

Synthesis of Procedures to Forecast and Monitor Work Zone Safety and Mobility Impacts



Final Report November 2005

Sponsored by

the Smart Work Zone Deployment Initiative

a Federal Highway Administration pooled fund study

and

the Midwest Transportation Consortium

the U.S.DOT University Transportation Center for Federal Region 7



IOWA STATE
UNIVERSITY

Technical Report Documentation Page

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Synthesis of Procedures to Forecast and Monitor Work Zone Safety and Mobility Impacts				5. Report Date November 2005	
				6. Performing Organization Code	
7. Author(s) Tom Maze, Garrett Burchett, and Joshua Hochstein				8. Performing Organization Report No.	
9. Performing Organization Name and Address Center for Transportation Research and Education 2901 South Loop Drive, Suite 3100 Ames, IA 50010-8634				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Organizations Name and Address Federal Highway Administration Midwest Transportation Consortium U. S. Department of Transportation 2901 South Loop Drive, Suite 3100 400 7th Street SW Ames, IA 50010-8634 Washington, DC 20590				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Visit www.ctre.iastate.edu for color PDF files of this and other research reports.					
16. Abstract <p>Administrative Final Rule CFR part 630 Subpart J "Work Zone Safety and Mobility" requires that state transportation agencies (STAs) develop policies to investigate the safety and mobility impacts as early as possible in the project development process. The rule provides some flexibility by allowing each state to set its own procedures and policies to comply with the rule and by allowing states to seek solutions which are commensurate with the severity of the potential impacts and require the most aggressive planning for "Significant Projects."</p> <p>This report provides a synthesis of what is currently being done by STAs across the country to plan, manage, operate, and evaluate work zone safety and mobility. The research to develop this synthesis was broken into three distinct steps. The first step was to review the literature regarding work zone safety and mobility strategies. The second was to conduct interviews with staff members at 30 STAs. The last step was to conduct more detailed case studies of three STAs.</p> <p>We found that only California and Ohio (there may be more states than this, but these were the two we discovered) had really thought about work zone impacts throughout the life-cycle of project development and project delivery and had documented the roles and interactions between different offices. Most agencies we interviewed lacked objective performance data, although many described processes where they have experts review and evaluate work zones on a periodic or continuous basis.</p>					
17. Key Words crashes—lane closure—mobility—safety—work zone				18. Distribution Statement No restrictions.	
19. Security Classification (of this report) Unclassified.		20. Security Classification (of this page) Unclassified.		21. No. of Pages 104	22. Price NA

SYNTHESIS OF PROCEDURES TO FORECAST AND MONITOR WORK ZONE SAFETY AND MOBILITY IMPACTS

**Final Report
November 2005**

Principal Investigator

Tom Maze

Professor, Department of Civil, Construction and Environmental Engineering
Iowa State University

Research Assistants

Garrett Burchett

Joshua Hochstein

Sponsored by
the Smart Work Zone Deployment Initiative
a Federal Highway Administration pooled fund study
and
the Midwest Transportation Consortium
the U.S.DOT University Transportation Center for Federal Region 7

A report from
The Center for Transportation Research and Education

2901 South Loop Drive, Suite 3100

Ames, IA 50010-8634

Phone: 515-294-8103

Fax: 515-294-0467

www.ctre.iastate.edu

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION	1
Research Steps	1
Findings.....	2
Organization of the report.....	2
CHAPTER 2. LITERATURE REVIEW	3
Long-Range and Policy Plans.....	4
Project Programming and Project Planning	5
Preliminary Design	9
Final Design.....	13
Contracting and Project Operations	14
Work Zone Postmortem.....	14
Work Zone Planning and Management in the Project Development Process	15
Measuring the Traffic Impacts of Work Zone Lane Closures	15
Deterministic Queuing.....	15
Microscopic Simulation (without network trip distribution capabilities).....	21
Microscopic Simulation (with network trip distribution capabilities).....	21
CHAPTER 3. STATE AGENCY SURVEY SUMMARY.....	23
Methodology	23
Responses by State Agency	26
Arizona Department of Transportation	26
Arkansas State Highway and Transportation Department.....	27
California Department of Transportation.....	28
Colorado Department of Transportation.....	29
Connecticut Department of Transportation	30
Illinois Department of Transportation	30
Indiana Department of Transportation.....	31
Iowa Department of Transportation.....	32
Kansas Department of Transportation	33
Kentucky Transportation Cabinet.....	34
Louisiana Department of Transportation and Development.....	35
Maryland Department of Transportation	36
Massachusetts Highway Department.....	37
Michigan Department of Transportation	38
Minnesota Department of Transportation.....	38
Missouri Department of Transportation.....	39
Nebraska Department of Roads	40
New Hampshire Department of Transportation.....	40
New Jersey Department of Transportation	41
New York State Department of Transportation	42
North Carolina Department of Transportation.....	42
Ohio Department of Transportation'	43
Oklahoma Department of Transportation	44

Oregon Department of Transportation	45
Pennsylvania Department of Transportation	46
South Dakota Department of Transportation	47
Tennessee Department of Transportation	48
Texas Department of Transportation	48
Virginia Department of Transportation	49
Wisconsin Department of Transportation	49
CHAPTER 4. STATE CASE STUDIES	51
Ohio Department of Transportation (ODOT)	51
PDP for Major Projects—Steps 1 & 2	53
PDP for Major Projects—Steps 3 & 4	53
PDP for Major Projects—Step 5	55
PDP for Major Projects—Step 6	55
PDP for Major Projects—Step 7	62
PDP for Major Projects—Steps 8 through 12 (Detailed Design)	62
PDP for Major Projects—Step 14 (Construction)	63
PDP for Major Projects—Post Construction Activities	67
Virginia Department of Transportation (VDOT)	68
TTC Planning	69
Work Zone Monitoring, Review, & Evaluation (60)	71
Night Work	74
Use of Virginia State Police (VASP) In Work Zones	76
Public Information & Outreach Strategies	76
Oregon Department of Transportation (ODOT)	77
Statewide Work Zone Planning	77
Project Level Work Zone Planning	78
ODOT’s Work Zone Traffic Analysis (WZTA)	81
ODOT’s “QuickFax” Service (71)	84
CHAPTER 5. CONCLUSIONS	85
Comprehensive Consideration of Work Zone Impacts throughout the Project Development Process	85
Policy and Policy Plan Level Direction on Work Zone Impacts	86
Performance measurement, data collection and data standards	86
REFERENCES	89

LIST OF FIGURES

Figure 2.1. Mn/DOT project development stages.....	6
Figure 2.2. Example of deterministic queuing theory.....	16
Figure 2.3. Volume and speed distribution before, during, and after a work zone queuing event.....	20
Figure 3.1. Surveyed states	23
Figure 3.2. Generic project development process.....	24
Figure 4.1. ODOT’s Red Flag Summary for maintenance of traffic (50)	54
Figure 4.2. ODOT’s MOT policy process (52).....	57
Figure 4.3. ODOT’s permitted lane closure capacity calculation process (53)	58
Figure 4.4. Example of ODOT’s permitted lane closure web site (52)	59
Figure 4.5. Work zone contra-flow concept utilized by ODOT (55).....	62
Figure 4.6. ODOT’s real-time work zone crash database main screen (57).....	65
Figure 4.7. ODOT’s work zone crash report data entry form (57).....	66
Figure 4.8. ODOT’s work zone crash frequency comparison chart (57).....	67
Figure 4.9. VDOT’s project development process (PDP) (59).....	70
Figure 4.10. VDOT’s work zone safety checklist form (61)	72
Figure 4.11. VDOT’s work zone review team interview form (62)	75
Figure 4.12. ODOT’s PDP highlighting traffic control planning (68)	79
Figure 4.13. ODOT’s traffic control supervisor’s work zone safety checklist (69)	80
Figure 4.14. ODOT’s standard work zone capacities (68)	82
Figure 4.15. ODOT’s traffic volume matrix (68)	83
Figure 4.16. ODOT’s work zone traffic analysis (volume vs. capacity) (68)	83
Figure 5.1. Average speeds at the second device.....	88

LIST OF TABLES

Table 2.1. Data elements for consideration during preliminary engineering for TMP refinement	10
Table 2.2. Caltrans TMP strategies and their elements	11
Table 2.3. Performance measures for the evaluation of work zone traffic management technology	12
Table 2.4. Highest free-flow measurement before queuing initiated.....	18
Table 2.5. Variables known to impact work zone capacity	19
Table 4.1. Project classifications and corresponding processes (49).....	52
Table 4.2. ODOT’s MOTAA potential constraints checklist (51).....	56

ACKNOWLEDGMENTS

The researcher would like to thank all the individuals who participated in our interviews. The names of the interviewees are listed in Chapter 3 and are associated with the individual states they represent. The authors are especially thankful for the guidance provided by Tom Notbohm, advisory committee chair, of the Wisconsin Department of Transportation. Other advisory committee members included Jim Brachtel, Iowa Division Office of Federal Highway Administration; Robert Alva, Kansas Division Office of Federal Highway Administration; Wallace Heyen, Nebraska Department of Roads; Kurt Miyamoto, Kansas Department of Transportation; Tracy Scriba, Office of Operations, Federal Highway Administration; and Daniel Sprengeler and Mark Bortle, Iowa Department of Transportation.

CHAPTER 1. INTRODUCTION

Federal Highway Administration (FHWA) has published Administrative Final Rule CFR part 630 Subpart J, “Work Zone Safety and Mobility,” on September 9, 2004. In general, the rule requires that state transportation agencies (STAs) develop policies to investigate the safety and mobility impacts as early as possible in the project development process: quantify the impacts, look for alternative actions which will reduce the impacts, select a work zone approach and communicate the impacts of the approach to the public, measure the safety and mobility performance of the actual work zone once it is put in place, and use the performance data of past programs to manage the impacts of future work zone activity. The rule provides some flexibility by allowing each state to set its own procedures and policies to comply with the rule and by allowing states to seek solutions which are commensurate with the severity of the potential impacts and require the most aggressive planning for “Significant Projects.”

The above paragraph greatly simplifies the specific processes outlined in the proposed rule. The reader wishing more information should read the rule and attend information workshops held by FHWA staff members, as well as read a soon-to-be-released implementation guide on the new rule (see FHWA Office of Operations Web site) (1). The purpose of this document is to provide a synthesis of what is currently being done by STAs across the country to plan, manage, operate, and evaluate work zone safety and mobility. This is by no means a comprehensive review of what is being done by STAs, nor does it provide enough detail to fully document the activities of any state. The purpose of the research described in this report is to provide a snapshot of what is taking place at STAs throughout the country so that professional staff at STAs attempting to meet the letter and spirit of the new Work Zone Safety and Mobility rule will have a conceptual view of what other STAs have and are using to plan, manage, operate, and evaluate work zone safety and mobility. Throughout the document, we attempted to document the individuals we spoke with at STAs.

Research Steps

The research to develop this synthesis was broken into three distinct steps. The first step was to review the literature regarding work zone safety and mobility strategies. The second was to conduct interviews with staff members at 30 STAs. The interviews were conducted over the telephone using an outline, but each interview was tailored to the responses and the domain of knowledge of the interviewee. The last step was to conduct more detailed case studies of three STAs. The case study states were selected by the advisory committee. There is some interaction between the three steps. For example, some of the issues discovered in the interviews lead to inclusion of that information in the literature review.

In all parts of this report, we attempted to follow the work zone elements in each step of the project development process, starting with activities well in advance of the project construction. For example, some agencies include consideration of work zone impacts in policy document (long-range plans and agency policy) long before the projects are detailed at even the conceptual level. We attempted to document followed strategies ranging from the policy level, conceptual level, and project planning and environmental documentation level, through design, during work

zone operation and work zone evaluation and monitoring, and through post project evaluation (postmortem).

Findings

All representatives of STAs had one or more strategy that their agencies had developed or were developing, and they spoke enthusiastically about progress they were making. Almost all individuals understood that the new work zone rule would encourage their agencies to think more comprehensively about work zone safety and mobility. A couple of agencies felt that they were very close or already met the spirit of the new rule.

In general, there were some weaknesses that were pretty consistently observed in most (not all) STAs:

1. A lack of agency policy level direction on work zone safety and mobility.
2. A lack of processes that identify the evaluations of work zone safety and mobility impacts throughout the project development and processes to understand how various offices (functional areas of expertise) should interact throughout the life-cycle of project development to plan, manage, operate, and evaluate work zone strategies.
3. A lack of common, consistent, and continuously applied performance data collection processes to allow the comparison of work zone safety and mobility at locations, between locations, and even between STAs.

Organization of the report

The first chapter is introduction. The next three chapters are stand-alone documents. Chapter 2 presents the literature review. Chapter 3 presents the results of interviews with representatives of 30 STAs. There are no comparisons made between states. Each interview attempts to document strategies that each STA uses to manage work zone safety and mobility. Chapter 4 documents the programs of three STAs—Ohio, Virginia, and Oregon. This chapter is intended to provide more specific details on strategies these STAs are using. The last chapter, Chapter 5, closes the report with conclusions and recommendations.

CHAPTER 2. LITERATURE REVIEW

Although the objective of the project is to look at safety and mobility strategies to improve the traffic operation of work zones, safety and mobility are often two sides of the same coin. That is, when congestion is reduced and traffic operations are more efficient, work zones are safer, and when work zones are safer, traffic operations are more efficient. However, policy initiatives and activities to improve work zones are generally motivated by mobility or safety, and while the implementers of the strategies may recognize the synergy between safety and mobility, the strategies are generally driven by one or the other concern. In this literature review, we will review safety and mobility strategies together and move through the work zone life-cycle, starting with project conceptualization and moving through the project life-cycle to the conduct of a postmortem following the completion of the work zone.

This review only investigates the literature at a very high level. National reviews of best practices and national self-assessments have been conducted to identify practices that are being applied by individual state transportation agencies (STA) with varying degrees of success (2,3,4). Much of the information presented here is derived from our survey of practices that states (individual results from specific STAs are summarized in Chapter 3) have applied throughout a project life cycle to better manage congestion and safety issues within work zones.

The outline for reviewing safety and mobility strategies follows a construction (or reconstruction) project development process, starting from the activities conducted earliest in the project development stages and working its way through the project delivery process to the actual construction and post-construction evaluations. Work zones for maintenance activities can have impacts on traffic operations similar to reconstruction projects, but are generally much shorter in duration and may be reviewed by an agency using some of the same processes it uses to assess the impacts of highway reconstruction projects. The Ohio Department of Transportation has developed a very nice model for defining a project's degree of complexity and the need for more or less preparatory effort for the work zone. This model is discussed in the Ohio case study in Chapter 4 of this report.

As highway reconstruction projects are developed, they conventionally go through several steps. Project development starts with long-range planning and other policy plans in which projects are dealt with at an abstract policy level. Next, in project programming, steps are taken to provide more definition to the project, starting with scoping and environmental documentation. Project programming may then move the project into preliminary engineering and then to final (detailed) design, where the plans and specifications are prepared to allow the STA highway reconstruction. During construction, there are operational and work zone quality control activities to manage. Following construction projects, there are opportunities to assess the project and look for lessons for continuous improvement. Although the steps sound straightforward and sequential, in reality the lines between each step can be blurred. For example, project programming includes programming for the construction itself, but pre-construction activities are also programmed, including project scoping, environmental documentation, and design. At each step in the project development process, decisions can be made regarding work zone safety and mobility. Therefore, the simple set of steps in the development process is used to discuss types of

mobility strategies. We have chosen to break project delivery into seven simple steps. In Chapter 4 we describe the Ohio DOT's process, and they have broken the project delivery process into 14 steps (all 14 steps are discussed in Chapter 4). The more coarse aggregation of steps used here provides enough detail for this discussion. The steps we use for illustration are as follows:

- Long-range network planning, policy planning, and network scoping
- Project programming and project planning
- Preliminary design
- Final design
- Contracting
- Project work zone administration and traffic operation
- Post-project evaluation (postmortem)

Following the discussion of actions taken at each of these seven steps of project development, we provide a brief discussion of the computer tools used to quantify and estimate work zone traffic operational impacts. Because the most important variable in determining queuing and delays at work zone is the estimate of the capacity of the work zone following a lane closure, the text discusses attributes of the work zone, the traffic, and the environment that can adversely impact capacity at work zone lane restrictions.

Long-Range and Policy Plans

Generally, long-range plans very broadly address specific improvements, and if they address projects at all, they lack definition. Therefore, it is difficult to address specific work zone mobility strategies and safety strategies, but it is possible to set policy for how projects will be designed, managed, and contracted. For example, some states may encourage the use of strategies to combine adjacent projects within an urban area, reduce the duration of projects, or encourage the use of innovative contracting strategies (contractor incentives and disincentives) to reduce the duration of projects or discourage simultaneous work on parallel corridors.

Some STAs have adopted policies or policy plans regarding work zone mobility. For example, some STAs have set policies on maximum queue length or maximum delays imposed on motorists due to work zones, or have even created prohibitions on daytime closures in urban freeways. For some states, these policies are imputed into lane closure policies that are based on hourly or daily traffic volume and define where and when the agency is precluded from closing one or more lanes. For example, the Minnesota Department of Transportation (Mn/DOT) publishes a manual that specifies when (during what hours of the day and days of the week) and where a lane can be closed (5). Implicit in this manual is a policy regarding the maximum amount of delay the agency can impose on road users when a lane is closed. Although it is a static manual, it is based on published highway capacities and historical traffic volumes and traffic patterns.

One of the issues associated with blanket lane closure policies is that the policy may not be founded on traffic demand and operational characteristics of the specific situation, and when broadly applied (in a one-size-fits-all policy), it may **not** result in a cost-minimizing solution. An

example in which economics is used to drive lane closure decisions, as opposed to delay estimates or queue length thresholds, is the system implemented by the Oregon Department of Transportation (ODOT) (6). ODOT was the first agency to use the national Highway Economic Requirement System (HERS) model and apply it at the state level. The Oregon has become the first state-level user of HERS and the national model evolved into the HERS-ST (state version) software package. This model is an economic model that estimates the user costs (safety and mobility), some environmental costs, and the agency costs for the highway system (e.g., improvements and system preservation). Using HERS-OR, ODOT developed a spreadsheet model to estimate the user costs for delays resulting from lane closures at various locations throughout their highway network. These costs are then used to evaluate the impact of lane closures, including work zone lane closures at a conceptual level of planning.

In many cases (such as the Mn/DOT example), the agency may not recognize practices that limit the maximum delay or maximum queue length as a policy-level decisions, but these limits informally become agency policy. In a few cases delay or queue length threshold at work zone lane closures were established through policy making. One state told us that maximum work zone delays were set by the state's governor following the governor's experiencing an excessive delay due to a work zone while traveling to an appointment.

As noted in the 2002–2003 FHWA work zone self-assessment, most agencies have not established goals for reducing crashes and delays in work zones (1). However, some agencies established such goals. For example, ODOT has stated that its goal is to “[m]aintain the number of fatalities in work zones per year at or below ten through the year 2010” (7).

Project Programming and Project Planning

The planning and programming processes tends to vary from STA to STA, but most construction or reconstruction projects begin with the identification of a system deficiency. When the system deficiency becomes a high priority, a conceptual-level plan is developed and project development activities are programmed into the Transportation Improvement Program (TIP) plan. At this point in the pre-construction process, decisions are beginning to be made about project scheduling, contracting method (design-bid-build, design-build, or another project delivery method), the consolidation of multiple projects into a single large project, and project costs and financing. Figure 2.1 is a graphic taken from the Mn/DOT *Highway Project Development Process Handbook* that shows the steps for taking a project from concept to construction to highway operation (8). Although the project development process can be drawn as a series of steps, for complex projects, the process is more likely to be interactive. For example, a project might be scheduled to be conducted as a design-bid-build project at the conceptual stage, but later, during preliminary engineering when a scheduling and phasing plan is developed, it is discovered that the standard delivery processes will needlessly delay the project. To expedite project delivery, the STA can decide to deliver the project using design-build, thus combining two steps and reducing the number of contracts with consultants and contractors.

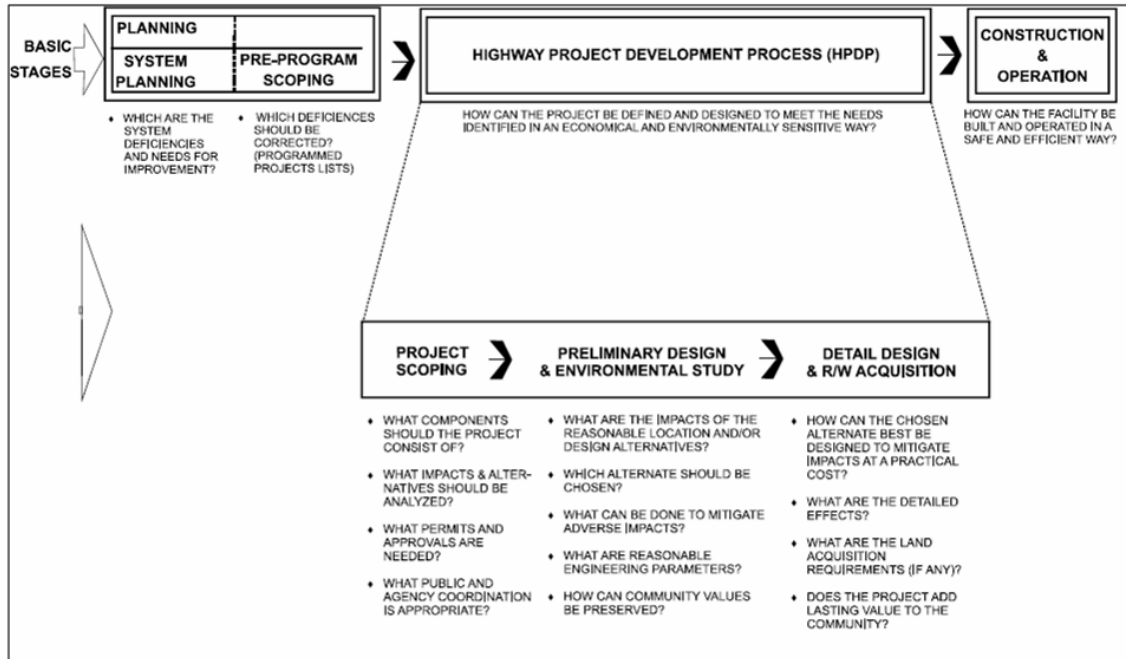


Figure 2.1. Mn/DOT project development stages

Clearly, the scale and location of a project will impact how early in the project development process the work zone impacts should be considered. For example, the reconstruction of a critical and major river crossing within a large urban area may be a good candidate for very early consideration of work zone impacts. Depending on local conditions, partial or complete closure of the bridge may trigger the use of a network model to understand the traffic impacts of the closure. On the other hand, the work zone impacts of converting a rural two-lane highway to a four-lane rural divided highway may not require early consideration. Considerations for the work zone management for routine and less complex projects may be appropriately considered much later, in the project’s final design.

