crashes can be converted to a crash rate and used as a performance measure and means of comparison to roadway characteristics prior to work zone implementation.

Mobility Performance Measure Requirements:

- Queue lengths are an important performance measure not just from a mobility standpoint but also from a safety perspective; queue lengths provide an indication of where advance warning signs should be placed to be most effective. Queue lengths are a required performance measure for Type B and C projects and are recommended when applicable (based on engineering judgment) for Type A projects. Based on the pre-construction impacts assessment (see next section), if the proposed work for a Type A project cannot be completed within the Region's allowable lane closure time periods (and thus sketch-planning-level modeling is required), queue lengths must be included as a performance measure.

- Travel times are a relevant performance measure, especially to motorists. Travel times provide an easily understood measure that can inform the public of delays. Travel time measurement is recommended when applicable (based on engineering judgment) for Type B projects and required for Type C projects.

- Volume and diversion percentage are useful performance measures when a detour is involved as part of the TMP so that VDOT and the contractor can gauge the effectiveness of a detour. These measures are not required but recommended when applicable (based on engineering judgment) for more complex projects.

Table B1 displays performance measure requirements for the three project types. Note that additional safety and mobility performance measures, such as incident clearance time or volume/capacity ratio, may be used when of interest.

Table B1. Performance Measure Requirements for Projects

Performance Measure Selection	Performance Measure	Project Type		
		A	**B**	**C**
Safety	Crashes (No.)	R	R	R
	Crash Rate	N	WA	R
	Complaints	R	R	R
Mobility	Queue Lengths	WA*	R	R
	Travel Times	N	WA	R
	Volumes	N	WA	WA
	Diversion %	N	WA	WA

R = Required; WA = Recommended When Applicable (based on engineering judgment); N = Not Required.
*Queue lengths required for Type A projects when proposed work cannot be completed within the Regional Operation's allowable lane closure periods.

2. Impacts Assessment

TMPs are developed from work zone impacts assessments, so it is imperative that VDOT accurately predict project impacts in order to (a) develop an appropriate TMP and (b) properly evaluate the TMP to learn for the future. VDOT's requirements for pre-construction impacts assessment have been established in response to the Final Rule and are included in VDOT IIM-LD-241.4 (Transportation Management Plan Requirements).[2] These requirements specify the complexity of analysis to be done based on project type, including types of simulation software to use:

- Type A: If the proposed work cannot be completed within the Region's allowable lane closure time periods an assessment of the Work Zone Traffic Impact will be completed using a sketch planning traffic analysis tool such as Quick Zone, QUEWZ and/or an operational-level traffic analysis software program as appropriate."

- Type B: An assessment of the Work Zone Traffic Impact will be completed using sketch planning traffic analysis tool such as Quick Zone, QUEWZ and/or an operational-level traffic analysis software simulation program such as CORSIM, Synchro or other applicable programs. Lane closures and detour routes will be implemented based on this evaluation.

- Type C: An assessment of the Work Zone Traffic Impact shall be completed using an operational-level traffic analysis software simulation program such as CORSIM, Synchro or other applicable programs.

VDOT must ensure that results from the impacts analysis, whether done by VDOT personnel or a consultant, are documented and given to those responsible for developing and implementing the TMP. Impact analysis documentation should be stipulated in the project contract. The measures used in the impacts analysis should also reflect the performance measures and data collection requirements for the project type.

During Construction

3. Monitoring

The performance of a TMP cannot be assessed without monitoring of traffic conditions and collection of data. VDOT has monitoring requirements and assignments for various work zone personnel described in IIM-LD-241.4 (Transportation Management Plan Requirements).[2] Specifically, changes to the TMP should be documented as an essential aspect of "lessons learned" from a project. The TMP Task Group recommends that all adjustments or changes be documented and included as part of the post-construction evaluation report discussed in the "Post-Construction" section. Changes (defined as any traffic control modification requiring a seal from a licensed Professional Engineer) are required to be documented. Adjustments, defined as a traffic control modification that is still within the standards or guidance of an applicable manual, are not required to be documented but are recommended.

Table B2 displays requirements and recommendations for documenting changes to the TMP.

Table B2. Monitoring Requirements for Projects

TMP Monitoring Requirements	Documentation	TMP Type A	TMP Type B	TMP Type C
Documenting TMP Changes	Adjustments	N	WA	WA
	Changes	WA	R	R

R = Required; WA = Recommended When Applicable (based on engineering judgment); N = Not Required

4. Data Collection

Data that are collected should be tied to performance measures. There are several sources of safety and mobility data that can be used by VDOT personnel to obtain data in a quick, cost-efficient manner.