Following conceptual plans, the next step in the project programming process is typically to conduct a detailed scoping study, at which point the project starts to move through the pre-construction project development process. In scoping, the limits of the project are determined and the fundamental functionality of the project is identified. The scoping document will identify the project components, identify project alternatives for evaluation, and provide a plan for agency and public involvement. From this point forward, until construction starts, planning and design decisions are made that impact work zone management during construction. The project scope will generally result in entering the project into the TIP. For high-impact projects, the California Department of Transportation (Caltrans) requires that a Transportation Management Plan (TMP) should be started during scoping. The traffic management and traffic mitigation costs from high-impact projects are likely to be significant, and these costs should be included as preliminary budgets are being developed (9). Although it is not clear that other agencies develop TMPs this early in the project development process, the FHWA’s work zone self-evaluation found that 57% of the STAs reported that their TIP was managed to avoid congestion due to poor scheduling of projects (3).

Naturally, when TMPs start very early in the process, the ultimate plan must evolve as the project's scope becomes more defined. However, it is important for projects with significant traffic impacts that planning begins early to allow enough time to execute the strategies in advance of the initiation of construction. For example, if car pooling were employed as a mitigation strategy, this might involve an entire project development process for the construction of park-and-ride lots, which may require years to execute.

The Work Zone Safety and Mobility Federal Administrative Rule Schedule uses language similar to that of Caltrans' guidance. The federal administrative rules specify that interstate system projects in transportation management areas (urban areas with a population of more than 200,000) with significant impacts must have a TMP. Similar to Caltrans' guidance, the federal administrative rules encourage STAs to begin developing TMPs early in the project development process. The administrative rules state that the "TMP consists of strategies to manage the work zone impacts of the project."

Understanding the impacts of a major project in an urban area is complex. Trips will be diverted from the impacted route to parallel routes, or travelers will look for alternative modes of travel. Some travelers may even find alternatives and may not make the trip at all. The conventional wisdom is that when the capacity of a specific roadway has been reduced, the number of travelers diverted to other routes and modes in the corridor will be approximately equal to the peak-period reduction in capacity required by the reconstruction project (10). Assuming that this is the case, then, understanding the paths and modes for diverted trips requires an analysis that uses a network model with trip distribution and perhaps modal split estimation capabilities.

More detailed study of traffic diversions during closures has shown that conventional thinking about trips in response to road closures or capacity decreases overestimates the trips that will reappear somewhere else in the network when capacity is decreased (i.e., during lane closures due to construction). In other words, when lanes are closed due to construction, the conventional assumption that trip makers will continue making the same trip following the same path or a parallel path may result in overestimated impacts. To further understand traveler behavior when facilities are closed, impact studies have been conducted for transportation system disruptions resulting from constructions projects, natural disasters, and other events that cause the total closure of a roadway. There are many such studies of landslides that have closed roads in New Zealand, earthquakes that have collapsed freeways in California, and transit strikes in large urban core areas (11). However, the most comprehensive, controversial, and widely cited study is one by Cairns, Hass-Klau, and Goodwin conducted for London Transport and the Department of Environment (12). The main questions this study set out to answer were (1) "what really happens to traffic conditions when road capacity is reduced or relocated?" and (2) "what are the underlying changes in travel choices and behavior that cause these effects?"

The authors collected over 150 sources of information regarding 100 locations and included over 60 case studies. Capacity reductions examined included road maintenance activities, bridge collapses, natural disasters, labor strikes, etc. In their case studies, the authors found that the unweighted average number of trips was reduced in the treated area or in the area by 41%. On

average, less than half of this traffic then reappears on alternative roads at the same or different times of day. This suggests that quite a few trips simply dissipate naturally.

The authors examined different kinds of conditions during which roads are reduced in capacity or roads are closed. The authors determined that the response (reduction in traffic) is a result of the number of alternative routes, the duration of the capacity reduction, and the alternative modes of travel. However, in studying even short-term closures due to railroad worker strikes, the authors found that users seemed to be able to accommodate capacity reduction very quickly. This is in part due to information available regarding the capacity reduction that allows the public to adjust their trip-making behavior. The authors found that in some cases, even on the first day of the disruption, there was no substantial “traffic chaos,” and the lack of chaos is often greeted with the bemusement of the press and transportation professionals. They also found that the extent of publicity and information before the change might itself influence expectations and outcomes.

From the work by Cairns, Hass-Klau, and Goodwin, we can see that travelers are amazingly resilient in working their way through a closure or a capacity reduction. However, much more research needs to be done to understand how travelers tend to accommodate construction road closures or partial closures. However, it is expected that the response is likely to be related to several variables, including the information available to the traveler about the work zone, traffic conditions at and around the work zone, the types of trips (recreational or work), alternatives and knowledge of alternatives, and the duration of the lane occupancy by a work zone. However, the good news that Cairns, Hass-Klau, and Goodwin discovered is that, given enough information, travelers will adjust and are amazingly resilient and resourceful when faced with a capacity reduction.

Saag, while conducting a synthesis of methodologies for reconstructing urban access-controlled facilities, found evidence that tends to conform to the findings of Cairns, Hass-Klau, and Goodwin (13). Saag found that “[e]ven when lane closures during construction are required, experience has shown that many predictions of dire adverse traffic conditions resulting from the closures did not materialize.” Saag also emphasizes the need for public information and communication. Saag recommends that the need to involve the public transcends all study phases, from early planning through construction.

An environmental study and documentation follow project scoping. To determine project limits and impacts, a preliminary geometric layout must be completed during environmental documentation. For projects with high impacts, environmental documentation involves planning for the work zone through involving the public, assessing the impacts of alternatives, and identifying strategies to mitigate adverse impacts. Alternatives considered during environmental documentation should be evaluated for their impacts both during and after construction.

The environmental document results in a preliminary geometric layout that can be used for a more specific assessment of the traffic impacts resulting from a high-impact construction project. At this stage, the TMP can be further refined. For major projects, the planning and design management approach for traffic is a comprehensive effort to accommodate traffic during

construction. The TMP should assess the impact to the region and determine potential solutions (e.g., demand management strategies, improvement of parallel routes, etc.) rather than offer localized remedies to specific issues within the project limits (e.g., individual traffic control devices). This information can be used to begin developing the traffic operation (TO) plan and to begin delivering the public involvement (PI) portions of the TMP. For example, at this stage the Ohio Department of Transportation conducts an analysis of the preferred alternative resulting from the environmental document to determine whether lane closures are feasible (given the department's maximum queue length policy) and, if lane closures are possible, the times of the day or days of the week during which lanes closures would be feasible (limited by their lane closure policy on maximum delay). Information on permitted lane closures helps drive further TMP planning as the TMP evolves.

Preliminary Design

Preliminary design should define the layout and types of facilities (e.g., interchange types); identify the roadway cross-section, profile, and alignment; and identify all right-of-way requirements and all roadway operational issues and traffic control. At this point, the TMP should begin to form. Designers can begin to look at the delay associated with alternative phasing and construction scheduling scenarios, alternative closures and detours, the impact throughout the network due to different lane closures and restrictions, and even full closures. Since traffic operation in the work zone will dictate the details of the temporary traffic control (TTC) plan, the development of a TTC for significant projects should take place at this stage.

Since traffic control plans have long been a requirement of federal aid projects, and since most states require traffic control plans for all projects, regardless of whether federal aid is involved, TTCs are a routine aspect of project development (14,15). What differs is the consideration given to TTCs so early in the project development process by the TMP.

During the preliminary staging in project development, a few STAs were found to have developed lists of data elements to check and consider when further evolving a TMP. (Ohio calls these red flags.) Table 2.1 lists elements that Caltrans identifies in its "Transportation Management Plan Guidelines" for consideration once geometric information is available (8).¹ Some of the items listed have to be determined through analysis (e.g., expected vehicle delay) and others are subjective (e.g., political or environmental sensitivity). Clearly, each individual STA might have more or fewer data elements that the TMP developer should take into account or elements that are unique to the agency. Caltrans further suggests that these data elements be taken forward to consider a fairly exhaustive array of potential strategies, as listed in Table 2.2.

Clearly, each strategy must be evaluated for cost effectiveness and the benefits and costs of applying the strategy. However, many of the strategies are known to work well and benefits far exceed the costs (such as media releases), and thus there is no need for an evaluation. However, others will depend on conditions, traffic demand, parallel routes, and alternative modes available. These impacts may also ripple through the network in the surrounding region for major projects in congested urban/suburban areas. In these cases, analysis tools such as work zone traffic

¹ The terminology in the list was slightly changed to make the list less unique to California.

operation models, simulations, multimodal demand models, or economic models (e.g., HERS-ST) should be used to select a set of effective strategies and design their characteristics (e.g., schedule for off-peak lane closures).

Table 2.1. Data elements for consideration during preliminary engineering for TMP refinement

Contingency plans	Expected vehicle delay
Lane closure policy and procedures	Public/media exposure
Coordination with TMC	Political or environmental sensitivity
Multi-jurisdiction communication and buy-in	Percent trucks
State and local police enforcement and involvement	Potential increase in crashes
Clearance of alternative routes for large and oversized trucks	Business impacts and affected activity centers/employers
Emergency closures	Conflicting construction projects
Special training or workforce development	Percent reduction in capacity
Duration of construction (months or years)	Special factors (if any)
Length of project (miles)	Impact on transit/railroad services
Urbanization (urban, suburban, or rural)	Viable alternative routes
Traffic volumes	Impact on the safety and mobility of bicycle and pedestrian traffic

Following good planning principles, each strategy should be linked to measures of performance to determine how effective the applied strategy was in reducing the safety and mobility impact of the work zone. Performance measures are typically applied to fulfill four functions (16):

1. To continuously improve services, in other words, to understand how the strategy is performing and whether adjustments of its application are necessary to improve performance
2. To strengthen accountability of either the STA's or the contractor's forces to ensure the strategy is achieving the desired effect
3. To communicate the results of strategies to the public and STA managers, which can be critical when decision-makers are asked to make difficult decisions and the public is asked to accept them, such as with full closures; they need to know how these high-cost short-term strategies achieve long-term gains
4. To provide better information for effective decision-making in the future, including resource allocation; in other words, to gain a knowledge base of the applicability and benefits of the strategy

Performance measures for work zones are currently far from standard and differ from one agency to the next, and the appropriate performance measures will often vary from project to project. For example, when a TMP calls for mitigation strategies, such as increased opportunities and support services for car pooling, the performance measures should include a measure of increase in car pooling use. Another project in which car pooling was not selected as a mitigation strategy clearly would not use increased car pooling as a performance measure. Further, a work zone may

involve a new strategy in which a specific technology is being deployed. In these cases, a unique performance measure may be employed for evaluation purposes.

Table 2.2. Caltrans TMP strategies and their elements

<p>A. Public information</p> <ul style="list-style-type: none"> • Brochures and mailers • Media releases (including minority media sources) • Paid advertising • Public information center • Public meetings/speakers bureau • Telephone hotline • Visual information (videos, slide shows, etc.) • Total facility closure • Local cable TV and news • Traveler information system (internet) • Internet • Notification to targeted groups: bicycle organizations, schools, organizations representing people with disabilities <p>B. Traveler information strategies</p> <ul style="list-style-type: none"> • Electronic message signs • Changeable message signs • Extinguishable sign • Ground mounted signs • Commercial traffic radio • Highway advisory radio (fixed or mobile) • Planned lane closure web site • Caltrans highway information network • Radar speed message sign • Bicycle and pedestrian information, e.g., detour routes <p>C. Incident Management</p> <ul style="list-style-type: none"> • Call boxes • Enhanced enforcement • Freeway service patrol • Traffic surveillance stations (traffic detectors and CCTV) • 911 cellular calls • Transportation management center • Traffic control officers • State police in TMC during construction • Onsite traffic advisor • State police helicopter • Traffic management team 	<p>D. Construction strategies</p> <ul style="list-style-type: none"> • Incentive/Disincentive contract clauses • Ramp metering • Lane rental • Off peak/night/weekend work • Project phasing • Temporary traffic screens • Total facility closures • Truck traffic/permit restrictions • Variable lanes • Extended weekend closures • Reduced speed zones • Coordination with adjacent construction • Traffic control improvements <p>E. Demand management</p> <ul style="list-style-type: none"> • HOV lanes/ramps • Park and ride lots • Parking management/pricing • Rideshare incentives • Rideshare marketing • Transit incentives • Transit service improvements • Train or light-rail incentives • Variable work hours • Shuttle service incentives <p>F. Alternative route strategies</p> <ul style="list-style-type: none"> • Ramp closures • Street improvements • Reversible lanes • Temporary lanes or shoulder use • Freeway or freeway connector closures • Temporary bicycle or pedestrian facilities <p>G. Other strategies</p> <ul style="list-style-type: none"> • Application of new technology • Innovative products • Improved specification • Staff training/development
--	---

Clear measures of work zone performance are implied by the Work Zone Safety and Mobility Self-Assessment guide (1). These are measurements of mobility that include measures of

throughput, such as flows measured in passenger car equivalents, queue length, queue length distribution, maximum queue length measurements, delay while traveling through the queue and the work zone, and travel time through the queue and work zone. Measures of safety include common measures, such as crash rate, crash frequency, crash severity, incident frequency, and time before clearance of incidents. As seen in the Ohio DOT case study, a comparison can be made between the crash frequency in the work zone segment and the crash frequency before the work zone was put in place. When the crash frequency exceeds the crash frequency before the work zone was implemented, a special safety study of the work zone is triggered. Regardless, as we found in our survey of STAs, very few STAs routinely collect and compile performance measurements. More often than not, performance measures are collected on an exception basis. For example, if an agency receives complaints about a specific work zone, this may trigger the measurement of backups.

Table 2.3 lists performance measures and the agencies that use these performance measures (17). These measures were created to measure the impact of specific technology being applied in the work zone. For example, a common application being used in several of the states was the use of speed monitoring devices with a changeable message sign (CMS) to tell the motorist their speed relative to the work zone speed limit and several independent evaluations of this technology have been conducted (18,19,20).

Table 2.3. Performance measures for the evaluation of work zone traffic management technology

Performance Measure	N. Carolina	Kansas	Ohio	Wisconsin	Arkansas	Georgia	Michigan
Number of crashes in transition zone	X	X				X	X
Average days between crashes	X						
Time between crashes	X						
Speed before and after CMS message (actual speed and speed variance)	X			X		X	X
Travel time through work zone (actual vs. predicted by travel time advisory)	X		X		X		X
Speed limit violation (variance in citations issued)	X						X
Alternate route usage (%)	X			X		X	
Work zone web site (number of hits)	X						
Motorist surveys (perceived accurate information, frequency of travel through work zone, web site knowledge and use, future support of system)	X		X		X	X	
Aggressive driving changes (%)	X						X
Time of freeflow conditions vs. congestion (%)		X				X	
Actual backups vs. computed backups					X		
Volume at which backups occur (VPH)					X		X
Average system failure time						X	
Speed changes when enforcement present (%)						X	X
Accuracy of sign message (recorded and observed)						X	X

Clearly, if there are going to be comparisons of work zone performance within a state and between states, common performance measures and standards for data collection and data processing need to be developed. However, regardless of the measures, the TMP must include resources for data collection, data storage, and data interpretation and analysis.

Caltrans guidelines also recommend that a contingency plan be part of the TMP. The contingency plan identifies what to do and what step to take if congestion and queues exceed what is anticipated and delays become unacceptable. Although Caltrans guidelines only address mobility issues for triggering contingency plans, it would also be prudent to have triggering criteria for a safety contingency plan. For example, Ohio has performance measures that trigger steps to investigate the work zone for safety issues, similar to congestion contingency triggering measures (see Ohio DOT case study). Caltrans contingency plans contain the following elements:

- Information that clearly defines trigger points that require lane closure termination (i.e., inclement weather, length of traffic queue exceeds threshold)
- Decision tree with clearly defined lines of communication and authority
- Specific duties of all participants during lane closure operations, such as a coordinator for state or local police, etc.
- Names, phone numbers, and pager numbers for the district traffic managers or the designee, the resident engineer, the maintenance superintendent, the permit inspector, the on-site traffic advisor, the state police division or area commander, appropriate local agency representatives, and other applicable personnel
- Coordination strategy (and special agreements if applicable) between the district traffic manager, resident engineer, on-site traffic advisor, maintenance, state police, and local agencies
- Standby equipment, state personnel, and availability of local agency personnel for callout (normally requires a cooperative agreement)
- Development of contingencies based on maintaining a minimum service level

Final Design

At the final design stage of the project development process, the details of the project are sufficient to allow an experienced contractor to construct the project. The products of final design are the plans, specifications, and the project cost estimate (PS&E). The PS&E includes the TTC plan for the contractor to execute. At the final design phase, the TMP should only need minor modifications, and for major projects, many of the activities listed in the TMP should already be underway before completion of the final design.

In many respects, the routine TTC plan process that STAs have always used to develop traffic control plans may be applied only after the plans have been made more complex by including more extensive rules and procedures governing mitigation plans, work schedules, performance monitoring, night-work requirements, and the use of intelligent transportation systems (ITS) in the work zone.

Contracting and Project Operations

While the work zone is operating, three aspects of monitoring the operations need to be taken into account:

1. Appropriate application of the TTC plan, drivers' ability to understand and follow temporary traffic control devices, the condition of traffic control devices, and modification to TTC to improve traffic operations and safety
2. Monitoring of mobility (delays and travel time) in the work zone and adjusting the work zone to meet mobility standards
3. Monitoring safety (conflicts, incidents, and crashes) in the work zone and then making corrections to improve safety in the work zone

The first aspect, reviewing the temporary traffic control, is uniformly conducted to some extent by every surveyed STA. Most agencies have standard procedures for checking the traffic control against the plans and having qualified individuals inspect the work zone while in service to make sure that the TTC devices meet standards, are set-up appropriately, and are conveying clear guidance to drivers. The FHWA has even developed a checklist for inspecting TTC in work zones (21). Some agencies go to the effort of placing a TTC specialist in major work zones to make adjustments to the traffic control on the fly.

Work Zone Postmortem

Most interviewed STAs did not conduct a formal postmortem review of specific projects or of the performance of all projects during a single year. Instead, exchange of information on the performance of work zones was largely done informally. For example, the Illinois DOT schedules quarterly meetings of traffic control supervisors to exchange experience and identify best practices. A few states indicated that they had formal end-of-the-year processes. For example, Colorado has a process in which each project's resident engineer and regional safety engineer rates each project on a score of 1 to 4 following a specific scoring criteria. All scores and safety statistics are then compiled into an end-of-the-year report. For example, Kentucky has a team that evaluates at least 25 work zones annually, and their findings become part of an annual construction evaluation; Minnesota prepares an annual work zone safety analysis, which also contains safety statistics from the last 11 years to report on safety trends; and during the peak of the construction season, Oregon sends 6 to 12 engineers out to tour as many work zones as they can in two weeks to identify deficiencies, and the results are prepared in an annual report.

The relative dearth of objective data after the project evaluations (postmortem) is largely due to the lack of performance data collected during the actual project. If data are uniformly and consistently collected for all work zones, then the agency can easily develop an annual report that evaluates the status of work zone performance and illustrates improvements in performance from year to year.

Work Zone Planning and Management in the Project Development Process

In this section of the literature review, the steps taken to plan and implement safety and mobility mitigation strategies are identified. This is not intended to provide the detail to allow an STA to adopt and apply a strategy, but rather it is intended to provide examples of what can be done at each project development step and spark the development of work zone safety and mobility strategies to satisfy an agency's unique circumstances.

Several agencies apply good work zone management principles in several of the steps of project development, with the exception of measuring work zone performance. We found practically no examples of good performance measurement of work zone safety and mobility. Much work remains to be done in this area to create performance measures and to encourage the need to review the performance of work zones.

In the next section, we briefly review analytical tools used to analyze work zone traffic operations and traffic impacts of work zone lane restrictions.

Measuring the Traffic Impacts of Work Zone Lane Closures

Simulation modeling methodologies used to measure the impacts of work zone can be categorized by three dimensions. The first dimension is the queuing model used; most simple procedures use deterministic queuing models. The second dimension is whether the model treats vehicles as individual entities, sometimes called microscopic simulation models, or traffic is treated as continuous flow, known as macroscopic models. Lastly, some models have network capabilities in which vehicles can flow through the model following multiple paths. The most sophisticated network models used to examine work zones have the capability to distribute trips along paths within the network based on internal algorithms, while more simplistic models require that the modeler distributes trips by hand. Each dimension is explained below.

Deterministic Queuing

Three macroscopic methods apply to modeling queues. These are steady state queuing models, a shock wave queuing model, and a deterministic queuing model. In this section, we will discuss only the deterministic queuing model. A reader looking for a comparison of all three should see references (22,23).

Because of its simplicity and elegance, deterministic queuing is most commonly used for model work zone queuing. A deterministic model of queuing is used by the *Highway Capacity Manual* to determine delay due to lane closures. Memmott and Dudek applied deterministic queuing to work zones in 1982, and this method is incorporated into the computer model QUEWZ, which is used by several state transportation agencies to determine expected delays at work zone lane closures, queue lengths, and user costs (24).

The underlying assumption of this model is that when the number of vehicles arriving exceeds the capacity, the difference between the arrival rate and the capacity is the number of vehicles stored in the queue. An example of deterministic queuing is shown in Figure 2.2. Figure 2.2

assumes that the bottleneck has a capacity of 1,400 vehicles per hour. Starting at time zero there is no queue, but a queue begins to build because the arrival rate (2,000 vehicles per hour [vph]) exceeds the discharge rate (1,400 vph), and at the end of one hour there are 600 vehicles queued upstream of the bottleneck. Figure 2.2 then shows the arrival rate dropping to 800 vehicles per hour after one hour at point B. The discharge rate now exceeds the arrival rate and the queue begins to dissipate. At the end of two hours, the queue has subsided. The number of vehicle-hours of delay the bottleneck imposes is the area of the triangle formed by points A, B, and C. Knowing the number of vehicles in the queue, the length of the queue can be determined by Equation 1.

$$D_t = \frac{L_t \cdot l}{N} \quad (1)$$

where

- D_t = The length of the queue at time t
- L_t = The number of queued vehicles at time t
- l = The average length occupied by a vehicle
- N = The number of lanes upstream from the lane closure

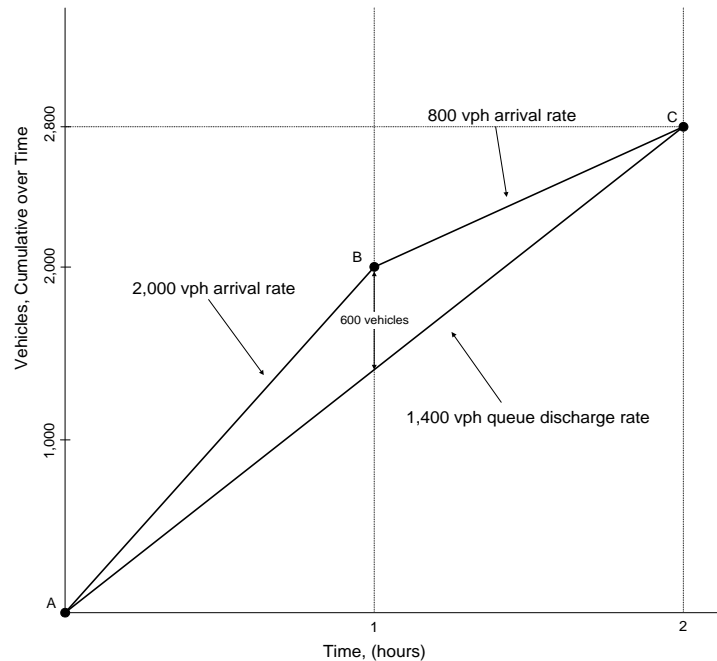


Figure 2.2. Example of deterministic queuing theory

Dixon, Hummer, and Rouphail point out that the difficulty with the deterministic approach is that it estimates the queue at a single point (25). In other words, the model treats the vehicles stored in the queue as if they were stacked vertically rather than distributed across a length of road upstream from the lane closure. Therefore, the behavior of the queued traffic upstream of the lane closure is not influenced by the lane closure.

Highway Capacity Manual methods and QUEWZ and its derivative models, including QUEWZ3, QUEWZ-85, QUEWZ-92, and QuickZone, all use a deterministic queuing model to estimate queue length and delay. Other agency-specific models have been built based on a similar methodology with inputs and outputs customized for the agency. For example, the Ohio DOT uses an agency-developed spreadsheet-based model for estimating work zone impacts (26). All versions of QUEWZ assume a closed network, meaning that all vehicles entering the simulation can only be discharged by going through the deterministic queuing model. QuickZone is a more sophisticated model that allows the user to create a network, but the principle model used to estimate delays and queue length is the deterministic queuing model. However, because QuickZone is a network model, it can estimate delay for an entire corridor, and the model can run network-level scenarios where traffic is diverted to parallel routes (detours). The user specifies the propensity for drivers to divert to a detour. Since manual input is required to estimate the network impacts of a lane restriction (a lane closure), the size of the network and the estimation of the impacts within the network may be limited to the mainline where work is being constructed and a few parallel diversion routes. This makes QuickZone applicable to many urban applications and almost all rural applications, but not to major closures in dense networks. For example, in the Minneapolis/St. Paul metropolitan area, the Mississippi River bisects both core cities. During 2004, Mn/DOT had construction and/or maintenance work scheduled for the bridges on all three of the interstate and interstate-like roadways crossing the river on the St. Paul side of the metropolitan area. The result was simultaneous lane closures for a few weeks on all three structures. Lengthy backups were experienced. Estimating the significant and complex network effects in the Minneapolis/St. Paul metropolitan highway system is significantly beyond the capabilities of QuickZone.

The ability of models based on deterministic queuing models to forecast queues, queue length, and delays accurately depends on the capacity estimate at the lane restriction, and therefore a good estimate of capacity is the most critical input. Although different programs may make different assumptions regarding the density of vehicles (vehicles per mile) in the queue to determine the queue length, all should calculate the same number of vehicles in the queue given the same capacity during a work zone-related lane restriction. Therefore, estimating the capacity of the roadway within the work zone becomes critical, and several recent studies have investigated the capacity of freeways with lane closures (27,28,29).

Dixon and Hummer found that in most cases the capacity of work zones is governed by the efficiency of drivers to converge into the through lanes at the merge point. Traffic control and enforcement activity that cause vehicles to merge into the through lanes upstream from the lane closure taper (early merge schemes) make the capacity of the work zone dependent on the efficiency of the merge upstream (where there is space to merge at high speeds). Traffic control and enforcement that results in vehicles merging at the lane closure taper (late merge schemes) result in the capacity being governed by the merge near the taper (where there are space limitations that require that merging occurs at low speeds). Dixon and Hummer also found that in some work zones in which construction work is taking place very close to the open lane, the proximity of the construction work to the open lane may govern the capacity of the work zone.

Table 2.4 shows traffic volume measurements taken immediately prior to the initiation of a queue at a work zone on I-80 near Davenport, Iowa, during the summer of 1998. The volumes

shown in the middle columns of Table 2.4 are the raw volume counts; the highest volume recorded just prior to queuing varies from about 1,300 vehicles per hour to almost 1,600 vehicles per hour, with a range of 300 vehicles per hour. When the flows are converted to passenger car equivalents, the maximum measured volume still varies by 300 vehicles per hour. The differences are dependent on a number of variables; several are listed in Table 2.5, as well as information about how these variables impact capacity. Unfortunately, capacity is partially dependent on driver behavior, and behavior is always going to have a certain amount of uncontrollable randomness.

Table 2.4. Highest free-flow measurement before queuing initiated

Date	Traffic conditions	Unconverted freeflow volumes		Converted freeflow volumes	
		Highest volume (vph)	Mean of 10 highest volumes (vph)	Highest volume (pcph)	Mean of 10 highest volumes (pcph)
6/19/98	Freeflow	1284	1216	1542	1374
7/2/98	Freeflow	1392	1302	1542	1442
7/10/98	Freeflow	1524	1438	1680	1630
8/7/98	Freeflow	1572	1375	1752	1493

Table 2.5. Variables known to impact work zone capacity

Variable impacting capacity	Attributes associated with variable	Known characteristics
Work zone lane closure configuration	The capacity of a lane closure is dependent on the number of lanes left open and closed and the location of the lane or lanes closed.	When one or more lanes are closed, the remaining open lane(s) have less capacity than normal through lanes. For example, when one lane of a two-lane segment is closed, the open lane has less capacity than one normal lane due to merging. The same is true when one lane is closed on a three-lane segment. Also, right lane closures have lower capacity than left lane closures because the right lane generally carries more traffic, resulting in more vehicles merging into the open lane. For estimates of capacity versus configuration see references (30,31).
Intensity and location of work	The capacity of the open lane will be impacted by visible construction work in proximity to the open lane(s).	Even when there is a concrete barrier between the driver and the construction activity, drivers will slow when the work is in close proximity to the open lane. Intensity and location of work have been found to negatively impact capacity by 1.85% to 12.5% (24).
Percentage of heavy vehicles	Due to their poorer speed change performance, high percentages of heavy vehicles will reduce capacity of the through lanes.	Because of poor speed-change performance, trucks have a greater impact on capacity after queuing than during freeflow. Al-Kaisy and Hall estimate that on level terrain, trucks equal 2.4 passenger cars and buses equal 1.5 passenger cars (25).
Driver characteristics	Drivers that have experience with the work zone are likely to select shorter headway and capacity will increase.	Commuters making routine trips are familiar with the work zone and are more likely to reduce headways through the work zone. Al-Kaisy and Hall found that during off-peak hours capacity reduced by around 7% and during the weekends by 16% (25).
Entrance ramp locations and volumes	Ramps in or in the area of the work zone are likely to create more turbulence in the traffic flow and reduce capacity.	Krammes and Lopex suggest that the capacity of the open lanes should be reduced by at least the volume of the ramp within or downstream of the taper (28).
Grade of lane closure	Positive grades will diminish the capacity of open lanes, particularly where there are a high proportion of heavy vehicles.	Al-Kaisy and Hall found that at only a 3% grade, passenger car equivalent factors for trucks increased from 2.4 to 2.7 – 3.2 (25). Although not supported by research findings, positive grades are likely to have the greatest impact if they are located at the lane closure merger point.
Duration of work	As the work zone increases in time, drivers are more likely to be familiar with the work zone and reduce their headways, thus increasing the capacity of the work zone with time.	The comments here are similar to those with regard to the driver characteristics.
Weather conditions	The <i>Highway Capacity Manual 2000</i> contains reductions in maximum volumes due to weather.	Recent work by Agarwal, Maze, and Souleyrette found that during trace rainfalls urban freeway capacity is reduced by 1%–3%; in rainfalls of 0.01 to 0.25 inches per hour, capacity is reduced 5%–10%; and for rainfalls above 0.25 inches per hour, capacity decreases by 10 %–17% (32).
Work time	When work is scheduled at night to avoid peak travel times, traffic control presents significant challenges. Drivers are more frequently impaired by drugs or fatigue and generally behave differently due to lower visibility and glare caused by roadway lighting.	There are significant differences in traffic flow for nighttime work zones than for daytime work zones. For example, Sullivan found that crash rates increased by 87% when he studied several urban work zones in California (33). However, much research remains to be done to understand driver behavior. Some of these behavioral issues will be answered by a current NCHRP study.
Location of merge point and enforcement	Merging upstream from the taper point of a lane closure increases capacity more than late merging. However, drivers not following expected merge discipline skip to the head of the queue and force themselves into it, creating a crash risk and turbulence and diminishing any efficiency gained through an early merge. Locating enforcement personnel can improve early merge behavior.	Very little is known about the benefits of enforcement, and most studies of enforcement focus on safety benefits as opposed to traffic flow efficiency benefits (34). It is believed that using enforcement personnel to support smooth behavior improves traffic flow.

There are also two different measures of capacity at lane closures and restriction. Table 2.4 shows the maximum flow immediately before queuing occurred (uncongested flow). For the purposes of estimating queue length and delay once queuing has occurred, the queue discharge rate is probably more important than the maximum uncongested flow rate. To understand how the two are different, a graph of the data taken in the work zone on I-80 near Davenport, Iowa, is shown in Figure 2.3.

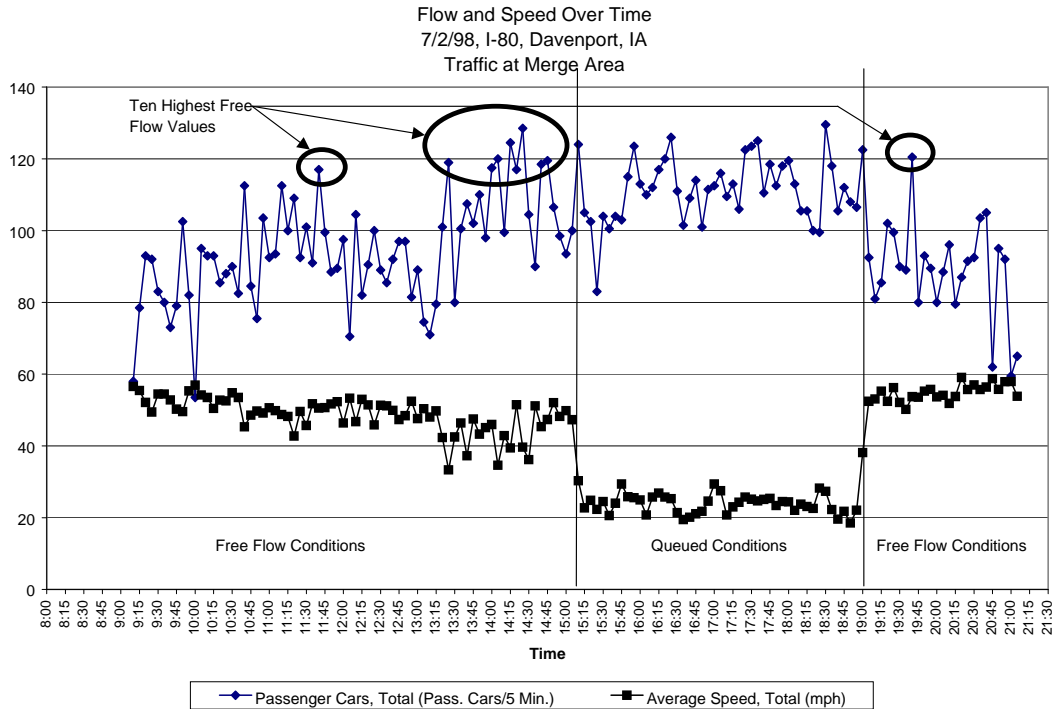


Figure 2.3. Volume and speed distribution before, during, and after a work zone queuing event

Figure 2.3 shows volume counts (at the top of the graph), average speeds (at the bottom of the graph), and vertical lines indicating when in time queuing started and when queuing dissipated. Each data point is the average of a five-minute period. Note that there is a precipitous drop in speed at the beginning of queuing and an increase in speed as soon as queuing ceases. Also, note that volumes, particularly at the beginning of queuing, decline. What is being observed is a capacity drop. That is, after queuing starts, the capacity of the work zone declines. The capacity after the capacity drop is the queue discharge rate. Thus, if the focus is on understanding the delay and queue length after queuing begins, then the queue discharge rate is needed. If the focus is on avoiding a queue and keeping traffic moving at freeflow, the focus is on the maximum flow rate immediately before queuing occurs. To keep traffic moving through the work zone efficiently, a traffic manager might employ metering or diversion strategies to keep the flow below the maximum throughput before queuing begins.

Microscopic Simulation (without network trip distribution capabilities)

Microscopic simulation generates vehicles as individual entities operating within the simulated environment. Each vehicle (entity) is assigned properties and moves through the traffic stream following predefined rules. The interaction between vehicles is defined by car-following and lane-change algorithms. Very popular microscopic simulation packages include the Federal Highway Administration's CORSIM software package and SimTraffic, part of the Synchro software package (other software packages with trip distribution capabilities will be discussed later) (35,36). Both of these software packages have no capabilities to distribute trips through the network independently of the operator's input. As a result, the operator must input traffic patterns, including turning movements at intersections. In other words, to understand the network impacts (diversions of traffic to alternative routes), the modeler must input changes to the traffic patterns to estimate network impacts of work zone-caused lane restrictions. Because these software systems do not have dynamic trip assignment capabilities, it is difficult (or impossible) to model dynamic traffic impacts in complex networks.

To overcome these difficulties, Anderson and Souleyrette integrated CORSIM with Tranplan (a regional travel demand model) (37). Tranplan includes a macroscopic model that distributes trips through the network based on link travel times. The process starts with the initial travel patterns, the travel times experienced by traffic are estimated using CORSIM, and then the travel times are fed back into Tranplan and the trips are redistributed to the network based on the travel time provided by CORSIM. The new trip distribution is fed into CORSIM and the link travel times are re-estimated. The two models interact with each other until the flow on links in the network converged to a constant volume. This was a clumsy method to get around the weakness of CORSIM.

Schnell and Aktan compared the results of CORSIM and SimTraffic's simulation results for traffic delay and work zone queue length in Ohio to the actual performance measured in the field. They found that CORSIM and SimTraffic's estimates of queue length were less precise than more simple models like QUEWZ (38). This is partially because the car-following algorithms and lane-change algorithms used in CORSIM were not developed for the work zone environment. However, in a later paper, Chitturi and Benekohal compared QUEWZ, FRESIM (the freeway simulator in CORSIM), and Quickzone and found that none of these programs offer accurate estimates of queue length at work zone restrictions (39).

Microscopic Simulation (with network trip distribution capabilities)

Advanced microscopic traffic simulators are available that have dynamic assignment capabilities. Several microscopic simulation software packages have dynamic trip assignment capabilities that make them an ideal environment for measuring the network impacts of work zone-related lane closures. We found no literature identifying a comprehensive list of applications of microscopic simulation with dynamic assignment capabilities for the analysis of work zones in complex highway networks. One of the first known largest applications was used to study the traffic impacts of the reconstruction of

I-15 through Salt Lake City in the late 1990s. The Salt Lake City study used a simulation software package with dynamic trip assignment named INTEGRATION (40). After the death of the developer of INTEGRATION, Michel Van Aerde, in 1999, other software packages have evolved that provide much better graphical output and easier to use interfaces.

SMARTTEST, a European commission project, was completed in 1997. At the time, the researchers identified 56 microscopic traffic simulation packages and evaluated 32 of these packages (41). Since then, more simulation packages have been created, but the ones that seem to be gaining the most commercial success are AIMSUN (developed by TSS, Barcelona), DRACULA (University of Leeds/WS Atkins), HUTSIM (Helsinki University of Technology), Paramics (SIAS & Quadstone, Edinburgh), and VISSIM (PTV, Karlsruhe). This is the opinion of Ken Fox, a simulation expert (42). All of these packages have dynamic trip assignment capabilities. These systems have much more robust capabilities than SimTraffic or CORSIM, but they also require more user inputs, are more labor-intensive to set-up, and require more expertise to use.

Another advanced microscopic simulation package, MITSIM, is being used by the Iowa DOT and the Des Moines Metropolitan Planning Organization (MPO) to model the traffic impacts of I-235 reconstruction in Des Moines (43). MITSIM is a product of the Massachusetts Institute of Technology's MITSIMlab. The MITSIMlab is a laboratory for evaluating the impacts of alternative traffic management system designs at the operational level and assisting in subsequent refinement. The model was implemented by the Iowa DOT's consultant Jacobs Civil Inc. and is operated by the Iowa DOT and Des Moines MPO. To date, no evaluation has been performed of the MITSIM application in Des Moines.

CHAPTER 3. STATE AGENCY SURVEY SUMMARY

A survey of state transportation agency (STA) practices and policies used to manage work zone safety and mobility impacts was conducted. The survey was conducted through the use of a structured outline for a telephone interview. The respondent was first sent a copy of the outline and then a telephone interview was conducted. Interviews varied in length, lasting anywhere from ten minutes to an hour. A copy of the interview outline can be found in Appendix A.

Methodology

Our team of researchers began the survey process by contacting state traffic engineers. Often, we were referred to other individuals within the agency that would assist the researchers in answering the survey questions. During the interview, questions were asked to lead the interviewee to a better understanding of the agency's practices. Although the interview was intended to cover all stages of project development—from project concept to postmortem—the interview often focused on the issues with which the respondent was most familiar. For example, if the individual interviewed was responsible for production of maintenance of traffic plans, then the discussion might focus on scheduling and phasing of construction to accommodate traffic control in the design phase, rather than covering topics the respondent was unfamiliar with during early project development or during system planning. A short report was developed from the findings from these interviews. The report was then returned to each respondent to let him or her modify and comment on the description of the STA's practices and to ensure accuracy of the report.

Figure 3.1 is a map showing surveyed states. The survey was conducted on thirty states. The number thirty was selected as a stopping point because of resource limitations. The decision whether to interview a state or not was purely arbitrary and partly related to whether the research team had contacts in a state.

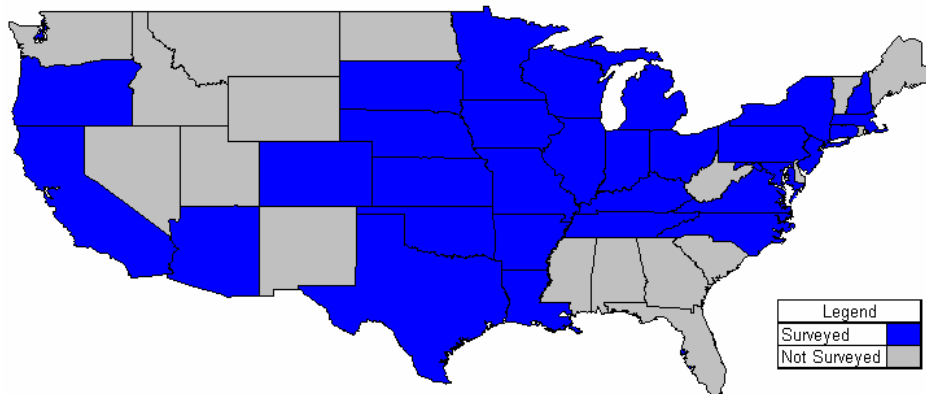


Figure 3.1. Surveyed states

The goal for developing the interview outline was to cover strategies used to manage work safety and mobility impacts at each step in the project development process. Figure 3.2 shows a simplistic representation of the fundamental steps of project delivery. Each STA may have different names for each step or have steps more finely divided; however, fundamentally, all highway project development follows the same process. Our purpose in this document is not to explore the development process (what goes on in each of the boxes), but rather to determine actions and plans that the STAs take at every step in the project development process to minimize work zone-related congestion and safety impacts. As individual STAs are discussed, it can be seen that STAs do make decisions and plans regarding work zone safety and mobility at every stage of project development. Very few of the interviewed STAs take into account work zone safety and congestion impacts at all stages of project development. Some of the best practices were found in states that focused on the evaluation of impacts at one step and then did an extremely good evaluation during that step. For example, a couple of states have extremely good processes for documenting the performance of the work zone during construction and then using this information to adjust the work zone and develop postmortem reports on what worked well and what did not work.

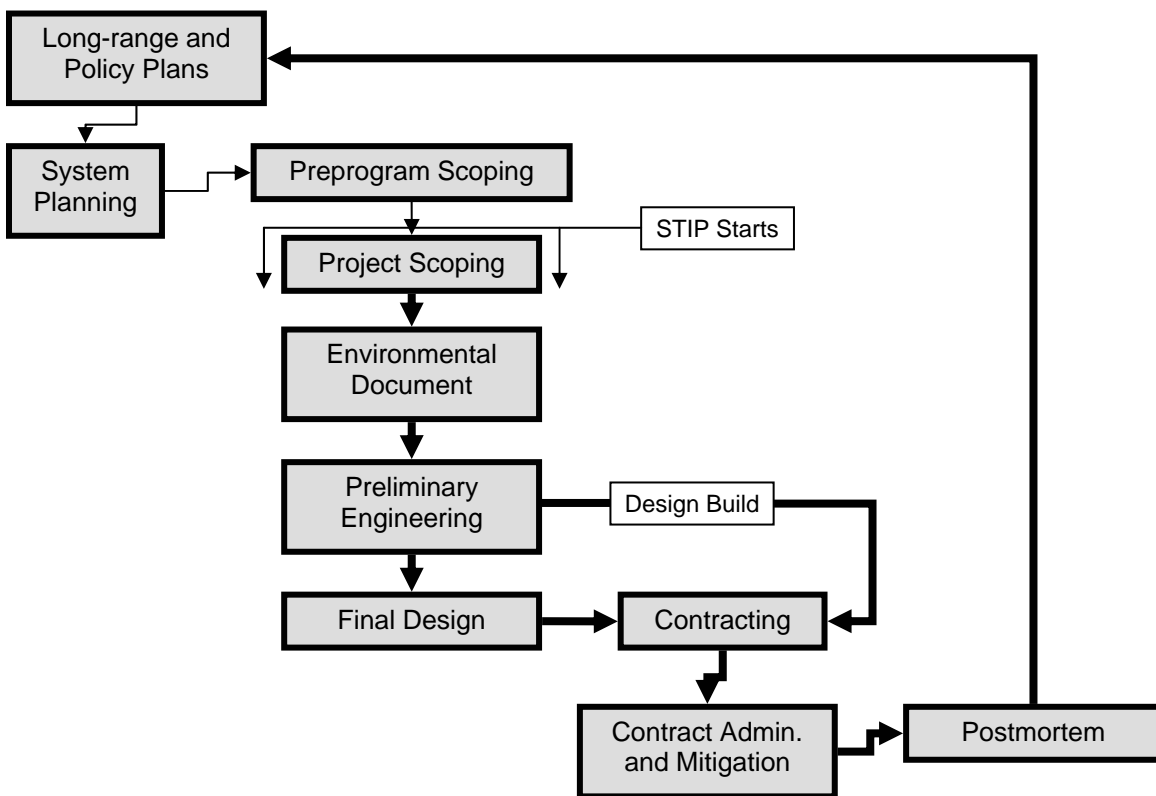


Figure 3.2. Generic project development process

The diagram shows the project development flow as a linear series of sequential steps, and the project development process for routine projects may linearly flow along this sequence of steps. However, for large and complex projects, the flow is less likely to be linear and may involve some backtracking of steps or modification to take into account

issues that are outside of the control of design professionals. An example might be a large-scale reconstruction project that enters final design as a traditional design-bid-build project and is scheduled to take six years to complete. Given the impacts to the community, local business leaders ask the STA to rethink the schedule and shorten the duration of reconstruction. In the process of re-examining the project, the STA backtracks and delivers the project using design-build and reduces the schedule to three years to complete.