Sources of safety data include:

- VDOT's *Roadway Network System* (RNS) and the statewide *Traffic Records Electronic Data System* (TREDS) are electronic databases containing crash information from all jurisdictions within the Commonwealth, including independent cities and counties. TREDS, hosted by the Virginia Department of Motor Vehicles (DMV), is a multi-agency system that VDOT, DMV, and Virginia State Police and local law enforcement can access. Law enforcement officers submit Virginia's standardized FR-300 crash reports into TREDS. The DMV has reported that currently approximately 70 percent of crash data are now entered electronically and is hoping that this percentage will approach 100 by the end of the year. By Fall 2012, all databases should be current to within a week of an incident, and TREDS data should be integrated with RNS, including georeferencing for crash locations. VDOT work zone personnel will be able to access crash data from RNS and identify work zone crashes (as well as causes of crashes) for a better understanding of safety of individual work zones.

- The *Virginia Traffic Database* contains crash, work zone, and lane closure data. Crash data can be matched up to work zone data to quickly determine crashes taking place in work zone areas, even those crashes taking place outside of work hours. Use of this database requires prerequisite training as well as a log-in account.

- TOCs can provide information on crashes during work zone hours as well as complaints about the work zone received from citizens.

Sources of mobility data include:

- Queue lengths
  - Queue lengths can be monitored by work zone personnel by using landmarks, mileposts, exits, etc., or an advance warning/queue management vehicle. The

TMP Task Group recommends that the queue management vehicle focus on monitoring and collecting queue data and that separate personnel be assigned to collect travel time data.
  - Queue lengths can also be estimated from speed/volume profiles of spot sensors set up in succession. The FHWA provides guidance for this methodology in its Primer on Work Zone Safety and Mobility Performance Measurement (September 2011).[3]

- Travel times
  - Floating car travel time runs. These can be conducted by VDOT or contractor personnel or be contracted to an outside consultant. Travel times runs should cover the route on which the work zone is located and any detour routes that have been designated. The runs should start upstream of the work zone and any queues and conclude past the work zone limits. Travel times can be calculated via a stopwatch or using GPS devices that record a vehicle's location every second.
  - Intelligent Transportation System (ITS) deployments such as Bluetooth readers or automatic vehicle identification (AVI) technology. These tools provide time stamps for vehicles passing points on a network; two or more of these placed in succession along a roadway can allow time calculation of a vehicle's travel time based on the elapsed time between time stamps. These tools can collect data for multiple days and provide a range of travel times, including trends outside of peak hours or during incidents.
  - Third-party travel time data such as Inrix. VDOT pays for and has access to a host of third-party travel time data. Analysis of these data does require expertise and significant time to process and combine link data.[4] However, as VDOT already pays for these data, this analysis can be done without having to go into the field if data are available for a given roadway during the work zone time period.

- Volumes and diversion percentages
  - VDOT has numerous continuous count stations on freeways throughout the Commonwealth that may be in close proximity to the work area.
  - Pneumatic tubes to collect volume and classification data can be installed along roadways, although contractors may be unwilling to install these on high-speed or high-volume roadways.
  - Wavetronix side-fire radar devices or similar devices that detect vehicle classification and speed can be set up along the side of a highway. These devices can often detect vehicles across several lanes and even opposing lanes.
  - ITS "Smart Barrels" can also be used; these barrels resemble work zone traffic control barrels and thus do not grab a driver's attention. These barrels are highly durable and can collect volume and speed data as well as help estimate queue lengths.[5]

Safety Data Collection Requirements:

- A visual safety performance evaluation using the Work Zone Safety Checklist should be completed by an inspector for all projects.

- Crash data should be collected and analyzed for all projects. This analysis will typically occur post-construction and be included with the post-construction TMP assessment. However, for long, multi-phase (Type C) projects, a safety assessment should take place at least every few months or at the end of each phase. The TMP Task Force recommends that VDOT follow the example provided by Ohio DOT,[6] which collects crash data for large-scale projects and compares crash rates for that segment of roadway during construction to the historic 3-year crash rate on that roadway prior to construction.

- All complaints related to safety should be addressed in the post-construction assessment.

Mobility Data Collection Requirements:

- For Type B and C projects, queue lengths should be monitored and recorded by work zone personnel. Queue lengths should also be monitored and recorded for Type A projects that cannot be completed within the allowable work hours and required pre-construction modeling. Peak hours and incidents should be documented to explain fluctuations in queue lengths.

- For Type C projects, pre-construction (baseline) and during-construction travel time runs should be conducted during peak hours for each phase. Travel time runs are also recommended when applicable for Type B projects. Travel times runs should cover primary routes in all directions and any detour routes as well. The runs should start upstream of the work zone and any queues and conclude past the work zone limits. Travel time runs should be conducted at least once during each project phase.