Large and complex projects often require significant traffic mitigation efforts (5 to 10 percent of the cost of the project). Because mitigation efforts have significant impacts on project budgets, the cost of the mitigation must be factored into financial plans prior to program planning.

One part of the project development process that is commonly confused is the difference between the project delivery method and the contractor selection methodologies and contractor incentives/disincentives. The two common delivery methods are design-build and design-bid-build, and these methods often get confused with methods used to provide contracts incentives or disincentives to minimize the impacts of their work. Although incorrect, design-build and contracting incentives/disincentives are commonly referred to as innovative contract methodologies. Both may seek the same objective—to shorten the project delivery schedule, but design-build is a project delivery method, while incentives/disincentives are contracting methods. The diagram in Figure 3.2 clearly shows that design-build takes a step out of the project developing process.

The focus of our survey was to identify policies, processes, and practices that STAs have developed and other STAs may wish to consider adapting and adopting when attempting to develop a Transportation Management Plan for a work zone under the new FHWA rule on work zone safety and mobility. Responses to the survey were routinely short, and often respondents explained that they would like to have more comprehensive processes for considering and mitigating work zone impact but resources were limited. However, almost every state was typically proactive in a specific area in which the respondent gave valuable insight on the STA's activities.

Once the practices of interest were identified, the researchers requested additional information. The result is the following summary of practices and policies that state agencies are currently completing to reduce congestion and improve safety in construction areas.

Responses by State Agency

Arizona Department of Transportation²

The Arizona Department of Transportation (ADOT) considers practices to reduce congestion at the system planning phase. Currently, the ADOT considers the congestion impacts at the system planning stage for complex urban projects where the scheduling of work on parallel or nearby corridors simultaneously would multiply the resulting congestion. The ADOT is creating a policy that will address congestion and safety on all projects as part of the new FHWA Rule 23 CFR part 630, “Work Zone Safety and Mobility.” The ADOT has observed that through additional construction planning projects in the urban centers of the state, congestion and safety in work zones can be better managed.

During design, the ADOT balances queue lengths and traveler delay with lane occupancy. The ADOT uses traveler delay cost to choose the number of lanes that can be closed during construction. Also, through the use of QUEWZ, a work zone traffic operations computer model, the ADOT makes decisions regarding the need and type of congestion mitigation. These analyses and decisions are completed on a project-by-project basis rather than through a set policy. The ADOT will also consider the use of full closures, nighttime work, and alternative phasing to reduce congestion. Most of the urban projects completed by the ADOT involve nighttime construction. The ADOT may use contractor incentives/disincentives, select contractors through A+B bidding, and use lane rental to reduce project duration and congestion. The ADOT has completed a design-build project in which the ADOT’s objective for selecting the design-build delivery methods was to reduce the duration of the project. Because the project had only been recently completed, the interview respondent could comment on ADOT’s experience with design-build method.

The ADOT has been very proactive in using a work zone evaluation process to improve existing work zones and to modify future work zone traffic management plans. The ADOT uses a work zone checklist created to assist the project engineer with analyzing the traffic control plan and evaluating the work zone on a daily basis. The ADOT trains these inspectors in two eight-hour work zone class sessions. Each inspector must complete both sessions prior to the construction season. This checklist evaluates each work zone for possible hazards, concerns, and lessons learned. The results of these evaluations are then distributed to offices involved in the project delivery process to help them improve the management of congestion and safety in future projects.

² Respondent Paul Patane, Transportation Engineering Specialist, Arizona Department of Transportation, Phoenix, AZ

*Arkansas State Highway and Transportation Department*³

The Arkansas State Highway and Transportation Department (AHTD) considers congestion and safety impacts of work zones when it is programming construction and during design. During this period, the AHTD considers driver delay costs associated with closing routes and with traffic volumes, and adjusts phasing and scheduling to reduce congestion. The AHTD does not have a specific threshold for queuing what they consider unacceptable. Instead, the experience of their traffic control engineers is used to determine when a lane closure is likely to create an unacceptable condition. The AHTD has used QUEWZ and CORSIM, a traffic simulation package, to examine traffic operation in special cases.

The AHTD also considers construction schedule methods such as full closures, nighttime construction, and alternative project phasing and builds into its contracts incentives/disincentives to manage congestion and reducing project duration through A+B bidding for contractor selection, lane rental, and liquidated damages. Alternative contracting incentives/disincentives are selected based on the conditions of the project and on their ability to reduce driver delay. The AHTD believes that using contractor incentives/disincentives has expedited projects and resulted in safer work zones. One example of the AHTD's ability to reduce congestion involves a contractor who was selected using A+B bidding on an interstate reconstruction project in central Arkansas. One paving company was able to place 13,000 tons of asphalt in one day, as compared to a more typical day when a paving contractor might place 6,000 tons. The AHTD plans to continue developing more formalized processes to allow the AHTD to comply with the FHWA rule on work zone safety and mobility.

The AHTD adds extra enforcement in high-volume work zones, and the cost of the added enforcement is generally a pay item in the contract. The project engineer generally determines the need for enforcement and can increase enforcement through a change-order.

The AHTD had established a policy on lane closure merging. They enforce an early merge, and merging for a work zone is always to the left. If the left lane is the lane occupied by the work zone, then the traffic will merge left, and the through lane of traffic is brought back to the right lane in advance of the work zone. The AHTD believes that uniformity and strict enforcement of early merging to the left reduces confusion and improves traffic flow.

³ Respondent Steve Peeples, Staff Construction Engineer, Arkansas State Highway and Transportation Department, Little Rock, AR

The California Department of Transportation (Caltrans) initiates their work zone congestion mitigation plans for major projects prior to project implementation planning, and the congestion mitigation planning begins as part of pre-programming project scoping. Part of the project scoping for major projects is to initiate a Transportation Management Plan (TMP) for the mitigation of traffic congestion and safety impacts. One of the driving factors for early consideration of work zone impacts and plans is that mitigation can cost as much as ten percent of the total project cost and the budget implications of mitigation need to be taken into account prior to project programming.

As defined by Caltrans, “A TMP is a method for minimizing activity-related traffic delay and accidents by the effective application of traditional traffic handling practices and an innovative combination of public and motorist, bicyclist and pedestrian information, demand management, incident management, system management, construction strategies, alternate routes and other strategies” (44). As part of the TMP process, Caltrans has created managers at the district level to maintain the integrity of the TMP while confirming the compliance of each project in meeting the goal of the TMP process. A TMP is completed for each “capital” project, while minor projects receive a “blanket TMP” and high-impact projects require a major TMP. A high-impact project is generally distinguished by being multi-jurisdictional, multi-faceted, requiring a mix of mitigation strategies, and lasting over a long period. “Blanket TMPs” are covered by completing a checklist of work zone planning activities, while a “major TMP” requires that the TMP manager must consider a combination of strategies to mitigate congestion and safety impacts of the work zone. This process is very comprehensive and has become an example for other states. An average TMP will be multi-jurisdictional, comprised of an innovative mix of traffic operations, and is implemented over a longer period of time.

At the center of Caltrans’ traffic control policies is a set maximum allowable delay of thirty minutes in any work zone. Although there is an exception process in which the lane closure committee can review the projects and either allow or deny an exception, Caltrans uses thirty-minute standard on all of their projects when evaluating a project’s scheduling, phasing, and designing and when evaluating the need to work during off-peak hours. As a result, most urban projects are completed as night projects.

California law does not allow Caltrans to use design-build as a project delivery strategy to reduce project delivery times. Caltrans has developed a process that has some of the characteristics of design-build to help reduce project duration. Caltrans uses a project delivery method they call design sequencing. When the design is 30 to 60 percent complete, contactors are allowed to bid on the project from partially completed plans. The design process continues and the contractor is allowed to work on a segment of the project when the plans and right-of-way acquisitions are completed. Through design

⁴ Respondent Greg Berry, Construction Safety Coordinator, California Department of Transportation, Sacramento, CA.

sequencing, design and construction proceeds simultaneously, thus reducing the total project duration.

*Colorado Department of Transportation*⁵

The Colorado Department of Transportation (CDOT) has begun examining different policies for complying with the new federal highway rules on work zone safety and mobility. Due to an increase in collisions over the last year, the state has recently set a goal to reduce collisions in work zones. This goal does not include a specific reduction, rather a commitment to continue to improve work zone safety. Also, as part of the CDOT's pre-design planning, project designers and planners will have a project pre-program scoping meeting in which the CDOT will analyze the scheduling of projects to avoid potential conflicts and manage the flow of projects. This meeting will include the district and CDOT program managers who will analyze available data to determine the project delivery approach and plan project management. Part of this scoping meeting is to address contract requirements for project work scheduling (e.g., full-closures, nighttime and weekend work, and other scheduling issues). This has led the CDOT to begin work on a nighttime closure manual and to increase the number of projects that are completed at night. The CDOT does use nighttime work, as well as alternative phasing, to adjust the work schedule to reduce congestion impacts. Due to the nature of Colorado's routes, a parallel corridor is not always present for a detour or a diversion; therefore, reconstruction work must be completed while a roadway is under traffic. The pressures of reconstruction under traffic have led the CDOT to attempt a wide variety of contracting incentives/disincentives to reduce congestion within a work zone and reduce project duration.

The CDOT has also initiated a program to evaluate work zones during and after the completion of the work zone. The CDOT uses traffic field reviews where the resident engineer and the district safety engineer review each work zone to evaluate compliance with the traffic control plans and to observe work zone operations under traffic. The CDOT conducts this field review closely after phase changes. The team has a rating system of one through four, in which four is the best or safest work zone. These are compiled and used in a year-end evaluation of all projects. This information is then used when discussing alternative project delivery processes at the next year's project scoping meetings.

⁵ Respondent San Lee, Traffic Specifications and Standards Engineer, Colorado Department of Transportation, Denver, CO.

*Connecticut Department of Transportation*⁶

The Connecticut Department of Transportation (ConnDOT) completes an extensive long-range planning process for its metropolitan areas. The ConnDOT will use current traffic volumes to prioritize projects that should not be completed at the same time or phased differently to minimize congestion as part of their pre-programming system planning.

It is the goal of the ConnDOT to minimize the impact of each construction project. A key part of this goal is to reduce collisions caused by the construction zone. This reduction includes additional planning for possible detours and alternative routes or phasing to minimize congestion on the transportation network.

Once the project design has been finalized, the ConnDOT then begins extensive public awareness campaigns to publicize the upcoming construction. For projects completed in major metropolitan areas of Connecticut, the ConnDOT will conduct construction and close lanes during off-peak hours, while using public awareness campaigns to encourage drivers to use rail or other forms of public transportation. The department has observed a large success rate through the use of these campaigns.

The ConnDOT relies heavily on added work zone enforcement to improve safety throughout the work zone's life. The ConnDOT frequently pays to have officers working inside work zones on high volume roadways. The use of added enforcement is defined through a state work zone enforcement policy, which outlines an agreement with the state police and identifies the activities that officers are to perform while patrolling work zones. The primary activity for the first officer is to be present. This officer will not enforce the speed limit or write tickets, but rather simply stay at the beginning of the work zone with the warning lights on. The second officer is required to stay at the end of the construction zone where he/she will act as ticketing or enforcement officer. The ConnDOT uses project funds to fund additional enforcement activities, although not all projects receive multiple officers. The department has observed benefits of this type of enforcement activity, resulting in a permanent agreement with the state police.

*Illinois Department of Transportation*⁷

The Illinois Department of Transportation (IDOT) considers the impact of work zones as part of its pre-programming system planning. An example of this planning is in the coordination of corridor projects in the Chicago area. The IDOT will look at the construction of parallel corridors or project phasing and space projects so that they are not under construction at the same time. This program of long-range planning has increased mobility along project corridors, while also reducing safety concerns. Also, as part of the system planning, or even later in the project development process, the IDOT

⁶ Respondent Brian Castler, Manager, Construction Operations, Connecticut Department of Transportation, Newington, CT.

⁷ Respondent Priscilla Tobias, Policy Engineer, Bureau of Design and Environment, Illinois Department of Transportation, Springfield, IL.

begins to look for projects that can be combined into larger single projects, thus reducing the duration of the project and frequency of work zones in a single geographic region.

After considerable planning, the IDOT then begins the selection of a project delivery method. Through the use of current information and traffic modeling, the IDOT selects a project schedule and reconstruction work schedule that best fits the local area. To reduce congestion, the IDOT is scheduling more nighttime work to take advantage of the lower traffic volumes. This includes rural interstate projects, which in the past were not considered for this type of construction. The IDOT has also used incentives/disincentives such as lane rental and liquidated damages more extensively on interstate projects to reduce congestion. The IDOT plans to continue examining additional alternatives for future consideration.

Overall, the IDOT has focused on planning work zone scheduling, lane occupancy scheduling, and on observing traffic operations in and around its major metropolitan areas. It is the observation of the IDOT that this additional planning has led to improved work zone safety and reduced traveler delay throughout the state. These processes have also led the IDOT to change rural construction policies to better implement the lessons learned from each project.

Due to a large number of deadly crashes in work zones in 2004, the Illinois legislature created a stricter work zone enforcement program. The new Illinois program increases work zone speeding fines and progressively increases fines for repeat offenders. The legislation also created a video enforcement pilot program, and allows officers to covertly enforce speeds by dressing like construction workers. Also created was a wide-spread public awareness program with the help of IDOT, the State Patrol, and the Illinois Toll Authority. A portion of the fines collected are used to fund the program.

*Indiana Department of Transportation*⁸

The Indiana Department of Transportation (INDOT) has created a number of policies to address project congestion and safety, many of which begin at the preprogramming system planning stage. The primary policy used for planning work zone lane occupancy is an Interstate lane closure manual. The policy defines the maximum acceptable queue length for a work zone and traveler delay costs. Whether to permit a lane closure is based on historical traffic volumes. The manual identifies when and where it is acceptable to close one or more lanes. Specifically, the policy sets a maximum queue length of one mile or a maximum delay time of ten minutes.

As part of the project programming process, INDOT may examine the use of design-build as a project delivery method. During final design, the INDOT examines the use of different alternative project contracting methods, including incentives/disincentives, A+B

⁸ Respondent Carl Tuttle, Operations Field Engineer, Operations Support Division, Indiana Department of Transportation, Indianapolis, IN.

bidding for contractor selection, and lane rental. The decision to use contractor incentives/disincentives is based on user delay or delay cost. These activities are project specific, where the INDOT will use historical information and work zone traffic operations modeling software (QUEWZ) to predict user delays.

To help mitigate traffic impacts of work zones, the INDOT uses public awareness campaigns and demands management strategies such as carpooling or modified transit schedules in more urbanized areas to further reduce congestion. In areas where paratransit or transit solutions are not applicable, work zone projects rely solely on awareness campaigns to notify the public of work zone delays. Law enforcement is also used in the work zone. The INDOT uses state funds to finance off-duty state officers to work in construction zones. This account is funded through work zone-related ticketing and by additional fines of \$0.25 on each moving violation (regardless of where such a violation occurs). The pervious year's ticket revenues generally set the budget for the current year's enforcement program. The primary objective of officers assigned to work zones is to write citations in and near the work zone.

Iowa Department of Transportation⁹

With the exception of a few large urban freeway reconstruction projects, the Iowa Department of Transportation (Iowa DOT) generally begins considering work zone traffic operations and traffic management in the project design phase. The Iowa DOT uses incentives/disincentives, liquidated damages, and lane rental on a regular basis to reduce the duration of projects and work zone lane occupancy. However, the Iowa DOT is currently considering an A+B bidding contractor selection process to further reduce the length of construction and, therefore, reduce the duration of work zone-induced disruptions. Many of the Iowa DOT's contracts are relatively small and limit the types of alternative contracting methods that can be used. However, the state is looking at alternative project sizing policies to increase the opportunity to schedule and phase larger jobs to minimize work zone-induced traffic disruption.

The Iowa DOT has changed their pavement design standard from a 20-year pavement life to a 40-year pavement life to mitigate future congestions that may occur due to reconstruction activities. Through this change, the Iowa DOT has started to use full-depth shoulders and other longer lasting designs that will help reduce future work zone-related disruptions. For example, the Iowa DOT is looking at the reconstruction of Interstate 80 in eastern Iowa and trying to decide how they can schedule and phase the reconstruction of the four-lane corridor to minimize the congestion while constructing a new six-lane facility. The Iowa DOT is currently investigating the schedule of constructing wider bridges and full-depth shoulders along I-80 to relieve congestion during the future reconstruction of the corridor.

The Iowa DOT also collects data through a dense network of Automatic Traffic Recorders (ATRs), and these data, along with traffic operations modeling, are used to

⁹ Respondent Dan Sprengeler, Traffic Control Engineer, Iowa Department of Transportation, Ames, IA.

plan traffic management strategies to mitigate work zone induced congestions and safety issues. Although completed during the design phase of the project, this information is valuable to the project engineers who can adjust traffic control plans to improve safety and reduce congestion. Another information resource that is available to work zone traffic management planners is the Iowa DOT crash database. The Iowa DOT has employed the use crash location software tools and reporting methods to create an easily documented crash location. The state plans to continue its advances in this area, but it is currently able to use the information to better evaluate year-end project reviews through work zone safety performance. The Iowa DOT is currently using fatal crash frequency as a preliminary performance measure for safety.

The Iowa DOT uses Extra Enforcement in the work zone and uses both the Iowa Highway Patrol and local enforcement officers on DOT projects. Extra enforcement is believed to provide safety benefits and the Iowa DOT has required extra enforcement on all major projects since 1996. The Iowa DOT also requires that all pavement repair and patching project on the freeway in urban areas is done at night.

*Kansas Department of Transportation*¹⁰

The Kansas Department of Transportation (KDOT) is another agency that typically begins considering work zone impacts during the design phase of project development. Initially, the KDOT attempts to analyze the project and determine a preferred contracting method, delivery method, and project phasing to mitigate congestion within the work zone. In order to complete these tasks, the KDOT is implementing a policy to guide the selection of alternative work scheduling. This policy will include recommendations covering full road closures, night work, and alternative phasing. In addition to these methods, the KDOT also uses contractor incentives/disincentive methods, such as lane rental and interim liquidated damages, and selects contractors based on A+B bidding. Once project scheduling, work scheduling, and phasing have been determined, the KDOT uses a work zone traffic operations computer model (QUEWZ) to determine the maximum queue length for a project. The KDOT will use the computer model to predict the minimum number of lanes that must remain open before congestion becomes unmanageable. The KDOT then uses this information to begin a public awareness campaign to reduce traffic volumes along the corridor. The KDOT has used traffic demand strategies, such as public awareness campaigns in urban areas, and has made these practices a standard for construction projects. The KDOT has observed that the public seems to react favorably to proactive measures.

¹⁰ Respondent Kurt Miyamoto, Traffic Control Engineer, Kansas Department of Transportation, Topeka, KS.

*Kentucky Transportation Cabinet*¹¹

The Kentucky Transportation Cabinet (KYTC) does not consider work zone impacts until the project development is being programmed in the STIP. The KYTC focuses on congestion management strategies that reduce queue length in work zones. The KYTC has completed some research to determine relationships between average queue lengths based on average daily traffic and the number of open lanes. The results of KYTC work zone traffic operations research is used in conjunction with a work zone traffic operations computer model (Quick Zone) to determine what lane occupancy will be allowed and what traffic control is required to maintain a minimum queue. These types of analysis are completed early as part of the preliminary design.

The KYTC also uses a number of work scheduling and phasing methods to reduce congestion impacts of construction. The KYTC used full road closures and alternate phasing on urban freeway projects, but most of the KYTC's urban freeway reconstruction work is completed as night construction or as weekend construction. This usually depends on the type of area (rural/urban). However, more and more of the KYTC's projects tend to use alternatives to conventional daytime construction schedules. The KYTC uses the design stage to determine how projects can be better phased and scheduled to minimize the overall delay within the region. During detailed design, the KYTC examines the contracting methods for the project. The KYTC commonly uses contract incentives/disincentives to get projects completed more rapidly, including A+B bidding for contractor selection, lane rental, and liquidated damages. The KYTC recently completed a design-build project in which the KYTC was able to reduce the total construction time. KYTC has conducted a few design-build projects and all were considered to be a success by reducing the duration of the reconstruction project.

Once large urban reconstruction projects are scheduled, the KYTC initiates discussions with the largest employers in the impacted area, which sometimes results in modifications of the construction schedule, the hours of the day, or days of the week when highway capacity is reduced for highway reconstruction. The KYTC also uses mitigation strategies, such as encouraging car pooling and the use of public transportation when it is appropriate. The KYTC's observation has been that these strategies do not reduce the congestion enough to be used on every project. However, the KYTC does tend to use public relation campaigns on a more regular basis with reasonable success.

Once the work zone is active, a group of engineers drives through a sample of project to evaluate traffic operations, adherence to the traffic control plan, and general safety performance. Any information obtained during these visual inspections is discussed as part of a yearly construction evaluation. These evaluations include project design, traffic control, safety performance, and future adjustments to improve the work zones. Although each project is not evaluated individually, specific notes from each project are used to discuss future changes that may be needed. Most often, the resources are not readily

¹¹ Respondent Dexter Newman, Division of Construction, Kentucky Transportation Cabinet, Frankfort, KY.

available to evaluate each project. On average, the KYTC will evaluate at least 25 projects per year. The KYTC has used this process to exchange ideas and improve the KYTC's plans as a whole. The KYTC feels that the process, although informal, has been very successful.

*Louisiana Department of Transportation and Development*¹²

The Louisiana Department of Transportation and Development (LDOTD) believes that they are in the initial stages of creating a formal program to address planning for work zone congestion and safety. The LDOTD has set a goal to reduce crash rates by ten percent in work zones each year, but has not yet established goals for congestion as part of their work zone-related policy. As part of developing work zone management strategy, the LDOTD completes a sequence analysis in which the LDOTD analyzes the sequencing of projects within a specific region to assist in the mitigation of congestion.

The LDOTD has set guidelines for maximum allowable queue length. If there is more than a thirty-minute delay, the LDOTD will open additional lanes to accommodate the congestion. Due to complaints from the public and members of the legislature, all construction in metropolitan areas is completed as night work. The LDOTD has considered other alternatives, but uses night work on a regular basis.

The LDOTD has attempted a number of different contractor incentive/disincentive methods and is trying design-build projects. The LDOTD is experimenting with the use of design-build on large projects in the hope that it will be more cost effective, but has been unable to evaluate the process. The LDOTD also uses A+B and A+B+C bidding for contractor selection. The C portion represents state's estimates of lifecycle cost, including maintenance and user delays, based on a 30-year analysis period. The C portion tends to level the playing field for asphalt and Portland cement concrete paving alternatives (45). The LDOTD also uses lane rental fees. The LDOTD plans to continue experimenting with strategies to reduce the safety and mobility impacts of work zones until a clear policy is created to define the best method for each project.

The most unique aspect of the LDOTD management strategies for work zones is the LDOTD work zone added enforcement strategies. The LDOTD has outlined specific duties and evaluation processes for their work zone enforcement activities. The LDOTD policy specifies three different activities for added law enforcement patrolling of work zone projects. The LDOTD specification for added law enforcement includes police presence, police enforcement, and a combination of both activities.

To evaluate the performance of a work zone, the LDOTD has created a position where the LDOTD employee travels to each work zone within Louisiana and evaluates the project's performance. A checklist has been created where the evaluator will document the performance of the work zone and identify changes that need to be made to improve traffic operations or safety. The completed checklist is given to the project engineer for evaluation. The LDOTD attempts to evaluate each work zone after a phase change. The

¹² Respondent Barry Lacy, Construction Division, Louisiana Department of Transportation and Development, Baton Rouge, LA.

LDOTD has discussed completing a more formal postmortem analysis of each project, but has no specific plans at this point in time. The LDOTD feels that they are beginning to document more work toward a formal evaluation process.

*Maryland Department of Transportation*¹³

The Maryland Department of Transportation (MDOT) considers congestion and safety impacts in preprogram system plans. Initially, the MDOT begins by considering multiple projects within a region as part of their system planning and attempt to space in time projects impacting the same region to reduce congestion. This consideration is informal, but the planners and designers attempt to pinpoint problematic areas and create a schedule that will minimize congestion. Due to an increase in work zone fatalities over the past year, the MDOT is creating long-range goals and plans for safety in their work zones. The MDOT plans to increase the number of projects that are analyzed as part of its preprogram system planning to continue to improve safety and congestion.

During design, MDOT tries to incorporate aggressive construction schedules and proactively use contractor incentives/disincentives to reduce congestion impacts within a work zone. Currently, the MDOT completes almost 85 percent of its reconstruction work at night. Projects not completed at night are in rural areas or where night work is not applicable to the situation.

The MDOT uses A+B bidding to select contractors and uses incentives/disincentives such as lane rental. Recently, MDOT delivered a project using design-build to reduce the duration of a project. The MDOT tends to use A+B bidding for contractor selection more than the other contract incentives/disincentives due to the success they have observed with the method.

Shortly before work zones are open, MDOT starts a campaign to inform motorists so they know what to expect and will look for alternative routes. The MDOT has started giving free metro bus passes to local residents to encourage them to use transit during construction. The MDOT gave out hundreds of free bus passes to commuters during last year's construction season. The MDOT felt that although the program was costly, it was successful in increasing the use of the bus system during construction.

An additional activity that is completed while the work zone is in operation is the use of enforcement. The MDOT typically uses one officer on each work zone project. The officer stays at the end of the queue with his or her warning lights on. The agreement between the department and the police is that the officer is on the site to provide presence rather than write tickets. In some recent projects, MDOT has used three officers: one serves as the presence officer, and the additional two officers serve as the enforcing or ticket-writing officers. MDOT hopes to expand this program to all major reconstruction projects over the next five years.

¹³ Respondent Terri Tabesh, Traffic Policy and Management Team, State Highway Administration, Maryland Department of Transportation, Hanover, MD.

The MDOT's most notable program is its training program for field traffic control managers and their resulting work zone management responsibilities. The process includes the monitoring of the work zone by a trained field inspector. The MDOT will not allow a queue longer than ½ mile or eight minutes of delay. If these thresholds are exceeded, the traffic control manager is responsible for adjusting the work zone to allow the queue to subside below eight minutes. This traffic control manager is trained to be the main instrument in improving safety and congestion. Traffic control managers undergo an additional training course each year that covers work zone design. This training provides the traffic control managers with useful tools in reducing work zone congestion and improved safety. The manager is a permanent member of the construction site until construction is completed. He/she is in charge of continually monitoring the work zone area. MDOT also uses a roaming crew that randomly checks construction zones throughout the construction season. Typically, the group includes two or four engineers who will evaluate each project for safety and consistency. The MDOT has put a great deal of effort into developing strong traffic control manager training programs. The MDOT plans to continue its training, expand the number of trained traffic control managers, and include contractors and enforcement officers.

*Massachusetts Highway Department*¹⁴

The Massachusetts Highway Department (MHD) relies on the “twelve-minute rule” to set its plans for dealing with work zone congestion. The rule was created based on experience and it is a maximum allowable driver delay due to a work zone before safety is jeopardized and traveler delay becomes intolerable. The MHD will suspend work within a work zone until the problem is eliminated if the threshold is met. This policy drives most of the decisions made by the MHD when work zone safety and mobility are taken into account when programming projects.

The MHD will use historical volume information and a work zone traffic operations computer modeling (Quick Zone) to predict delays at a location. Through this process, the MHD will plan and schedule lane closures to meet the twelve-minute rule. The MHD will set the schedule for work zone-related reductions of roadway capacity defining when and during what periods the contractor will be able to occupy lanes. Plans may result in nighttime work, work during off-peak hours, or may include a full road closure. The decision is based on which alternative method can best accommodate the traffic throughout the region.

Other strategies used to meet the twelve-minute rule include contractor incentives/disincentives. The MHD has used lane rental and liquidated damages to reduce lane occupancy. The MHD has also experimented with design-build to deliver a project in a shorter period, which reduces the project's duration.

¹⁴ Respondent Michael McGrath, Deputy Chief Engineer Construction, Massachusetts Highway Department, Boston, MA.

*Michigan Department of Transportation*¹⁵

The Michigan Department of Transportation (MDOT) employs contractor incentives/disincentives and alternative project delivery methods to reduce exposure to work zone congestion and reduced safety. The MDOT does not set a maximum or minimum delay or queue length threshold, but instead all decisions are project specific. Once a project is far enough into the design process to have design geometric layouts completed, the MDOT designers select traffic control strategies. Project scheduling and work scheduling alternatives include full lane closers, nighttime work, and alternative project phasing. Designers at the MDOT use a traffic operations modeling software developed by the University of Michigan that operates much like QUEZS to estimate work zone queuing and delay. This process typically leads to the selection of the most appropriate contracting incentive or disincentive methodology. Typically, the MDOT uses A+B bidding for contractor selection and lane/ramp rental. The MDOT has attempted to reduce the duration of projects through design-build, though their satisfaction with it has been mixed.

An additional strategy that drives a number of decisions made by the MDOT is the “mixes-of-fixes” program. Depending on the projects, the MDOT examines a reconstruction project and determines a strategy that will minimize long-term life cycle costs, including user costs due to work zone congestion. This may involve looking at longer life designs or examining reconstruction when a maintenance project may fix a problem within five to seven years. The possibility of reconstruction is investigated so that the same section of roadway does not have to experience a work zone twice.

The MDOT has also created a program that provides active monitoring of a work zone. On specific projects, the MDOT will hire a work site traffic supervisor or consultant who will monitor the work zone and make changes, if needed, throughout the life of the work zone. This is a pay item on each project, and the MDOT has documented specific tasks and requirements. These consultants or supervisors must complete a four-day course and must have over 4,000 hours of work zone-related experience to take the course. The American Traffic Safety Service Association’s (ATSSA) trained instructors usually instruct these courses. Supervisors are typically only used on larger projects, such as interstate reconstructions. A training course is generally taught to applicants twelve times per year. These supervisors provide constant monitoring and improved safety.

*Minnesota Department of Transportation*¹⁶

The Minnesota Department of Transportation (Mn/DOT) does not start considering the impacts of work zone until the project is in its design phase. The planning, scheduling, and designing of work zones in the Twin Cities metropolitan area are driven by the Mn/DOT’s lane closure policy. The lane closure manual specifies the time of day, day of

¹⁵ Respondent Jeff Grossklaus, Highway Development, Michigan Department of Transportation, Lansing, MI.

¹⁶ Respondent Jon Jackels, Pavement Marking and Work Zone Engineer, Minnesota Department of Transportation, St.Paul, MN.

the week, and number of lanes of major roadway in the metropolitan area that can be closed. A closure is allowed so long as it does not exceed maximum levels of delay and queuing. The manual was established through the Mn/DOT's Traffic Management Center and applies to both construction and maintenance activities. The document is in a spreadsheet format that allows for easy application by Mn/DOT designers and planners. Using the standards for lane closures outlined in the manual, designers will develop work zone schedules, project phasing, and traffic management plans which meet the minimum requirements of the manual. To further reduce the traffic impacts of work zones, the Mn/DOT uses contractor incentives/disincentives. The Mn/DOT has also successfully used design-build project delivery to shorten the time to deliver a project, thus reducing the safety and mobility impacts of the work zone.

*Missouri Department of Transportation*¹⁷

At the Missouri Department of Transportation (MoDOT), for each major project a team of construction engineers, design engineers, and planners develops a Traffic Management Plan. These major projects are mostly in the Kansas City and St. Louis Metropolitan areas. Through the creation of the project Traffic Management Plan, the MoDOT determines the best course of action to reduce congestion and improve safety. The MoDOT does not set a maximum queue length, but instead sets a goal for minimizing the effects of congestion. Throughout this process, the MoDOT considers the upcoming construction projects for the year and attempts to plan for multiple projects at the same time to minimize the disruption of several separate projects, while looking at parallel corridors to relieve congestion. While developing the Traffic Management Plan, the MoDOT team considers full road closures, night construction, and alternative project phasing. The Traffic Management Plan also drives the selection of contracting options used by the MoDOT. The MoDOT uses A+B and A+B+C bidding for contractor selection and lane rental on most MoDOT projects. The core team of engineers discusses the possible benefits of each alternative in terms of traveler delay costs. The best activity is used in the final Traffic Management Plan.

Once a plan has been determined and the proper course of action is set, the MoDOT uses a consulting firm to create a traffic operations computer model of the preliminary plan. This computer model allows the MoDOT to modify their plan and gives a basis for their public awareness campaigns. A public awareness campaign may be initiated as early as three years prior to the construction of a project. The awareness campaign generally includes discussions with trucking companies, an analysis of commuting traffic patterns, or the purchase of ride share spaces near urban areas. One year prior to the project, the awareness campaign will begin relaying information to the public about the upcoming project. This will include information about alternative routes the public will have once construction begins. The program has been well received in the urbanized areas. Through this combination of planning and public information, the MoDOT feels that they are able to reduce much of the traveler delay while increasing safety in the work zones.

¹⁷ Respondent Dan Bruno, Statewide Work Zone Coordinator, Missouri Department of Transportation, Jefferson City, MO.

*Nebraska Department of Roads*¹⁸

The Nebraska Department of Roads (NDOR) considers work zone traffic management during the final design phase of project development. Due to the rural nature of a majority of roads, long-term planning is not always required. However, the NDOR begins their planning process by determining the proper project scheduling or phasing to minimize work zone impacts on traffic. The NDOR schedules full closures or nighttime construction to mitigate delays to commuting traffic in the Omaha/Lincoln area. Once the phasing and schedule are developed, the NDOR uses contracting strategies to further encourage the contractor to reduce the duration of the project or the duration of lane occupancy. The NDOR commonly uses A+B bidding for contractor selection and contractor incentives/disincentives. Although decisions regarding contracting methods are determined as part of the design phase, they assist the NDOR in reducing congestion in work zones throughout the state. Also, as part of the design phase, the NDOR considers the design life of the project. Specifically, the NDOR will consider full-depth shoulders and longer lasting concretes to extend the life of a pavement. The NDOR also uses maintenance activities as a short-term solution until a route can be completely reconstructed.

Once the project is underway, the NDOR uses a team of safety engineers to evaluate the operation and safety of work zones. These engineers evaluate half of the construction work zones each year. In most cases, the project manager will lead the evaluation team when it is evaluating his/her project's work zone. In other instances, the district engineer may lead the evaluation team. This team of engineers will rate each district's ability to maintain a work zone and then provide the district with a measurable standard to improve work zone management strategies on future projects.

*New Hampshire Department of Transportation*¹⁹

The New Hampshire Department of Transportation (NHDOT) considers a project's work zone-induced congestion and the impacts on safety during the design phase. In general, one lane can handle 1,500 vehicles per hour, and any additional vehicles create congestion. Using 1,500 vehicles per hour as a rule-of-thumb provides the NHDOT with a threshold for targeting work zone locations with higher hourly volumes. In cases where the threshold is exceeded, the NHDOT considers alternative phasing or schedules to mitigate the effects of congestion. The NHDOT considers night work, full closure, and combining phases as part of the project design. Once a schedule and phasing have been selected, the NHDOT selects contracting methods to encourage the contractor to further reduce the impacts of the work zone. The NHDOT has used A+B bidding for contractor selection and lane rental and is satisfied with these methods.

Once a work zone is operating, the NHDOT uses police to monitor traffic on all urban interstate projects and on as many additional projects as the budget allows. The NHDOT

¹⁸ Respondent Wallace Heyen, Signal and Marking Engineer, Nebraska Department of Roads, Lincoln, NE.

¹⁹ Respondent Ted Kitsis, Bureau of Construction, New Hampshire Department of Transportation, Concord, NH.

requires the officers to stay closer to the beginning of the work zone and to minimize any ticketing or enforcement activities. It is the NHDOT's observation that when officers begin enforcing the law, the officers tends to spend little time in the work zone. The officer's primary responsibility is to be a part of the work zone's traffic control. The enforcement or presence is paid directly to the state or local police by the NHDOT. The state police or local police are reimbursed directly. The locations are selected by the roadway functional classification where the routes in larger cities, routes with higher volumes, or routes with higher speeds will receive the majority of the funding for enforcement.

*New Jersey Department of Transportation*²⁰

The New Jersey Department of Transportation (NJDOT), as part of long-range systems plans, uses a traffic operations group to analyze construction projects so that corridors in the same regions are not affected at the same time. The NJDOT considers known county and municipal projects as part of this process. The NJDOT has observed that the public prefers construction to be completed as soon as possible, no matter what the effects of the work zone may be. The State of New Jersey, including NJDOT, is devoting resources to a program called "Fix-it-First." Fix-it-First focuses on identifying key infrastructure assets needing reconstruction through coordinated planning of several state agencies (46). Repairing these assets should improve the competitiveness of the region and enhance the quality of life. As part of the Fix-it-First program, the NJDOT has been asked to reconstruct/improve key transportation assets, which have placed pressure on the department to deliver and complete projects in urban areas.

As a result of the Fix-it-First program, the NJDOT is receiving pressure to more quickly deliver these time-sensitive projects. To accomplish this, the NJDOT has delivered projects using the design-build method. To reduce the impact of work zone-related congestion, the NJDOT uses night closures and full closures. The NJDOT has used contracting methods to expedite project delivery, including A+B bidding for contractor selection and lane rental.

During reconstruction, the NJDOT attempts to maintain all lanes through the work zone whenever possible. When this strategy is not possible, the NJDOT uses benefit-cost analysis based on changes in user delay and increased costs of construction to avoid occupying lanes or to create diversion routes when developing the traffic control plan. This is completed through a manual method developed by the NJDOT.

The NJDOT also uses demand reduction strategies to reduce congestion. The NJDOT initiates this process soon after an environmental document is completed to broaden the scope of the strategy. Most of the NJDOT's strategies are completed through the state transit authority. Through public awareness campaigns, the NJDOT targets drivers throughout the corridor and sponsors activities to shift the public to public transit systems. The NJDOT attempts to discuss the project with many groups and the public

²⁰ Respondent Patricia Ott, Traffic and Safety Engineer, New Jersey Department of Transportation, Trenton, NJ.

prior to the construction to provide them with a solid understanding of what to expect and with opportunities to plan for alternatives to minimize the delays they might experience.

*New York State Department of Transportation*²¹

The New York State Department of Transportation (NYSDOT) considers congestion and safety primary goals that must be addressed at the earliest planning stages. Many strategies relate to actions and policy goals set by the NYSDOT to relieve work zone-caused congestion and safety issues. Specifically, the NYSDOT attempts to schedule projects so that multiple projects do not impact the highway network in the same region at the same time. The NYSDOT attempts to maintain Level of Service E or better in urban areas. This process has been institutionalized in the NYSDOT's planning and design process. The NYSDOT completes a process to analyze the sequence or phasing of projects to minimize the work zone safety and congestion impacts. The intensity of the planning effort varies with the needs of each corridor. The NYSDOT does not set statewide standards; rather, each project is evaluated based on specific traffic volumes and the number of available lanes.

On high-volume highways, the NYSDOT has set restrictions on when lanes can be closed. The NYSDOT relies heavily on night construction in their most urbanized areas. If the NYSODT cannot meet the project goal of Level of Service E for traffic flow with a traditional schedule, the NYSDOT considers alternative schedules, such as nighttime work or full road closures.

The NYSDOT attempts to group work zone projects as part of their preprogramming system planning. During the last year's construction season, the NYSDOT grouped a number of smaller projects and closed a four-lane, high-volume expressway for two weeks and detoured traffic. Within the two weeks, the entire project was completed and traffic was restored. The public was very accepting of the process and was pleased with the shortened construction. The NYSDOT tends to rely on better planning and scheduling of projects to minimize congestion and delays. This starts with network-level project scoping to avoid conflicting projects during the same time period and with project-level planning to identify opportunities to avoid conflicts. Then, at the design phase, it involves investigating alternatives for phasing projects and scheduling work so that congestion is minimized.

*North Carolina Department of Transportation*²²

The North Carolina Department of Transportation (NCDOT) uses their traffic control plans created during design to address work zone congestion and safety concerns. NCDOT has experimented with delivering projects using design-build methods to shorten the duration of projects, and it looks for opportunities to combine several projects into one to minimize work zone-related impacts. Generally, the NCDOT relies on the careful

²¹ Respondent Charles Riedel, Traffic Engineering and Highway Safety, New York State Department of Transportation, Albany, NY.

²² Respondent Stu Bourne, Division of Highways, North Carolina Department of Transportation, Raleigh, NC.

development of traffic control plans to minimize the impacts of work zone-induced congestions and crashes. As a standard, for each traffic control plan, the NCDOT uses a maximum queue length of two miles to govern when and where it can allow lane closures and restrictions. After 50 percent of the traffic control plan is completed, the NCDOT discusses the project with designers and planners to determine the contracting method that best reduces congestion and improves safety.

The contracting methods that the NCDOT is using has changed due to recent modifications to the NCDOT's risk management policy, which allows them to use more detours and full lane closures to reduce exposure to legal liability. The NCDOT determines possible risks of construction projects and determines the appropriate activities to minimize the risks.

Once the traffic control plan is finalized, a contracting method is selected to again reduce congestion and improve safety. The NCDOT typically decides within twenty-four months of construction which methods the project will use. The NCDOT has used A+B bidding for contractor selection, lane rental, and other incentives/disincentives to reduce lane occupancy and work zone-related restriction. The NCDOT determines if other mitigation efforts are needed on a case-by-case basis.

Ohio Department of Transportation^{23,24}

The Ohio Department of Transportation (ODOT) routinely combines projects on routes or completes projects in different years to minimize congestion in high-volume corridors. The ODOT does not have set goals for safety or congestion; rather, it attempts to minimize the safety and congestion impacts of work zones on a project-by-project basis. Congestion/safety issues of work zones are considered during the project development stages of the project development cycle. The ODOT considers congestion goals to be a function of the number of lanes available to provide sufficient capacity in the work zone. Safety goals concerning work zone crashes are established at the beginning of a project's construction. Historical crash frequency in the same section before the work zone is used as a baseline crash frequency. It is an ODOT's objective to not increase the number of crashes during work zone operation when compared to the baseline (without the work zone). The ODOT follows a six-step process in which they analyze when a route can be closed and what queue lengths are acceptable. The six-step process is presented below.

1. Select segment of freeway to be analyzed.
2. Determine segment characteristics—driver type (urban/rural), terrain type, and number of available lanes.
3. Determine a traffic volume calculation method to be used from the list presented below, ranked in order of priority:
 - Method A—Automatic Traffic Recorder (ATR)—Actual Hourly Counts for Section: the ATR is located in the segment

²³ Respondent Dave Holstein, Office of Engineering, Ohio Department of Transportation, Columbus, OH.

²⁴ The Ohio Department of Transportation is also the subject of a more thorough discussion in the next chapter.

- Method B—ATR—Hourly percentages to distribute the traffic throughout the day: the ATR is upstream or downstream of the segment on the same route
 - Method C—Hourly percentage to distribute the traffic throughout the day from a closed ATR applied to Average Annual Daily Traffic (AADT) estimates: the ATR is on a different route but has similar traffic distributions
 - Method D—AADT using statewide distribution
4. Select work zone lane capacity from a pre-calculated table based on the truck percentage and terrain for the freeway segment. The table identifies capacity of a work zone with a defined number of lanes left open given the percentage of trucks in the traffic stream and the terrain.
 5. Determine hourly closure volumes—if volumes exceed work zone capacity, no closure is permitted.
 6. Define district comments (i.e., if there is a Bengal's game, no road closure will be allowed for two hours before and two hours after the game).

The ODOT commonly schedules work at nighttime on high-volume routes and uses other alternative work schedules to reduce congestion. The ODOT has created a flow chart outlining the steps to be followed when conducting alternative analysis for work traffic control alternatives.

The ODOT routinely utilizes incentives/disincentives to reduce the work zone impact imposed on traffic. The use of incentive/disincentive contracting methods has become the norm. The ODOT is expanding the use of innovative contracting. Through their planning process they are identifying projects or parts of projects where innovative contracting has the most potential for reducing the impacts of work zones.

The ODOT is very proactive in its planning activities and has one of the most proactive programs for identifying deficiencies, for identifying strategies for relieving deficiencies, and for implementing planned strategies.

*Oklahoma Department of Transportation*²⁵

The Oklahoma Department of Transportation (ODOT) uses the slogan “get in, get out, and stay out” as its policy on work zone lane closures. This policy drives a great deal of the ODOT’s decisions in their early project planning processes. To reduce the frequency between reconstruction projects, the ODOT has adopted a pavement design life of 30 years. Interstates and interstate design standard routes are completed with full depth shoulders, and bridges are widened during reconstruction to keep shoulder lanes open when crossing the bridge and thereby reducing congestion on future reconstruction projects. Most of the ODOT’s new projects include longer lasting materials to extend pavement life. These design standards affect the planning decisions made on each project.

²⁵ Respondent Red Miller, Assistant Division Engineer, Oklahoma Department of Transportation, Oklahoma City, OK.

The ODOT bases the decision to use longer lasting design on reduced future user delay. When developing the traffic control plan during design, the ODOT considers night construction, full closures, and other scheduling alternatives to determine the lowest cost to the driver. This is also true when the ODOT is deciding on a contracting method. Typically, the ODOT will select from A+B or A+B+C bidding for contractor selection, lane rental, and other incentives/disincentives for their construction projects. The C component in A+B+C bidding consists of a maximum time limitation on project milestones. The ODOT has found that these methods create incentives for the contractor to find innovative ways of reducing lane occupancy.

After the final design for the project has been completed, the ODOT focuses on the previous experience of the project engineer to develop plans for congestion mitigation. Although modeling is used early in the process, project engineers rely on personal knowledge to define congestion mitigation strategies for the project.