- For Type B and C projects, the TMP Task Group recommends collecting volume and diversion data if applicable; however, this task is not required.

- Additional data collection and analysis, such as heavy vehicle composition or safety service patrol (SSP) responses to incidents, is encouraged but not required.

Table B3 displays safety and mobility data collection requirements. Note that these correspond to performance measure development requirements.

Table B3. Data Collection Requirements for Projects

Data Collection Requirements	Data Type	TMP Type		
		A	B	C
Safety	Crashes (No.)	R	R	R
	Crash Rate	N	WA	R
	Complaints	R	R	R
Mobility	Queue Lengths	WA	R	R
	Travel Times	N	WA	R
	Volumes	N	WA	WA
	Diversion %	N	WA	WA

R = Required; WA = Recommended When Applicable (based on engineering judgment); N = Not Required.

Post-Construction

Following construction, it is imperative that VDOT and work zone personnel use the collected data and performance measures to evaluate the TMP through a post-construction assessment. VDOT's TMP Development Guidelines (and other states' guidelines including Wisconsin and Illinois) suggested the following should be included in the post-construction assessment:

- An overall statement reflecting the usefulness of the TMP
- Changes necessary to correct oversights in the TMP
- Changes made to the original plan and their level of success
- Public reaction to the TMP
- The maximum and average delay time encountered (e.g., average queues, slowdowns) during peak and off-peak periods, and delay history over the duration of the project
- Identification of the peak traffic periods
- Frequency of legitimate complaints and the nature of the complaints
- Types and numbers of crashes that occurred during construction
- Types and numbers of safety service patrols incidents
- Level of success and performance log for each strategy of the TMP implemented
- Suggested improvements or changes for similar future projects.

A copy of VDOT's TMP Assessment Form is provided at the end of this appendix. This form was derived from a similar form developed by the Rhode Island Department of

Transportation. This form should be completed following the completion of a project and should incorporate work zone data and lessons learned. The TMP Assessment form shall be completed by the Work Zone Safety Coordinator with assistance from VDOT and contractor work zone personnel. The Project Manager shall sign off on the form and submit the form to the State Traffic Engineer no later than one month following completion of a project.

Overall TMP Performance Assessment Process

As mentioned, TMP Performance Assessment is a process that proceeds throughout the life cycle of a project. It begins by establishing performance measures and predicting impacts before construction. These measures should be tied to data that will be collected in the field. Changes to the TMP should also be documented, and lessons learned should be evaluated upon completion of construction. Figure B1 displays a flow chart of how the VDOT TMP evaluation process should proceed through a construction project depending on the project type.

GUIDELINES FOR AGENCY-LEVEL TMP PROCESS ASSESSMENT

Section 630.1008(e) of the Final Rule[1] requires agencies to perform a *process* review of TMPs at least every 2 years. This review "may include the evaluation of work zone data statewide and/or randomly selected projects." An overall review of TMP processes should address the following questions:

- Which management strategies have proven to be either more or less effective in improving the safety and mobility of work zones?
- Are there combinations of strategies that seem to work well?
- Should TMP policies, processes, procedures, standards, and/or costs be adjusted based on what has been observed or measured?
- Are the best decisions in planning, designing, implementing, monitoring and assessing work zones being made?

In 2009, VDOT Central Office personnel conducted a Work Zone Safety Program Process Review[7] as required by the Final Rule. This process review was led by the Work Zone Safety Team of the Traffic Engineering Office and included the review by others from the Location and Design, Scheduling and Contract, and Operations divisions of VDOT, Regional Traffic Engineering personnel, and FHWA Virginia Division personnel. The Process Review consisted of the following elements:

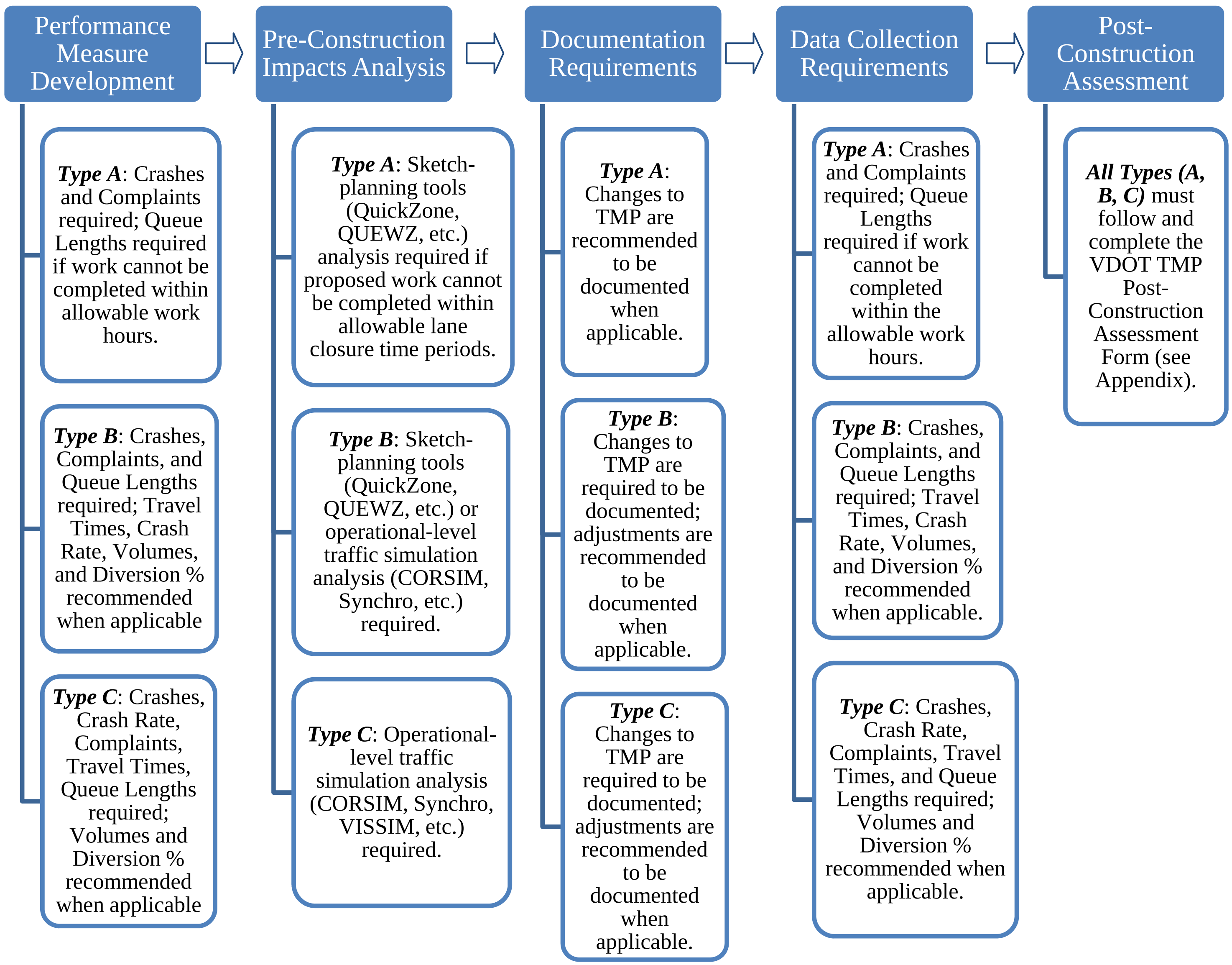

Figure B1. TMP Performance Assessment Requirement Flow Chart

- Survey of field personnel on the use of Transportation Management Plans
- Work Zone Team review of select construction projects in the Eastern, Central, and Northwestern Regions and interviews with project and district personnel
- Review and evaluation of work zone crash data from the previous two years.
- Review of other activities of the Work Zone Safety Team.

Following the results of this Process Review, the TMP Task Group recommends that a similar Process Review take place at least every two years. The regions of the Commonwealth should vary for each process review so that within four years, all regions of the state have been examined. The Process Review should incorporate the results of previously assessed TMPs that have been evaluated using the methodology described in these Guidelines. These already-completed assessments should serve as a supplement to the Work Zone Team review of select construction projects in a region.

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VIRGINIA DEPARTMENT OF TRANSPORTATION

POST-CONSTRUCTION TRANSPORTATION MANAGEMENT PLAN (TMP) PERFORMANCE ASSESSMENT

This Assessment shall be completed by the project's designated Work Zone Safety Coordinator upon completion of the work and approved by the Project Manager to document lessons learned and provide recommendations on how to improve the TMP process and/or modify guidelines. The responses should allow the reviewer of this completed Assessment to understand the successes/failures of the project TMP and its requirements. Please attach any relevant documents, project logs, etc. as well as any responses which cannot fit within the provided space.