In each district, a resident engineer is in charge of the district's annual work zone review. The review is a report that takes information gained from visits to each work zone and creates a lessons learned discussion to improve future projects. This report is submitted to the division traffic engineer for final review.

After recent fatalities that occurred in flagging operations, the ODOT has used the Wizard CB Alert System with tremendous success. The wizard warns approaching drivers (predominately truck drivers) through a warning over the CB radio (for more information see the source (47)).

Oregon Department of Transportation^{26,27}

The Oregon Department of Transportation (ODOT) starts planning for work zones very early as part of its long-range statewide network development and policy plan. The ODOT has recently created a position for a Statewide Mobility Manager to analyze delays and impacts on project corridors and statewide levels due to the large number of construction work zones in the next eight to ten years in Oregon. The central focus of the new Mobility Program is to minimize the delay to the general public and commercial vehicles on the major Interstate and on non-freeway corridors crossing the state. Oregon outlines their goals to reduce congestion and delay in their 1999 long-range Oregon Highway Plan. The long-range plan documents policies that emphasize the efficient management of the highway system to increase safety and to extend highway capacity, partnerships with other agencies and local governments, and the use of new techniques to improve road safety and capacity. There are limited specific references to work zone delay in the long-range transportation plan.

²⁶ Respondent Scott McCanna, Traffic Control Plan Engineer, Oregon Department of Transportation, Salem, OR.

²⁷ The Oregon Department of Transportation is also the subject of a more thorough discussion in the next chapter.

From a safety standpoint, the ODOT's goal is to maintain the number of fatalities in work zones at or below ten per year through the year 2010. ODOT has outlined a number of performance measures and concerns in a document entitled "2003 Work Zone Safety Performance Plan." The ODOT has created a safety action plan that includes work zone crashes as part of the overall safety plan within the ODOT.

The ODOT uses a very simple spreadsheet based on the *Highway Capacity Manual* to determine the required number of open lanes needed for each work zone. As a part of the ODOT's Transportation Improvement Program (TIP), Traffic Demand Management (TDM) strategies are discussed and proposed at the project planning and preliminary project design stages of project development. Corridor Studies, Interchange Refinement Plans, and Strategic Development plans recommend the inclusion of TDM strategies to optimize the use of the current infrastructure.

Each project during the preliminary engineering phase is subjected to a work zone traffic analysis that helps determine lane closure restrictions and hours of operation. This information is used to develop the construction staging plan and schedule. At the ODOT, the key task of the Traffic Control Plans Designer is to use the work zone traffic analysis data combined with the construction schedule, type of work, terrain, season, available alternative routes, and economic-political influences to determine the best course of action. The ODOT states that economics definitely come into play in terms of perceived user delay costs or impacts to industries, although very little formal reporting is developed. The most common comparison is the scenario of the short-term full closure versus the lengthy, staged construction under limited lane occupancy. Over the last couple of years, the ODOT has begun delivering projects using design-build project delivery. They have also used A+B, A+C, and A+B+C bidding to select contractors under conventional design-bid-build project delivery. The ODOT has observed mixed results with these types of contracts. The ODOT observed that while they tend to save some time in the overall duration of the project, the project seems to be a bit more expensive to both develop and construct. Another component the ODOT is more frequently including in their highway construction projects is the use of the incentive/disincentive clauses for accelerated construction. These clauses have proven very advantageous in getting critical work completed in a shorter period of time. While this method is understandingly more expensive, it also carries the disincentive component which acts like a fine assessed to the contractor should they miss a particular deadline. So far, incentives paid out to contractors for these types of contracts have outweighed penalties paid in.

*Pennsylvania Department of Transportation*²⁸

The Pennsylvania Department of Transportation (PennDOT) has been making more proactive use of work zone traffic operations modeling (Quick zone) in measuring the impact of work zones. The results of Quick zone analysis drive the decisions regarding how much and what types of traffic mitigation strategies are needed, restrictions on work

²⁸ Respondent Arthur Breneman, Traffic Engineer and Operations, Pennsylvania Department of Transportation, Harrisburg, PA.

zone lane occupancy, and types of contract incentives (48). The PennDOT has also been making use of real-time monitoring of traffic through traffic management center surveillance systems and through portable trailer cameras to actively monitor the work zone and congestion. Any problems observed through the intelligent technology systems by the management centers are directed to the project inspector for evaluation. This real time process allows the PennDOT to quickly adjust the traffic control plan to improve safety and congestion.

In addition to ITS technology, the PennDOT works with law enforcement to monitor the relative safety of work zones. The Pennsylvania State Police submits copies of work zone crash reports to the district office on a weekly basis. Staff in the district office analyze any severe or reoccurring accidents within the week. The crash reports are also given to the project inspector for further investigation and, based on these reports, the project engineer can modify the traffic control plan. The goal is to achieve an almost real time adjustment to the traffic control to improve congestion and safety concerns.

The PennDOT uses additional enforcement on a number of projects each year. They pay for enforcement with project funds that are typically set in the planning phase of the project. The officers are told through an agreement to float with the queue or to perform a presence patrolling. This activity was selected because, when officers are writing tickets, they are not always visible to the public.

The PennDOT also uses a collision database to analyze annual work zone crash data. The PennDOT then uses this information to determine safety benefits of different traffic control plans. This information is then given to designers and planners for consideration in future construction projects.

*South Dakota Department of Transportation*²⁹

The South Dakota Department of Transportation (SDDOT) initially explained the rural nature of many of the state's projects and stated that many activities to reduce congestion are not always needed. However, after completion of the survey, it was observed that the SDDOT does apply proactive strategies to relieve congestion on their construction projects in urban areas or along heavily trafficked intercity routes. South Dakota has experimented with design-build method to shorten the duration of a major urban interstate reconstruction project.

A large portion of the SDDOT's traffic control planning is completed during the project design, where the designers consider the length of the work zone area, the delay imposed on motorists traveling through the work zone, and the maximum queue length of vehicles waiting to travel through the work zone. The SDDOT attempts to keep delay under 10 to 15 minutes. To meet this goal, the SDDOT uses night work, as well as full road closures with detours. The SDDOT also uses alternative contracting methods, such as A+B bidding, for contractor selection, lane rental, and other incentives/disincentives. The

²⁹ Respondent John Adler, Traffic Operations Engineer, South Dakota Department of Transportation, Pierre, SD.

SDDOT uses incentives/disincentives to assist in accelerating the progress of projects, especially on interstate projects. The SDDOT considers congestion as part of the design phase and attempts to mitigate the effects. Although most projects are rural, the SDDOT has taken a proactive approach to reducing congestion and improving safety throughout the state.

*Tennessee Department of Transportation*³⁰

The Tennessee Department of Transportation (TDOT) identifies locations throughout Tennessee that are considered choke points. The TDOT uses a long-range plan to target these areas and improve mobility as funds become available. The process also incorporates safety through a goal set by the TDOT to reduce crashes in work zone areas by 10 percent over the next five years.

A secondary policy set by the TDOT was to set volume maximum thresholds for lane closures. Through these standards, the TDOT determines the required number of lanes before congestion reaches unacceptable levels. The TDOT also uses these maximum allowable queue lengths in alternative phasing and construction hours.

To mitigate congestion and avoid closures resulting in unacceptable delays, the TDOT uses nighttime work and investigates alternative phasing. Also, the TDOT uses A+B bidding for contractor selection, lane rental, and other incentives/disincentives on construction projects to reduce the duration of work zones and lane closures.

*Texas Department of Transportation*³¹

The Texas Department of Transportation (TxDOT) also has a program to identify bottleneck areas that may require additional highway capacity. The TxDOT has special funding to relieve bottlenecks through capacity expansion. Through this program, the TxDOT is working on reducing project delivery time by 15 percent over the next five years. The TxDOT is specifically looking at design-build methods and contractor incentives/disincentives to achieve this objective. Thus, the TxDOT evaluates every project to determine how the project's duration can be shortened. It is the TxDOT's goal to create project guidance that will help them select the most preferred project delivery strategy. The TxDOT has created a number of preliminary documents with the hope to eventually develop a more comprehensive and long-range planning system to move projects more quickly through the project delivery process. The TxDOT wants to create a plan that will be easily implemented by all of the districts over the next five years.

³⁰ Respondent Mark Holloran, Director of Construction, Tennessee Department of Transportation, Nashville, TN.

³¹ Respondent Doug Skowronek, Traffic Operations Department, Texas Department of Transportation, Austin, TX.

Virginia Department of Transportation^{32,33}

The Virginia Department of Transportation (VDOT) addresses congestion and safety during the project programming process. Recently, the VDOT has observed that the public realizes the advantages of full road closures and night work. The public seems to prefer full road closures to get the route back open as soon as possible. The VDOT has used this information along with alternative contracting methods to reduce traveler delay costs. The VDOT is using A+B bidding for contractor selection, lane rental, incentives/disincentives, and design-build project delivery to speed-up the project delivery process. The design-build projects, although limited, have gone surprisingly well, and the VDOT hopes to expand them in future years. Through the use of each contracting method, the VDOT observes reduced construction duration and a satisfied public.

The VDOT has developed an extensive work zone evaluation process. The VDOT uses a work zone checklist that the project engineer completes daily to monitor and evaluate the work zone. The checklist utilizes a point system to give a score to both the VDOT and the contractor on the performance of the traffic control plan. The checklist includes an eleven-point documentation of the work zone's activities. After completion, the checklist is discussed with the resident engineer, contractor, and project inspector. The evaluations are then sent to the VDOT headquarters for further evaluation. These evaluations have led to changes in work zone design standards and adjustments in future projects.

*Wisconsin Department of Transportation*³⁴

The Wisconsin Department of Transportation (WisDOT) uses traffic control polices and lane closure policies to improve congestion and safety in work zones. The WisDOT has created a lane closure policy that uses a threshold of 30 minutes for a maximum delay and/or a maximum queue length of 2 to 3 miles depending on the average daily traffic and facility type. The WisDOT observes that the typical capacity for one lane at a lane closure is 1,500 to 1,600 vehicles per hour. The capacity of a lane following a lane closure was set through a combination of experience and modeling. The WisDOT has used this value to create a traffic control policy.

Part of the WisDOT's traffic control policy is to evaluate the type of contract to be used at 30 to 60 percent completion of the design. The WisDOT selects from lane rental, incentives/disincentives, and recently has used A+B bidding for contractor selection. The WisDOT has used these alternatives to mitigate congestion and delay.

³² Respondent David Rush, Transportation Engineering Specialist, Virginia Department of Transportation, Richmond, VA.

³³ The Virginia Department of Transportation is also the subject of a more thorough discussion in the next chapter.

³⁴ Respondent Tom Notbohn, Bureau of Highway Operations, Wisconsin Department of Transportation, Madison, WI.

The WisDOT does use extra police enforcement in work zones. The cost of added enforcement is paid from project funds. The largest difficulty with this use of enforcement is finding officers to work overtime or additional hours. The WisDOT chooses where added enforcement is needed, but does not provide training and does not prescribe how the officers will patrol the work zone. The WisDOT relies on the enforcement officer to write citations and maintain an enforcement presence in the work zone.

After the completion of specific projects, the WisDOT completes a short informal evaluation process. This evaluation generally relies on the experience of the onsite engineers to convey concerns or lessons learned from the project. This information is then used to improve future projects.

CHAPTER 4. STATE CASE STUDIES

The interviews of thirty individuals at thirty State Transportation Agencies (STAs) regarding their work zone practices contained short descriptions of what each state is doing during the Project Development Process to plan, design, develop, monitor, and evaluate work zone traffic control. Often, the results of the interviews were defined by the experiences of the respondent. In other words, the respondents may have been able to intimately describe the portion of the process they are responsible for, while unable to fully describe the entire process. Although the short descriptions are useful, illustrating that many states are attempting various strategies to reduce congestion and improve safety in work zones, understanding the means being used to carry out specific strategies requires a more thorough investigation of STA processes.

Based on the survey results, the project advisory committee selected the STAs in Ohio, Virginia, and Oregon for further investigation. This chapter presents a case study of each state's work zone procedures. The information contained in each study was obtained through conversations with several contacts at each STA, as well as through a review of internal documentation acquired from those contacts. An attempt was made to limit these studies to a manageable level of detail; therefore, some details the STAs feel are important may have been omitted from this review.

Ohio Department of Transportation (ODOT)

The Ohio Department of Transportation (ODOT) was selected for detailed study because they have developed and successfully implemented a comprehensive Project Development Process (PDP), which effectively incorporates work zone planning and management. ODOT's Maintenance of Traffic (MOT) Policy was implemented in 2000 to address work zone impacts (safety and mobility) throughout the various stages of project development on all Interstate and freeway projects. The ODOT MOT policy requires that practitioners (1) assess the potential impacts of work zones during project planning, (2) provide early identification of potential "red flag" issues, (3) select and execute a TMP which maximizes traffic safety and minimizes traffic delay in work zones, (4) analyze historical and real-time work zone crash data to manage and improve work zone safety, (5) perform process reviews, and (6) receive training appropriate to the job description of each individual. This case study describes how the ODOT MOT policy is carried out.

ODOT districts are responsible for executing the MOT policy for projects in their respective regions. Each District Deputy Director (equivalent of a district engineer) appoints a District Work Zone Traffic Manager (DWZTM) who is responsible for coordinating and monitoring all projects that may impact traffic flow on Interstates and multi-lane divided highways within their district. This individual has many duties that will be discussed throughout this case study.

Depending on project size, complexity, and/or potential environmental impact, ODOT projects are first categorized as minimal, minor, or major. Minimal projects are defined as transportation improvements generated by traditional maintenance activities. Minor projects are defined as transportation improvements that are generally located on an existing alignment and may include only slight alignment adjustments. Finally, major projects are defined as transportation improvements which are expected to (1) have a significant impact on the highway’s public access, level of service, traffic flow, mobility patterns, or mode shares; (2) require substantial right-of-way acquisition; (3) involve a high degree of public controversy; and/or (4) require a substantial financial investment to complete all aspects of project development. As soon as the project classification has been assigned, the PDP can begin. It is recommended that the project classification be revisited at the conclusion of planning activities to determine if it is appropriate to continue using the original classification. It is crucial that any classification change be made as early in the process as possible to allow all subsequent project development activities to proceed accordingly. Table 4.1 presents a side-by-side comparison of the PDP for all three project categories. Having a well-documented PDP, where all offices involved understand where and when they are to engage, is a major key to ODOT’s effectiveness in managing work zone impacts. The steps of the major PDP are described herein, highlighting where, when, and how work zones are considered.

Table 4.1. Project classifications and corresponding processes (49)

Minimal	Minor	Major
	STEP 1 – Develop Purpose and Need	STEP 1 – Work With Stakeholders to Understand Problems, Needs, and Goals
		STEP 2 – Conduct Research and Technical Studies
STEP 1 – Determine Scope, Schedule, and Budget	STEP 2 – Determine Scope, Schedule, and Budget	STEP 3 – Identify and Evaluate Conceptual Alternative Solutions
		STEP 4 – Develop Strategic Plan
	STEP 3 – Perform Environmental Analysis and Preliminary Engineering	STEP 5 – Develop Conceptual Alternatives
		STEP 6 – Develop Feasible Alternatives
		STEP 7 – Develop Preferred Alternative
	STEP 4 – Prepare Environmental Clearance and Develop Stage 1 Design	STEP 8 – Prepare Environmental Clearance and Develop Stage 1 Design
STEP 2 – Develop Stage 3 Design	STEP 5 – Develop Stage 2 Design	STEP 9 – Develop Stage 2 Design
	STEP 6 – Complete Right-of-Way Plan and Begin Acquisition	STEP 10 – Complete Right-of-Way Plan and Begin Acquisition
	STEP 7 – Develop Stage 3 Design	STEP 11 – Develop Stage 3 Design
STEP 3 – Prepare Final Plan Package	STEP 8 – Prepare Final Plan Package	STEP 12 – Prepare Final Plan Package
STEP 4 – Award Contract	STEP 9 – Award Contract	STEP 13 – Award Contract
STEP 5 – Construct Project	STEP 10 – Construct Project	STEP 14 – Construct Project

PDP for Major Projects—Steps 1 & 2

The objectives for Step 1 of the PDP for major projects include (1) defining the study area, (2) assembling an all-inclusive list of stakeholders who may be impacted by or have a need to know about the highway improvement project, and (3) developing a Public Involvement Plan (PIP). First, the study area is defined based on input from ODOT technical staff and consultants. The study area must be large enough to include all areas that contribute to the transportation problem as well as all areas that may be involved in solving the problem, including any detour routes that may potentially be used during construction. The study area is then refined using input received from stakeholders. Stakeholder involvement is essential during every step of the major PDP. Stakeholders provide information and offer a unique perspective in identifying the transportation problem and what changes or improvements are needed to have a successful project. ODOT's "Public Involvement Guide" outlines how to identify and involve stakeholders and how to develop and implement a PIP for a major project. This process is dependent on the type, length, and duration of the planned construction project as well as the demographics of the study area.

To achieve the Step 1 objectives, it may be necessary to simultaneously begin some Step 2 activities. Step 2 of the PDP includes collecting, analyzing, forecasting, and documenting a broad range of transportation conditions within the study area. Base maps of the study area are developed to show the locations of existing transportation facilities, all possible detour routes, and the project's logical termini. During Step 2, an "Existing and Future Conditions Report" is prepared which documents the data collected, all analyses conducted, and the existing and future expected conditions in the study area. However, the most important product from Step 2, in regard to work zone impacts, is a "Red Flag Summary Report." "Red Flag" locations are areas of concern within the study area that could potentially cause revisions to the anticipated scope of work, the proposed project development schedule, or the estimated project budget. A section of this summary is dedicated to maintenance of traffic issues in work zones and is shown in Figure 4.1. This MOT Red Flag summary allows ODOT to begin considering the potential impacts of work zones during project planning. Finally, Step 2 concludes with the composition of a draft "Purpose and Need Statement." This document summarizes all Step 2 activities and serves as the primary criteria used to identify, evaluate, and eliminate advance planning level conceptual alternatives. It is revised during Step 4 of the PDP and is used in Step 6 to assess feasible design alternatives.

PDP for Major Projects—Steps 3 & 4

The planning study to develop conceptual project alternatives takes place during Steps 3 and 4 of the PDP. The recommended alternative(s) from this planning study are general conceptual alternative solutions. The specific alignment, roadway design, and construction details of the recommended solutions do not begin to be considered until Step 5 of the PDP when the conceptual alternatives begin to be further developed.

Indicate if the following maintenance of traffic issues are present or should be considered during project development. Provide additional comments as needed.

	Design Issue	Comments	References*
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Can traffic be detoured?		TEM: 602-6
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Is the local alternate detour route in good condition? Are there any load limits or bridge width restrictions?		
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will the detour route have a detrimental impact on emergency vehicles, school buses or other sensitive traffic?		
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Are there any load limits on the proposed detour route?		
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Does the project fall within the permitted lane closure map?		TEM: 630-4
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Is existing bridge width sufficient to maintain traffic?		TEM: 640-2
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will temporary pavement be required?		TEM: 640-2, 640-11
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Should temporary pavement be retained after project completion?		TEM: 640-11
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will the speed limit be lowered by more than 10 mph during construction?		TEM: 640-18
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Is the existing shoulder in good enough condition to support traffic during construction?		TEM: 640-5
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Does pedestrian traffic need to be maintained?		TEM: 64-25
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will additional width be required on culverts or bridges to maintain traffic?		TEM: 640-2
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will a temporary structure/runaround be required?		TEM: 640-11
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will a cross over be utilized?		TEM: 640-11
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will the road need to be closed for short durations (e.g., 15 minutes for beam erection)?		TEM: 640-8
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Can drive access be maintained at all times?		TEM: 640-10
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Can trucks make turning movements during construction?		
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will portable concrete barrier wall obstruct stopping sight distance?		LDV1-201.2
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Will additional signal heads be needed for drives and/or side roads?		TEM: 605-13
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Are there any issues regarding access to the work site?		TEM: 640-9
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Are there any issues regarding construction timeframes (e.g., time of day, time limits)?		TEM: 606-3 640-14
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Have innovative contracting ideas been considered? <i>Specify.</i>		
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Are there specific requirements for maintaining railroad traffic?		TEM: 606-19
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Does it appear that the maintenance of traffic will require additional right of way?		
<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Possible <input type="checkbox"/> Not Applicable	Are there any other maintenance of traffic issues? <i>Specify.</i>		

Figure 4.1. ODOT’s Red Flag Summary for maintenance of traffic (50)

During Step 3 of the PDP, all reasonable conceptual alternative solutions to the transportation problem are identified, discussed, and evaluated. The alternative evaluation criteria must be directly tied to the project goals and objectives identified by the stakeholders in Step 1 and the draft “Purpose and Need Statement” written in Step 2. The final documentation from Step 3 should recommend a conceptual alternative solution or a narrowed list of solutions to be considered for further evaluation and describe how those decisions were reached.

Step 4 of the PDP involves developing a “Strategic Plan” or a full “Planning Study Report.” The determination of whether to do a Strategic Plan or a Planning Study Report is based on legal and environmental requirements for advancing the project. This documentation describes the recommended design concept and scope and establishes the “Funding, Timetable, and Project Delivery Strategy,” which may require the project be divided into “sub-projects.” This is where construction phasing may start to be considered.

PDP for Major Projects—Step 5

Step 5 of the PDP is where the recommended conceptual alternative from Steps 3 and 4 begins to be further developed. During this step, the project team uses the study area base map developed in Step 2 to locate and design the alignments of preliminary corridors between project termini. In developing these corridors, the goal is to avoid and/or minimize as many design and environmental “Red Flags” as possible, including those identified in Figure 4.1. Once these preliminary corridors are developed, the advantages and disadvantages of each corridor are identified in a comparative matrix to provide a quantitative basis for selecting a few (typically 2 or 3) to be further analyzed in Step 6. Step 5 concludes with the composition of a “Conceptual Alternatives Study.” This documentation includes the “Strategic Plan” developed in Step 4 as well as a complete description of the preliminary corridors selected for further analysis.

PDP for Major Projects—Step 6

During Step 6 of the PDP, an “Assessment of Feasible Alternatives” is conducted. The purpose of this assessment is to evaluate and compare each corridor selected in Step 5 based on their potential environmental and design consequences. Different design alternatives within each corridor are examined to determine which one minimizes impacts within the corridor, while meeting the project’s needs to the highest degree possible. This evaluation provides the basis for recommending a “preferred alternative” at the beginning of Step 7. The environmental component of the “Assessment of Feasible Alternatives” is described in ODOT’s *Environmental Process Manual*. A detailed list of the design components, which must be addressed in the “Assessment of Feasible Alternatives,” is provided in ODOT’s *Location and Design Manual*. One of these items is maintenance of traffic. ODOT conducts a Maintenance of Traffic Alternative Analysis (MOTAA) to address maintenance of traffic issues during the “Assessment of Feasible Alternatives.” The MOTAA is described in detail in the following section.