WORK ZONE INFORMATION:
PROJECT TITLE:
WORK ZONE SAFETY COORDINATOR:
LOCATION:
DISTRICT/REGION:
UPC#

1) Summarize/describe all changes necessary to correct oversights in the TMP:

2) Summarize/describe all changes made to the original TMP and their level of success:

3) Describe public reaction to the TMP including the frequency and nature of complaints:

4) Summarize travel times encountered during peak periods (if required):

Starting location:		
Ending location:		
Date	Method Used (i.e., floating car, Bluetooth, etc.)	Average Travel Time

5) Summarize queues encountered during peak periods (if required):

Date	Method Used (i.e., advance warning vehicle)	Queue Length
During-construction average queue length:		
During-construction maximum queue length:		
Predicted average/maximum queue length from impacts analysis:		

6) Summarize/identify the peak traffic periods and any discrepancies in these periods from the pre-construction impacts assessment:

7) Summarize the types and number of crashes that occurred during construction:

	Property Damage Only	Injuries	Fatalities	Total
Rear-End				
Angle				
Side-Swipe				
Fixed-Object				
Off-Road				
Other				
Total				

8) Summarize the types and number of safety service patrol responses (when applicable):

9) Summarize/describe the most successful and least successful strategies from the TMP:

10) Summarize/describe any suggested TMP improvements or changes for future similar projects:

This completed assessment shall be forwarded to the State Traffic Engineer following approval below

Project Manager Approval
Name:
Title:
Unit
Signature
Date:

APPENDIX C

STATE AGENCY SURVEY RESPONSES

Safety Impacts

1. *Does your agency ESTABLISH work zone safety performance measures at (a) the agency program level and/or (b) the individual project level?*

Nineteen states said that they established safety performance measures at the agency/program level, while 12 states said that they establish safety performance measures at the individual project level. The *Domestic Scan* suggested that agency/program level safety performance measurement is much more common than agency/program level mobility performance measurement, as safety performance lends itself to an agency's overall policies and practices, not just one specific project. Note that only 6 states said that they evaluate safety performance on both the agency and individual project level; this could possibly be due to the wording of the survey question.

2. *Does your agency EVALUATE work zone safety performance measures at the program and/or individual project level?*

Twenty states said that they do evaluate safety performance measures; 12 said that they do not.

3. *What types of performance measures does your agency use with respect to safety impacts of a TMP? (number of crashes, worker injuries, number of complaints, subjective rating of safety, or other – please specify)*

Twelve states said that they were using number of crashes as a safety performance measure; 7 states use worker injuries; 5 states use number of complaints; 9 use a subjective rating of safety; and 10 states gave other measures, including number of fatalities and crash *rate* (although some states may already be incorporating number of crashes into a crash rate). Other states suggested more mobility-related measures such as queues and delays. It is somewhat surprising that only 12 states claimed to use crashes as a safety performance measure. Note that only states that answered "yes" to the previous question could answer this question; hence, fewer responses.

4. *What safety data and information sources are available in your agency for projects that could be utilized for work zone performance assessment? (project logs, field observations, crash records, operational data, other – please specify)*

Eleven states use project logs; 17 use field observations; 20 (all who responded) use crash records; 11 use operational data; and 4 use other sources such as technical inspectors' reports. This supports the Domestic Scan's assertion that crash records are the most common source of safety (crash) information. Again, only states that answered "yes" to Question 2 could respond to this.

Mobility Impacts

5. *Does your agency ESTABLISH work zone mobility performance measures at (a) the agency/program level and/or (b) the individual project level?*

Sixteen states said that they establish mobility performance measures at the agency level, while 15 said that they establish mobility performance measures at the individual project level. This somewhat agrees with the Domestic Scan's assertion that fewer states establish mobility performance measures at the agency level, and more establish mobility performance measures at the individual project level, which lends itself better to selected measures. Like Question 1, 6 states said that they establish mobility performance measures on both levels, although only 3 of the states were states who said they do both for safety.

6. *Does your agency EVALUATE work zone mobility performance measures at the program and/or individual project level?*

Similar to Question 2, 20 states said that they do evaluate mobility performance measures; 11 said that they do not.

7. *What types of performance measures does your agency use with regards to operational impacts of TMPs? (average queue length, maximum queue length, volume to capacity ratio, average delay, maximum delay, travel time, subjective rating of delay/congestion, other – please specify)*

Eight states use average queue length; 10 use maximum queue length; 9 use V/C ratio; 10 use average delay; 14 use maximum delay; 9 use travel time; 8 use a subjective rating of delay/congestion; and 3 used other measures such as level of service. This suggests that "maximums" may be more popular than "averages" but also suggests that there is no agreed-upon "best" mobility performance measure. Note that only states that answered "yes" to Question 6 could answer this question.

8. *What mobility data and information sources are available in your agency for projects that could be utilized for work zone performance assessment? (project logs, field observations, count stations, travel time data, other – please specify)*

Eleven states use project logs; 20 use field observations (all who responded); 10 use count stations; 9 use travel time data; and 4 use other sources such as public feedback or ITS. This is consistent with the Domestic Scan's assertion that (manual) field observations are the most common (and, most likely, the most inexpensive) source of work zone mobility data. Oregon DOT noted that they are just beginning to introduce "Smart Work Zone" traffic management systems to measure work zone traffic operations and report real-time information and warnings to motorists; these systems will be limited to large, long-term projects. Again, note that only states who answered "yes" to Question 6 could answer this question.