Maintenance of Traffic Alternative Analysis (MOTAA)

As part of the “Assessment of Feasible Alternatives,” a MOTAA must be performed, submitted for review, and approved for any projects following the major PDP. The goal of the MOTAA is to analyze the projected impacts on the traveling public that may result from the implementation of a work zone. The purpose is to determine which feasible alternative minimizes work zone impacts so that this information can be taken into account when conducting the “Assessment of Feasible Alternatives.” It is not the intent of the MOTAA to require a detailed design of each alternative’s work zone. Instead, it is intended to identify and compare any major potential functional faults associated with common work zone layout alternatives. The MOTAA is accomplished by examining each work zone layout alternative for the presence of the potential work zone constraints listed in Table 4.2. Where a constraint is identified, it should be clear which phase(s) of the construction the constraint will be present in and it should be explained in enough detail so that ODOT personnel can determine its magnitude and make an informed decision when the time comes to mitigate the constraint or select another alternative. A final summary should be provided that includes a recommended work zone alternative (part-width, cross-over, hybrid, or full-closure) based on the identified constraints. This process allows ODOT personnel to identify work zone problems before any detailed design work takes place and enables them to engineer a solution to those problems into the final design.

Table 4.2. ODOT’s MOTAA potential constraints checklist (51)

Constraint/Factor to be Considered	Work Zone Alternatives/Options			
	Part-Width	Cross-Over	Hybrid	Full-Closure
Ability to Meet Work Zone Policy				
Ability to Maintain All Accesses				
Ability to Provide Required On-Ramp Merge Decision Sight Distance				
Right-of-Way Impacts				
Environmental Impacts				
Final Bridge Widths				
Significant Impacts for Construction Duration and/or Construction Costs				
Significant Impacts to Earthwork, Retaining Walls, Pier Clearances, Profile Differences, etc.				
Ability to Maintain Existing Drainage and Lighting Systems				
Constructability and Construction Equipment Access				
Location of Cross-Overs (e.g., Can Cross-Overs be Located Near the Project?)				

In order to examine each work zone alternative for its “Ability to Meet The Work Zone Policy” in Table 4.2, ODOT personnel must ensure that each alternative will provide sufficient throughput traffic capacity so that traffic may flow efficiently through and/or around the work zone. A basic outline of this “MOT Policy Process” is shown in Figure 4.2. This process forces ODOT personnel to consider all reasonable countermeasures to reduce delay through a work zone prior to its implementation.

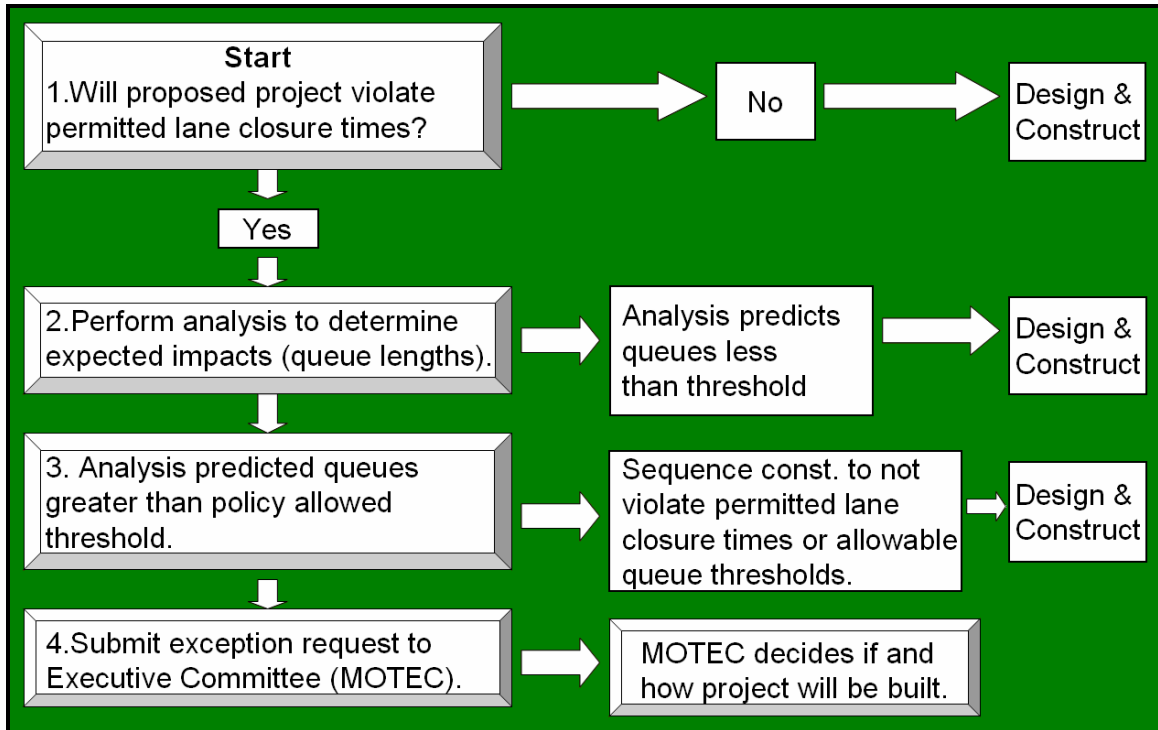


Figure 4.2. ODOT’s MOT policy process (52)

ODOT does not have specific work zone congestion goals. Instead, ODOT considers work zone congestion to be a function of the number of available lanes required to maintain sufficient capacity through a work zone. The DWZTM is responsible for developing, maintaining, distributing, and providing guidance to district personnel, county managers (districts sub-divided into counties), and consultants in the use of a Permitted Lane Closure Map (PLCM). The PLCM is a map indicating the time(s) of day when any section of an Interstate or Freeway within a district can have its number of lanes reduced. The permitted lane closure capacity calculations are conducted through a six-step process shown in Figure 4.3. These calculations are used to create the PLCMs which are maintained on ODOT’s website and are currently accessible at https://dotaw100.dot.state.oh.us/plcm/plcm_web.jsp. An example of a PLCM is shown in Figure 4.4.

Step 1:	Select Segment of Interstate/Freeway To Be Analyzed
Step 2:	Determine Segment Characteristics (Terrain Type/Number of Available Lanes)
Step 3:	Determine Traffic Volume Data Collection Method To Be Used (See Below)
Step 4:	Select Work Zone Lane Capacity Using The Table Below
Step 5:	Determine Hourly Closure Volumes (See Below) If volumes exceed work zone capacity (vphpl), no lane closure is permitted.
Step 6:	Provide District Comments/Exceptions (i.e., If a Bengal's game is scheduled, no lane closures will be allowed for two hours before or after the game.)

Traffic Volume Data Collection Methods Ranked In Order of Priority:

Method A:	Actual Hourly Breakdowns For The Section. An automatic traffic recorder (ATR) is located within the segment.
Method B:	Hourly Percentages. An ATR is located upstream or downstream of the segment on the same route.
Method C:	Hourly Percentages From A Close ATR Applied To Average Annual Daily Traffic (AADT). An ATR is located on a close, but different route which has similar traffic distributions.
Method D:	AADT Determined Using a Statewide Distribution.

Work Zone Capacity Table (Vehicles per Hour per Lane - vphpl):

The Highway Capacity Manual 2000 (Formula 22-1) was used to determine theoretical capacity of a roadway lane. ODOT simplified this formula to be based on two variables: terrain type and truck percentage.

Terrain	Truck Percentage		
	< 15%	15% ≤ x < 30%	≥ 30%
Level	1490	1390	1330
Rolling	1310	1100	1000
Custom	Please contact PLC administrator for use of custom capacities. These should only be used in unique situations.		

Note: Work Zone intensity and Work Zone Ramp Factor are assumed to be 0 vphpl

Hourly Closure Volumes Determination:

Weekday closure volumes for the construction season are calculated using the seasonal adjusted Thursday ADT in August for Rural locations and the seasonal adjusted Friday ADT in August for Urban locations. For the non-construction season, weekday closure volumes are calculated using the seasonal adjusted Thursday ADT in December for Rural locations and the seasonal adjusted Friday ADT in December for Urban locations. If the segment is using an ATR, the maximum Thursday or Friday ADT volume is selected from August or December (excluding Christmas week).

Weekend closure volumes for the construction season are calculated using the seasonal adjusted Friday ADT in August for Rural locations and the seasonal adjusted Saturday ADT in August for Urban locations. For the non-construction season, weekend closure volumes are calculated using the seasonal adjusted Friday ADT in December for Rural locations and the seasonal adjusted Saturday ADT in December for Urban locations. If the segment is using an ATR, the maximum Friday or Saturday ADT volume is selected from August or December (excluding Christmas week).

Figure 4.3. ODOT's permitted lane closure capacity calculation process (53)

ODOT Permitted Lane Closure										Print	
District 6	County: FRA	Route: IR-270	DIR: BOTH	Calculation Year: 2003	Section: US33 (Dublin) to Sewmill Rd						
BEGIN LOG 17.290	Calculation Method: D	ADT using statewide distribution									
END LOG 19.830	Road Class: URBAN	(Urban or Rural)									
	Terrain: ROLLING										
	Lanes per direction: 3										
<p>There shall be no lane closures on Holidays or Holiday weekends. The following are considered holidays: Memorial Day, Fourth of July, Labor Day, Thanksgiving, Christmas, New Years, Easter. No lane closures are allowed after 12 noon on the day preceding the holiday weekend until 6 am the day after the holiday weekend. Ex. Holiday falls on a Monday then no lane closures from 12 noon on Friday until 6 am Tuesday holiday. For holiday weekends no lane closures are allowed after 12 noon on the day preceding the holiday weekend until 6 am the day after the holiday weekend. Ex. Holiday falls on a Monday then no lane closures from 12 noon on Friday until 6 am Tuesday</p>											
ATR# 0 ADT Year 2001 ADT 118639 Percent Trucks 12 Annualized ADT 98470 Capacity 1310 per lane			Seasonal Traffic Adjustment Weekday 118639 Weekend 88712 Construction 84888 Non-Construction 84888								
Legend * = Lane Closure(s) Not Permitted 3.2 : Ratio Of Lanes 3 : Available Lanes 2 : Lanes Open Season Construction April 1 - Nov 30 Non Construction Dec 1 - March 31 Last Updated: 1/22/04 3:31 PM											
Ratio of Lanes			3.2			Traffic Volume per open lane			3.1		
Season	Weekday	Construction	Weekend	Non-Const.	Weekend	Non-Const.	Weekday	Construction	Weekend	Non-Const.	
Hour of the Day	Mon-Fri	Sat-Sun	Mon-Fri	Sat-Sun	Mon-Fri	Sat-Sun	Mon-Fri	Sat-Sun	Mon-Fri	Sat-Sun	
0-1AM	297	222	274	212	444	444	547	424	444	424	
1-2AM	208	155	191	149	415	310	383	297	415	310	
2-3AM	178	133	164	127	356	266	328	255	356	266	
3-4AM	208	155	191	149	415	310	383	297	415	310	
4-5AM	267	200	246	191	534	399	492	382	534	399	
5-6AM	653	488	602	467	1305	976	1204	934	1305	976	
6-7AM	* 1513	1131	* 1395	1082	* 3025	* 2262	* 2790	* 2165	* 3025	* 2262	
7-8AM	* 2195	* 1641	* 2024	* 1570	* 4390	* 3282	* 4048	* 3141	* 4390	* 3282	
8-9AM	* 1780	* 1331	* 1641	1273	* 3659	* 2661	* 3282	* 2547	* 3659	* 2661	
9-10AM	* 1394	1042	1286	997	* 2788	* 2065	* 2571	* 1995	* 2788	* 2065	
10-11AM	1246	931	1149	891	* 2491	* 1863	* 2298	* 1783	* 2491	* 1863	
11-12PM	* 1394	1042	1286	997	* 2788	* 2065	* 2571	* 1995	* 2788	* 2065	
12-1PM	* 1424	1065	* 1313	1019	* 2847	* 2129	* 2626	* 2037	* 2847	* 2129	
1-2PM	* 1642	1153	* 1422	1104	* 3085	* 2307	* 2845	* 2207	* 3085	* 2307	
2-3PM	* 1780	* 1331	* 1641	1273	* 3659	* 2661	* 3282	* 2547	* 3659	* 2661	
3-4PM	* 2165	* 1619	* 1997	* 1549	* 4330	* 3238	* 3994	* 3098	* 4330	* 3238	
4-5PM	* 2432	* 1819	* 2243	* 1740	* 4864	* 3637	* 4486	* 3480	* 4864	* 3637	
5-6PM	* 2580	* 1929	* 2380	* 1846	* 5161	* 3859	* 4759	* 3693	* 5161	* 3859	
6-7PM	* 1969	* 1387	* 1723	* 1337	* 3737	* 2794	* 3446	* 2674	* 3737	* 2794	
7-8PM	1275	954	1176	913	* 2551	* 1907	* 2352	* 1825	* 2551	* 1907	
8-9PM	1008	754	930	722	* 2017	* 1508	* 1860	* 1443	* 2017	* 1508	
9-10PM	949	710	875	679	* 1698	* 1249	* 1551	* 1181	* 1698	* 1249	
10-11PM	741	554	684	531	* 1483	* 1109	* 1368	* 1061	* 1483	* 1109	
11-12AM	564	421	520	403	1127	843	1039	806	1127	843	

Figure 4.4. Example of ODOT's permitted lane closure web site (52)

The “MOT Policy Process” begins by asking the question, “Will the proposed project violate the permitted lane closure times indicated on the PLCM?” Any project that will violate these times requires the district to perform a quantitative analysis to estimate the queue lengths that will be generated each time a lane closure is proposed outside the allowable times given in the PLCM. For locations and times where queues are normally present without lane closures, this “Queue Analysis” must compare the existing queue lengths to those expected during a possible work zone lane closure. Multiple construction stages should be analyzed separately if the DWZTM feels that there are significant changes in the geometrics or operation of the work zone that could adversely affect traffic flow conditions. However, this analysis should not be conducted until the pavement recommendation has been formulated by the District’s Pavement Review Team and all necessary bridge work has been determined.

The “Queue Analysis” can be conducted with a variety of commercially available traffic impact simulation/prediction programs such as Highway Capacity Software (HCS), Synchro/SimTraffic, Corsim, Netsim, QuickZone, or QUEWZ. ODOT prefers QUEWZ because a field comparison conducted by Schnell et al. (54) in 2002 showed that it produced more accurate estimates of queue lengths and delay times in work zones than the other software packages. QUEWZ’s road user cost output option is able to analyze a specified lane closure configuration and its corresponding schedule of work activities to provide the user estimates of traffic speeds, queue lengths, diverted traffic volumes, and additional road user costs for each hour affected by the lane closure. In general, a vehicle is considered part of a queue if its average operating speed is 10 miles per hour (mph) or less; however, the DWZTM should use his or her discretion in determining what constitutes a queue. To obtain meaningful results, traffic volume and vehicle mix (percent trucks) data put into the model must be current and should account for seasonal traffic surges that may occur during the estimated construction period. Also, the simulation should not be conducted until QUEWZ’s default parameters have been calibrated to more accurately reflect the site conditions expected in the work zone.

ODOT’s MOT Policy sets forth the following queue length thresholds for the evaluation of work zones:

- Queues of 0.75 miles or less are acceptable, no matter the duration of the queue.
- Queues greater than 0.75 miles which are not expected to exceed 1.5 miles are acceptable only if the queue length is expected to remain in this range for two hours or less.
- Queues exceeding 1.5 miles are unacceptable, no matter the duration of the queue.

If the results of the “Queue Analysis” show that the expected work zone queue lengths are acceptable, then the PDP may continue. However, if the expected work zone queue lengths violate the allowable policy thresholds, the work zone must be reconfigured or the construction phasing altered until the “Queue Analysis” results are acceptable. If this is not possible or practical and the alternative continues through the PDP as a preferred alternative, the DWZTM must submit an exception request to the Multi-Lane Coordinator

(MLC) during the development of the “Preferred Alternative Verification” in Step 7 of the PDP. The exception request must include a comparison of alternate work zone strategies highlighting construction phasing, construction costs, road-user costs, queue lengths, queue durations, and any other mitigation strategies associated with each alternative. The MLC will review the exception request, solicit comments from other offices as needed, prepare a recommendation, and present it to the Maintenance of Traffic Exception Committee (MOTEC). MOTEC is comprised of ODOT’s Assistant Director of Planning and Production, ODOT’s Assistant Director of Highway Management, and ODOT’s Deputy Director of Highway Operations. MOTEC may approve a recommendation, reject it entirely, reject phases of it, or request further work zone alternative development or analysis from project personnel. Once MOTEC has reached a decision, the MLC reports their finding back to the DWZTM. MOTEC approval must be obtained prior to submitting for “Stage 1 Detailed Design Review” during Step 8 of the PDP.

MOTEC grants very few exceptions. Instead, MOTEC may recommend innovative contracting or construction techniques to attempt to minimize the duration of the work zone. ODOT’s *Innovative Contracting Manual* describes which types of projects should be considered for various innovative contracting methods. Innovative contracting methods typically use incentive/disincentive (I/D) provisions to motivate contractors to provide quality transportation facilities while minimizing the duration of the project and maintaining a competitive bidding process. MOTEC may also recommend other mitigation strategies, such as ITS applications or public information campaigns, to better manage the work zone once it is implemented.

ODOT’s “MOT Policy Process” has successfully led to more frequent use of (1) I/D contracting methods, (2) innovative MOT schemes such as the contra-flow concept illustrated in Figure 4.5, (3) short-duration full closures, (4) off-peak and night work to adhere to the PLCM, and (5) aggressive public information campaigns.



Figure 4.5. Work zone contra-flow concept utilized by ODOT (55)

PDP for Major Projects—Step 7

Based on the “Assessment of Feasible Alternatives” completed in Step 6, Step 7 begins with the recommendation of a preferred alternative. Step 7 concludes the project planning process by finalizing the development of the preferred alternative so that detailed design can begin in Step 8. This includes investigating any assumptions made during the “Assessment of Feasible Alternatives,” revising any design plans, performing any additional environmental field studies necessary to further define the environmental impacts, obtaining necessary waterway permits, and preparing/submitting the required NEPA documentation (EIS, EA, or CE). These activities are conducted in order to develop the “Preferred Alternative Verification” which is a design submission that describes the preferred alternative. ODOT’s *Location and Design Manual* provides a detailed listing of the submission requirements which must be included in the “Preferred Alternative Verification.” One of these items is the Conceptual Maintenance of Traffic (CMOT). CMOT summarizes the results of the MOTAA conducted in Step 6. If any lane closure or exception requests are required, they must be documented in the CMOT and submitted at this time. Step 7 concludes as the preferred alternative is presented to federal and state agencies, stakeholders, and the public for review. At this time, agencies are asked to concur on the preferred alternative, its impacts, and any proposed mitigation.

PDP for Major Projects—Steps 8 through 12 (Detailed Design)

The detailed design phase of the PDP takes place during Steps 8 through 12. Stage 1 detailed design occurs during Step 8 of the PDP and further develops the design submitted for the “Preferred Alternative Verification” in Step 7. Stage 1 design plans should provide enough detail to develop preliminary right-of-way plans. A list of

elements included in a typical “Stage 1 Design Submittal” is presented in ODOT’s *Location and Design Manual*. If the preferred alternative is changed during Stage 1 detailed design, then those changes are presented to the stakeholders at the conclusion of Step 8.

Stage 2 detailed design takes place during Step 9 of the PDP after the Stage 1 design plans have been reviewed and approved. Stage 2 detailed design incorporates any Stage 1 design review comments and completes a majority of the “final” design plan preparation. ODOT’s *Location and Design Manual* presents a list of design elements that should be included in a typical “Stage 2 Design Submittal.” The Traffic Management Plan (TMP) is completed during Stage 2 detailed design and is one of these items. The DWZTM is responsible for the development of the TMP and, for any project approved by MOTEC, he or she must submit the TMP to the MLC for final approval. The TMP details the selected scheme for accommodating traffic during construction and should incorporate the following as applicable: (1) consideration of stakeholders’ needs, (2) identification of alternate routes, (3) incident management strategies, (4) a public relations campaign, and (5) a project communications plan. After Stage 2 detailed design is complete, Step 9 of the PDP concludes with the completion of a constructability review. This review evaluates a number of design issues including maintenance of traffic, construction equipment access, and project phasing.

After the final right-of-way plans are developed in Step 10, Stage 3 detailed design is conducted during Step 11. The principal work items in Stage 3 design include the addition of quantities to the plans and a final cost estimate. ODOT’s *Location and Design Manual* describes what should be included in the “Stage 3 Design Submittal.” Finally, the design phase of the PDP concludes with the preparation and submittal of the “Final Plan Package” during Step 12. The “Final Plan Package” presents the necessary design information for bidding and construction. Once it has been approved, the project moves from design to contract administration.

PDP for Major Projects—Step 14 (Construction)

After the project has been contracted and awarded in Step 13, the construction process takes place during Step 14, the final step of the PDP. The contractor is responsible for constructing the work as detailed in the contract documents, while ODOT is responsible for monitoring, managing, and documenting the contractor’s activities to ensure the terms of the construction contract are fulfilled. At the beginning of Step 14, a pre-construction conference is held to introduce all the project participants and to discuss the actions necessary for successfully executing and completing the contract work. This conference provides a forum for project personnel to discuss any areas of interest or concern regarding the execution of the contract documents. A few of the items on the agenda for this meeting may include public involvement, maintenance of traffic, or any related safety concerns. Public involvement coordination prior to the beginning of any construction work is essential as the public should be made aware of construction schedules, road closures, detours, and/or any construction that will affect the local

community's daily activities. Having an informed public should help neutralize frustrations during the construction process and improve the safety of the work zone.

Once construction is ready to begin, the DWZTM is responsible for implementing the TMP and assuring that it is implemented as approved. Work zone implementation must also conform to ODOT standards, policies, and the *Ohio Manual of Uniform Traffic Control Devices*. A contractor may submit an alternate maintenance of traffic plan for consideration by the DWZTM; however, it must be approved before the start of construction. Once implemented, every Interstate and "Interstate look-alike" work zone is inspected and rated by the ODOT Office of Traffic Engineering (OTE) for adherence to standards, specifications, and safety concerns. Any safety concerns are immediately brought to the attention of the DWZTM for correction. ODOT standards are revised as necessary to address common deficiencies that are discovered during these inspections. The results of these inspections factor into an Organizational Performance Index (OPI) and each District Deputy Director is held accountable for his or her district's OPI rating.

ODOT does not have any specific overall goals for work zone safety. However, at the beginning of project construction, safety goals concerning work zone crashes are established for each individual project. ODOT's objective is to keep work zone crashes for a project at or below the historical crash rate for that same roadway section prior to implementation of the work zone. In response to FHWA's "Final Rule on Work Zone Safety and Mobility", Section 630.1008 (c), which declares, "States shall use field observations, available work zone crash data, and operational information to manage work zone impacts during project implementation," ODOT developed a process in 2004 to compare "real-time" work zone crash data with historical pre-work zone crash data in order to quickly identify, investigate, and correct "problem" locations within work zones. ODOT has automated this "Real-Time Work Zone Crash Data Analysis" using a Microsoft Access Database program (56). The initial menu of this program is shown below in Figure 4.6.