9. *Does your agency have a process to estimate road user costs and use this process to select work zone strategies (full closures, detours, night work, etc.)?*

Thirteen states said that they do have a process to estimate road user costs (RUCs), while 8 said that they do not.

Impacts Assessment

10. Does your agency utilize software tools to predict the impacts of work zones on traffic operations?

Twenty-eight states said that they do use software tools to predict work zone impacts prior to construction; 3 states said that they do not. Of the states who said that they do not use software tools, it could be that those agencies rely on lane closure/queue charts.

11. What software tools does your DOT use for analyzing anticipated work zone impacts? (QuickZone, QUEWZ, Highway Capacity Manual, other sketch planning tools, Synchro, VISSIM, CORSIM, Dynasim, other – please specify)

Eleven states said they use QuickZone; 5 said they use QUEWZ; 16 use some sort of HCM software; 5 use other sketch planning tools; 11 use Synchro; 7 said they use VISSIM; 7 said they use CORSIM; 1 said they use Dynasim, and 11 states mentioned other tools such as in-house-developed lane closure spreadsheets. The Domestic Scan suggested that spreadsheet tools based off of the Highway Capacity Manual, which some states may have encompassed under “Highway Capacity Manual” are very common; more complex simulation tools are used for larger, more intense projects. Note that only states who answered “yes” to Question 10 could respond to this question.

12. Do the types of software tools to predict work zone impacts vary based upon project intensity/complexity?

Seventeen states responded “yes”; 10 responded “no” – not sure what to make out of this?

13. With regard to software output, how important are the following when analyzing the operational impacts of a TMP? (rate “not important” to “very important”: average queue length, maximum queue length, V/C ratio, average delay, maximum delay, travel time)

Table C1 displays responses.

Table C1. States’ Preferences to Performance Measures When Analyzing TMP Impacts

Performance Measure	Not Important	Somewhat Important	Very Important
Average Queue Length	7.1% (2)	53.5% (15)	39.3% (11)
Maximum Queue Length	3.6% (1)	32.1% (9)	64.3% (18)
Volume to Capacity (V/C) Ratio	14.3% (4)	46.4% (13)	39.3% (11)
Average Delay	3.6% (1)	46.4% (13)	50.0% (14)
Maximum Delay	14.3% (4)	21.4% (6)	64.3% (18)
Travel Time	7.4% (2)	59.3% (16)	33.3% (9)

14. Rate the following statement: my agency is generally satisfied with traffic analysis software when it is used to predict work zone impacts (from "strongly disagree" to "strongly agree").

Four states strongly agree and 10 agree, 9 were neutral, 4 disagreed, and 1 state strongly disagreed! Agencies were allowed to make comments. One state noted that their "current software is inaccurate, difficult, and time-consuming to use…training seems to be unavailable." That state developed their own sketch planning spreadsheets. Some states noted that they were generally satisfied with results but have seen over-estimates of queues and road user costs, especially from QUEWZ. One state commented that their issue with software tools was "gaining consistency statewide with our designers using the software." Oregon DOT, who use their own web-based software known as the Work Zone Traffic Analysis (WZTA) Tool as opposed to the software tools we listed, was one of the few states who "strongly agreed" that they are satisfied with their traffic analysis software. They noted that a recent study of their software's benefit-cost ratio suggested a ratio of 9.31:1 over five years (dollars spent in development/maintenance/operation versus savings related to reduced delay).

Monitoring

15. Does your agency check field conditions (i.e., queue length, delay, capacity, etc.) during the project against (a) the anticipated impacts of a work zone predicted by software tools and/or (b) predefined performance thresholds?

Twelve states said that they check field conditions against software-predicted impacts; 12 also said that they check against predefined performance thresholds. 4 states said that they do both.

16. Are the data collected used to update and revise TMPs during construction?

Seventeen states said "yes"; 12 said "no."

17. Are the data collected used to update and revise agency policies and procedures (post-construction)?

Sixteen states said "yes"; 14 said "no."

Information Dissemination

18. What types of tools does your agency use to disseminate information to motorists and agency personnel in regards to work zone conditions? (open-ended)

Nearly all states mentioned 511 systems and/or changeable message signs. Many also mentioned press releases, social media such as Twitter, web sites, and media outlets such as TV and radio stations.

19. Does your agency assess the effectiveness of its public awareness/motorist information strategies? If yes, how are they assessed?

Ten states said “yes”; 19 said “no.” Of states that said they do assess public information strategies, explanations included observing if the public adjusted driving routes or public outreach surveys. Texas DOT mentioned that districts are asked to review TTC, TO, and PI strategies annually in a post-project review and forward results to Traffic Operations Division. They noted that there are “no formal performance measures” but rather input on strengths and weaknesses of strategies used.

Additional Questions

20. What are your agency’s biggest “barriers” to sound POST-construction work zone impacts assessment (i.e., manpower, data, funding, etc.)?

A lack of personnel (manpower) was an overwhelming response from states as to why post-construction assessment of work zone strategies and impacts is not completed more thoroughly. Data and funding were also common responses. A few states noted an issue of consistency; that is, states have not established methods or performance measures for post-construction assessment.

21. Does your agency currently have guidelines for assessing TMP performance?

Nineteen states said they had some sort of guidelines for assessing TMP performance, while 11 said that they do not. The extent of these guidelines varies. Some mentioned that their guidelines are limited or in their infancy, such as a process review every 2 years. One state mentioned that they had a policy but extremely limited manpower to do the work. New York state has developed a work zone inspection program which has been modified and updated over the years. They stated that “the most successful method is having an extremely experienced design/review team that fulfills the function on ALL regional projects.” NYSDOT has a fairly rigorous post-construction inspection report form which “grades” a project. NYSDOT, Wisconsin, and Illinois were kind enough to send us their TMP policies.

APPENDIX D

VDOT SURVEY RESPONSES

1. *What region/district are you associated with?*

We received four responses each from Northern Virginia (NOVA) and Northwest Region, two responses from Central Region, and one response each from Southeast Region and Southwest Region.

Performance Measures

2. *What types of performance measures do you use with regards to SAFETY impacts of a TMP? (check all that apply)*

All respondents used number of crashes as a safety performance measure. Number of complaints, worker injuries, a subjective rating of safety, and SSP/police response time were also mentioned as safety performance measures.

3. *What types of performance measures do you use with regards to MOBILITY impacts of a TMP? (check all that apply)*

While there was no 100 percent-universal response to this question, the most commonly cited mobility performance measures (in decreasing order) were travel times and maximum queue length, average queue length and average delay, and maximum delay and volume to capacity ratio. Other cited measures include a subjective rating of congestion, incident clearance time, and bicycle/pedestrian mobility during closures.

4. *To what extent are these performance measures dependent upon available data?*

As expected, the safety and mobility performance measures used by various VDOT districts are overwhelmingly "highly dependent" upon available data. One district noted that these performance measures are only "somewhat dependent" upon available data.

Work Zone Impacts Assessment

5. *Who is the responsible party for work zone impacts assessment during project development in your district/region (i.e., contractor, VDOT traffic engineering personnel, VDOT work zone personnel)?*

All responses included some sort of VDOT personnel, including inspectors, traffic engineering and work zone personnel. Multiple respondents also stated that the contractor has some responsibilities as well.

6. *What DATA do you use to assess and/or predict work zone impacts during project development/prior to construction?*

Multiple respondents cited the VDOT Allowable Work Hours Tool developed by VCTIR. Hourly traffic volumes (seasonal adjusted AADT or pre-construction counts), geometry and driving patterns, traffic mix, and accident data were also cited.

7. *Do you have a spreadsheet tool developed to estimate project impacts (prior to construction)?*

Of those who responded, four said "yes," while four said "no." This inconsistency is somewhat confusing.

8. *Do you use software tools to predict the traffic impacts of a work zone?*

Of those who responded, five said "yes," while three said "no." This is again confusing; it could be that the specific respondents are not familiar with software tools to predict work zone impacts (as opposed to entire districts/regions not using software tools).

9. *What software tools do you use for analyzing predicted work zone impacts? (check all that apply)*

Of those who responded, 100 percent (four responses) used the *Highway Capacity Manual* and VISSIM; 75 percent use Synchro. QUEWZ, QuickZone, CORSIM, GIS, and "other sketch planning tools" were also used. No respondents used Dynasim.

Other Pre-Construction Information

10. *Do you ever incorporate performance measures into contract language (i.e., using performance-based specifications as opposed to method-based specifications)?*

Four responded with "yes," while three responded with "no." One respondent explained that Road User Cost (RUC) information is used to set incentives/disincentives when applicable and needed to complete a critical phases of work where traffic is most impacted.

11. *Do you incorporate Road User Costs (RUCs) into agency cost analyses?*

Five respondents (71%) said that they do incorporate RUCs into agency cost analyses.

12. *Do you undertake a formal maintenance of traffic (MOT) alternatives analysis during project development?*

Five respondents (71%) said that they do compare traffic alternatives during project development. One respondent commented that for Megaprojects, a formal alternatives analysis occurs only on major short-term or long-term closures.

13. *Do you have and/or use a permitted lane closure chart?*

Five respondents (71%) said that they use a permitted lane closure chart. One respondent stated that they believe that this question refers to the LCAMS database used by NOVA.

14. Do you have "lane rental provisions" (i.e., a contractor can pay a fee to close additional lanes even if adverse impacts are expected from these closures)?

Only one of seven respondents (Southwest region) said that their region/district does allow for lane rental provisions.

Data Collection and Monitoring

15. Do you REQUIRE work zone performance monitoring in TMPs?

Three out of six respondents said "yes."

16. Are contractors expected to monitor work zones or do you use agency staff (i.e., project engineers, inspectors) for monitoring?

Reponses were quite varied for this question. One respondent stated that VDOT specifications require a designated work zone safety person on contractor staff. Another respondent stated that "contractors are expected to, but don't do a very good job, so we end up doing it." Multiple responses listed VDOT staff or inspectors, which could be an outside consultant.

17. What are your main sources of work zone SAFETY data? (check all that apply)

Of those who responded, all six used field observations. Police crash reports, customer surveys/complaints, crash reports from work zone personnel, and fire/rescue dispatch frequency were also cited.

18. What are your main sources of work zone MOBILITY data? (check all that apply)

Six respondents replied to this question, and there was no overwhelming response. TMCs were the most popular response, followed by travel time data and count stations; project logs were also used by two respondents.

19. Do you have access to real-time work zone data (crashes, queue lengths, travel time, etc.)?

Five out of six respondents said that they do have some access to real-time work zone data. These data come from cameras and data accessed by the Traffic Operations Center.

20. Do you employ any types of electronic data collection during work zones?

Three out of six respondents stated that they do employ electronic data collection. These data include traffic volumes (on some major projects) and speeds.

21. Do you have an electronic system for entering crashes?

Only two out of six respondents (Central, NOVA) stated that they have an electronic system for entering crashes.

22. Do you have a database management system for any of the following: lane closures, crash analysis, traffic performance? (check all that apply)

Only 3 respondents answered this question, but all 3 stated that they have database management systems for lane closures and traffic performance ("511, Virginia Traffic and Traveler Information Database"). Two also stated that they have a crash analysis database.

23. Do you use any customer surveys for work zone performance assessment?

Three out of six respondents said that they do use customer surveys. These can take the form of "customer awareness surveys." One respondent stated that surveys are done via VDOT's communications staff ("CRM system").

24. What role, if any, do Traffic Management Centers (TMCs) play in work zone monitoring in your district/region?

TMCs seem to play a major role in work zone monitoring. TMCs use cameras to monitor congestion (where they are available) and coordinate/report lane closures. TMCs also coordinate Highway Advisory Radio and Safety Service Patrol.

25. Do you monitor travel times/queue lengths that occur in the field and compare them to estimates from impacts analysis?

Five out of six respondents said "yes."

26. Do you monitor travel times/queue lengths experienced in the field and compare them to predefined performance thresholds?

Four out of six respondents said "yes."

Updating/Revising TMPs and Agency Policies

27. Do you ever use monitoring/performance results to make changes to TMPs during construction?

Four out of six respondents said "yes." For example, based on traffic monitoring, a location adjustment was made to a merge taper and sign spacing for a project along I-295 southbound over I-64. In Northern Virginia, "constant changes to traffic operations" are made "to optimize traffic flow while maintaining safety for all modes of travel"; this occurs around the I-495 HOT Lanes, the Dulles Rail Metro project, BRAC, and the I-95 4th lane widening.

28. Do you ever use performance results to make changes to work zone policies?

Three out of six respondents said "yes." Changes could include hours of operation, acceptable configurations, and coordination between projects.

29. Do you ever use performance results to make changes to design standards?

Only one out of six respondents said "yes"; this referred to changing sign spacing due to roadway geometry. One respondent stated that this is not a district responsibility but rather a headquarters responsibility.

30. Do you ever use performance results to make changes to capacity values used in traffic impacts analyses?

Three out of six respondents said "yes." One example mentioned was multiple-lane ramp lane closure time. Another respondent referred to the I-495 HOT Lanes project, in which the highly congested and dynamic environment is constantly having data collected on it so that staff "has a better understanding of the capacity to move traffic."

Final Thoughts

31. What are your district's/region's biggest barriers/constraints to doing more with work zone data (i.e., personnel, time, etc.)?

A lack of personnel was mentioned by multiple respondents. One respondent mentioned limited real-time data or non-user-friendly data. Respondents from Northern Virginia mentioned that available right-of-way on an over-capacity system and finances also constrain the ability to collect more data.