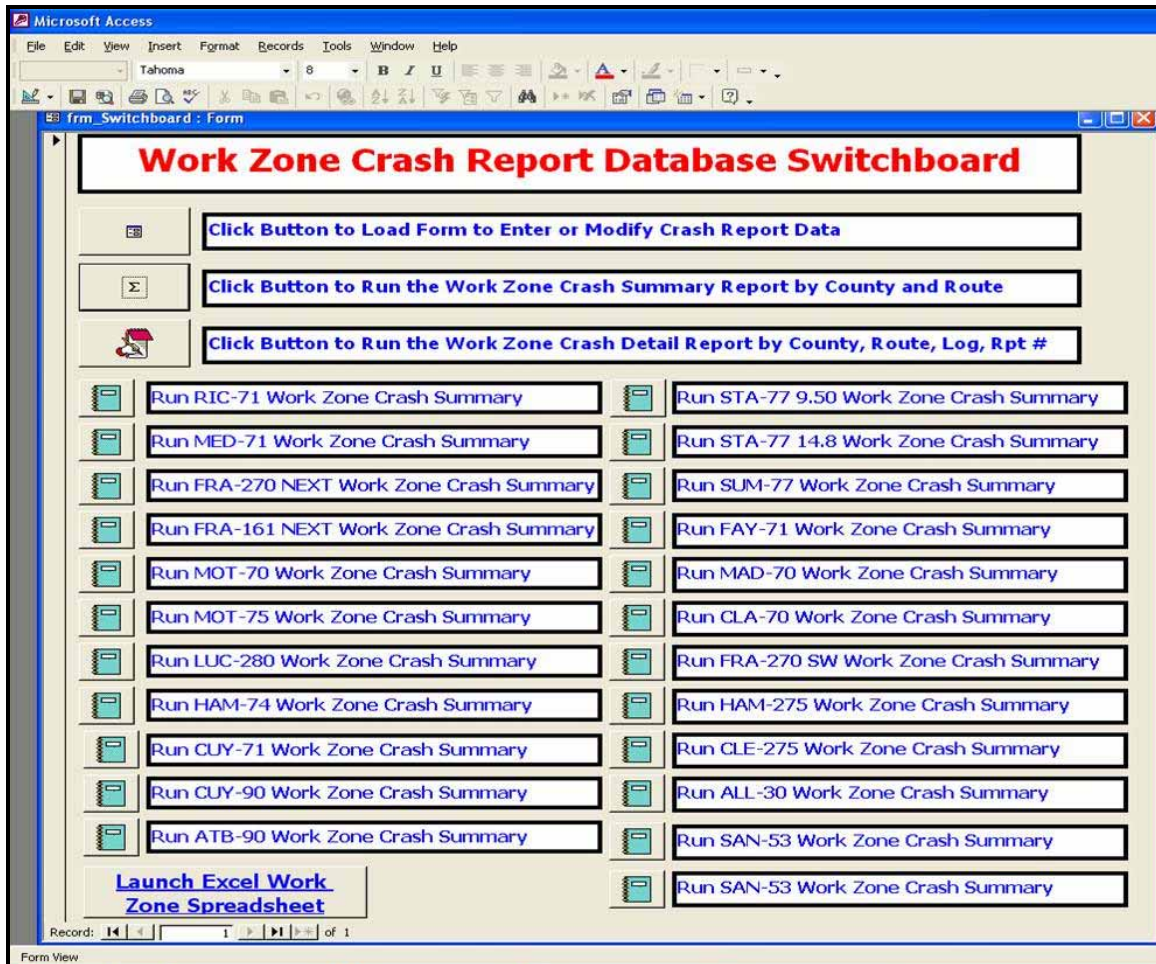


Figure 4.6. ODOT’s real-time work zone crash database main screen (57)

ODOT’s “Real-Time Work Zone Crash Data Analysis” is conducted on candidate projects which are first identified during the previous non-construction season. Prior to work zone implementation, the historic, pre-construction crash data are input into the Access Database and ODOT coordinates with local law enforcement agencies to have copies of future work zone crash reports set aside for pick-up every two weeks. After the work zone is implemented, new crash data are entered into the database as the reports are gathered using the program’s “Crash Report Data Entry Form” shown in Figure 4.7. The database application then breaks the work zone into half-mile segments, sorts the crashes into their proper segment, and performs a “before-after” comparison of the pre-construction and construction crash frequencies for each half-mile segment as shown in Figure 4.8. A number of other work zone crash tables, charts, graphs, queries, and analyses can be generated automatically and quickly refreshed as soon as new crash data is entered into the database. Output of this nature is used to identify abnormally “high-crash” segments. After these locations are identified, a field visit is conducted to investigate possible causes and solutions to the high-crash frequency experienced in that particular area. This process allows ODOT to identify work zone safety issues in near real-time, immediately correct those problems, and improve overall work zone safety.

Work Zone Crash Report Database Switchboard

Click Button to Load Form to Enter or Modify Crash Report Data

Click Button to Run the Work Zone Crash Summary Report by County and Route

Click Button to Run the Work Zone Crash Detail Report by County, Route, Log, Rpt #

Click To Access Data Entry Form

Crash Report Data Entry Form

LOCAL REPORT: 04-0163-09 ROUTE TYPE: IR ROUTE NUMBER: 75 ROAD CONDITION: ROAD - DRY

SEVERITY: FATAL STREET2 REFERENCE: MILEPOST 23 CRASH TYPE: OTHER NON COLLISION

COUNTY: BUT YEAR: 2005 LIGHT CONDITIONS: DARK - LIGHTED

CRASH DATE (MM/DD/YY): 04/26/05 LOG: 5.23

HOUR: 0 VEHICLE TYPE 1: 38 VEHICLE TYPE 2: 2 WORKZONE TYPE: WORKZONE LOCATION: PROJECT NUMBER: Date Entered: 05/23/05

DAY: TUESDAY CONTRIBUTING FACTOR: IMPROPER CROSSING DIRECTION OF TRAVEL: WEST LOCATION: NON - INTERSECTION

Figure 4.7. ODOT’s work zone crash report data entry form (57)

In addition to monitoring work zone safety, ODOT also monitors work zone queues during project construction. This is done in compliance with Section 630.1008 (c) of FHWA’s “Final Rule on Work Zone Safety and Mobility” which says, “States shall continually pursue improvement of work zone safety and mobility by analyzing work zone crash and operational data from multiple projects to improve State processes and procedures” (8). In an effort to continually improve their ability to model work zones and provide adequate work zone capacity, ODOT measures work zone queue lengths and compares them with the expected queues generated by the computer models during the MOTAA. Queue lengths are typically measured one week after a project begins or a week after a phase change to allow drivers to become accustomed to navigating the new work zone conditions. If the measured queues exceed the allowable queue thresholds, the DWZTM must inform the MLC of the situation and propose immediate corrective action. The DWZTM, in cooperation with OTE, will examine the possible causes of any differences between the expected queue lengths and those generated by the actual work zones. Lessons learned from this “Queue Review” process will be applied to improve future “Queue Analyses.” OTE may also perform travel time measurements through work zones to correlate queue lengths with travel time. These studies allow ODOT to use expected queue lengths to predict travel time increases for use in future work zone public relations campaigns.

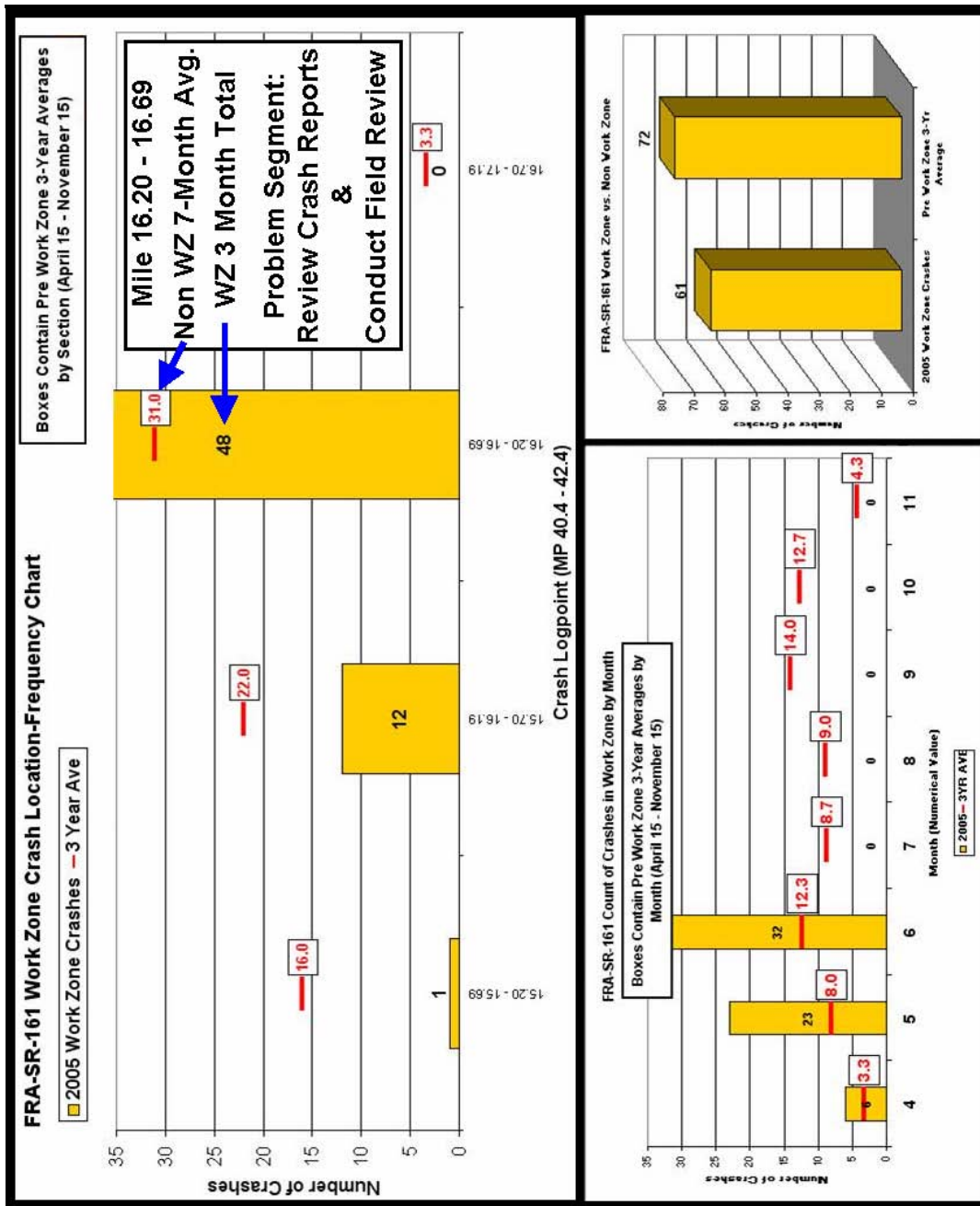


Figure 4.8. ODOT's work zone crash frequency comparison chart (57)

PDP for Major Projects—Post Construction Activities

The post-construction phase of the PDP involves documentation, coordination, and meetings to finalize the project. During this stage, project personnel meet in a post-construction conference to review all aspects of the project and to determine the project's challenges, successes, and failures. The discussions held during the post-construction conference are documented in a "Record of Learning" which may serve as a valuable source of information for future construction projects. Post-construction activities may

also include monitoring/measuring the completed project's operational performance, performing general maintenance, and servicing any additional operational needs.

Process Review & Training

Section 630.1008 (e) of the "Final Rule on Work Zone Safety and Mobility" specifies, "States shall perform a process review at least every two years to assess the effectiveness of State work zone safety and mobility procedures" (8). To comply with this policy, ODOT analyzes historical work zone crash data every two years seeking additional "lessons learned" which may be applied to their work zone policies, processes, and specifications to enhance work zone safety and mobility on future construction projects. Revising policies, procedures, and standards helps to ensure that problems encountered in the past will not be repeated. ODOT's "Process Review" has led to a number of policy revisions, including new standards for paved shoulders in work zones, detailed design standards for work zone merge locations (lane closures and on-ramps), and consideration of work zone off-ramp capacity needs. These revisions are now accounted for during the MOTAA.

Section 630.1008 (d) of the "Final Rule on Work Zone Safety and Mobility" declares, "States shall require personnel involved in the development, design, implementation, operation, inspection, and enforcement of work zone related transportation management and traffic control be trained appropriate to the job decisions each individual is required to make" (8). In response, ODOT implemented the largest internal training initiative in their history. In late 2003, ODOT launched the Highway Technician (HT) Academy, which is a comprehensive training and certification program for ODOT personnel involved in highway design, construction, and management. Completion of the HT Academy coursework and certifications should provide ODOT with a sufficient number of trained inspectors to support their increased construction program (ODOT's Jobs and Progress Plan) that was made possible through a six cent per gallon fuel tax increase. Upon request, ODOT OTE will also train DWZTMs in the development/revision of PLCMs, the use of queue modeling software, work zone traffic control strategies, and work zone inspection. Finally, ODOT also made it a requirement for consultants to be certified at a Traffic Academy as part of their pre-qualifications. Traffic Academy is a two-day ODOT work zone design training course for consultants desiring to prepare complex roadway plans.

Virginia Department of Transportation (VDOT)

The Virginia Department of Transportation (VDOT) is committed to maintaining the safest possible work zones by developing highway safety policies, standards, and guidelines related to work zone safety. VDOT work zone safety requirements are considerably higher than what is found in the *Manual on Uniform Traffic Control Devices (MUTCD)*. Part VI of the MUTCD covers traffic control standards for work zones. VDOT has developed its own version of Part VI of the MUTCD entitled the *Virginia Work Area Protection Manual (VAWAPM)*, which contains the state's policies, standards, and guidelines for temporary traffic control (TTC) in work zones. The

VAWAPM is revised and issued by VDOT's Work Zone Safety Round Table Discussion Group which consists of VDOT Traffic Engineering Division staff and District Work Zone Safety Coordinators (DWZSCs). This group is the forum for discussing and building consensus for changing VDOT policies, practices, and guidelines regarding work zone traffic control. The VAWAPM includes provisions for (1) TTC planning during project scoping and design; (2) daily work zone monitoring, review, and evaluation; (3) scheduling work at night or during other off-peak hours; (4) the use of Virginia State Police (VASP) in work zones; and (5) public information and outreach strategies. This case study describes how VDOT is conducting each of these activities.

TTC Planning

In 2001, a Joint Legislative Audit and Review Committee study found that VDOT was significantly underestimating construction costs at each phase of a project's life (58). When project costs are underestimated, insufficient funds are budgeted for the actual cost of the project and agencies are then forced to delay or cancel other road projects in order to finish those that have been started. Conversely, gross overestimation can lead to missed opportunities to fund other needed projects. The problems associated with accurately and consistently estimating transportation project costs are not unique to VDOT and have become a nationwide challenge. One of the key underlying issues for VDOT was that the agency did not have a consistent, documented, statewide approach for sufficiently conducting detailed project scoping during the planning stages of project development. Many early cost estimates tended to be based on judgment, incomplete project information, and broad project concepts. As a result, costly items such as traffic management devices and crossovers were added as needed during project construction to manage work zone congestion and safety and were not included in the initial project budget. In May of 2002, VDOT management made the assessment that the agency could not continue to do business in this fashion and organized a Project Scoping Committee to develop an improved project scoping process. VDOT felt that a consistent, thorough, and well-documented project scoping process was inextricably entwined with obtaining better project cost estimates. The more refined and detailed project concepts are in the early stages of project development, the more information planners will have to make an accurate cost estimate for the project. As a result, VDOT developed the Project Development Process shown in Figure 4.9. The more detailed PDP led to the implementation of a Project Cost Estimation System (PCES) in 2003 as well as a project development website that archives the history of each project in one location.

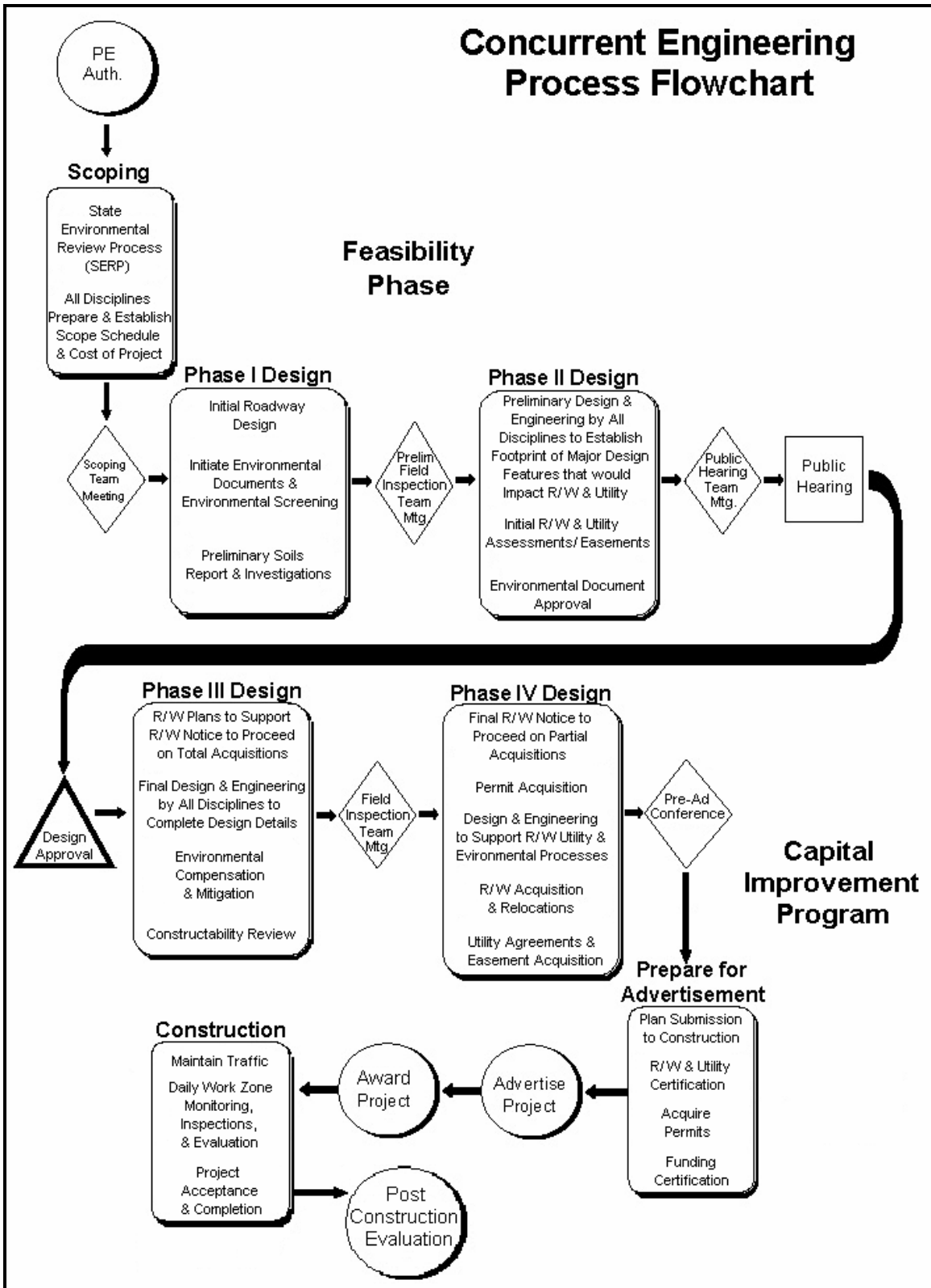


Figure 4.9. VDOT's project development process (PDP) (59)

The advancements in project scoping also forced VDOT personnel to perform TTC planning during the early stages of project development. The primary objective of TTC planning is to provide for the safe and efficient movement of traffic through and/or around work zones while protecting construction workers, responders to traffic incidents, and construction equipment. A TTC plan describes the measures to be used for accomplishing this objective. The VAWAPM presents a number of typical TTC plans depicting common applications of TTC devices for various highway types and work activities. TTC plans can range in scope from being very detailed to simply referencing the typical drawings contained in the VAWAPM. The final TTC plan selected depends on the nature and complexity of the project and its location. TTC planning is completed for all VDOT highway construction and maintenance projects prior to occupying the TTC zone. Planning for all road users is included in this process.

Work Zone Monitoring, Review, & Evaluation (60)

Once a work zone is set up and the TTC plan has been implemented, VDOT uses a number of concurrent, proactive strategies to minimize travel disruption and mitigate the impacts of construction/maintenance activities on the traveling public. Most noteworthy is VDOT's work zone monitoring, review, and evaluation process. Work zones are carefully monitored on a daily basis to ensure that the TTC devices are functional, clearly visible, and in compliance with the TTC plan and the VAWAPM.

Work zone reviews are conducted on three separate levels. First level reviews are performed daily by a trained and/or certified project inspector who is designated as the project's "Safety Officer" (SO). SOs are knowledgeable in the fundamental principles of TTC as well as the work activities being performed. They must be capable of identifying any existing or potential safety hazards within a work zone. The SO examines the scenes of motor vehicle accidents within the project limits, ensures that the work area is free of known safety hazards, and ensures that proper checks are made on the functionality of signs, channelizing devices, barricades, pavement markings, etc. The SO's work zone review is documented using the Work Zone Safety Checklist Form (WZSCF) shown in Figure 4.10. An explanation form, which describes each field found on the WZSCF is included in Appendix B of the VAWAPM. The WZSCF was developed to provide a consistent way of reviewing and documenting the TTC operation in construction and maintenance work zones. At the end of each day, the checklist is reviewed by the SO, resident engineer, and the contractor. These reviews help the SO identify any aspect of the work zone that does not meet state standards. When used correctly, any work zone deficiencies found are noted on the WZSCF and detailed information is provided to allow rapid and thorough correction of the problem(s). A copy of the WZSCF is then given to the contractor so that he or she knows exactly what needs to be corrected and can address the problem(s) as soon as possible. The SO has the authority to halt the construction work until remedial measures are taken. If deficiencies are found, a follow-up review is required within a reasonable amount of time to ensure that the problem(s) has been corrected by the contractor. Any corresponding changes to the TTC plan are then documented. Once the daily checklists are completed, they are sent to VDOT headquarters for further evaluation. When the project is finished, reviews of the

contractor's performance and the performance of the TTC plan are conducted utilizing the completed WZSCFs. VDOT also uses the information gathered from the checklists to evaluate their work zone processes and procedures. If any aspect could be improved upon, that information is relayed to VDOT's Work Zone Safety Round Table Discussion Group for future consideration.

FORM #TE - 97001

WORK ZONE SAFETY CHECKLIST TRAFFIC ENGINEERING

URGENT: CORRECT IMMEDIATELY
 5-WORKING DAYS TO CORRECT
WHEN URGENT IS MARKED DENOTE ITEM.

CONSTRUCTION / MAINTENANCE / UTILITY / PERMIT

RESIDENCY: _____ CONTRACTOR / AREA HEADQUARTERS: _____
 CITY / COUNTY: _____ PROJ. NO. / PERMIT NO. LOCATION: _____
 TYPE OF OPERATION: _____ DAY / DATE: _____ TIME: _____
 PERSON IN CHARGE: _____ POSTED SPEED: _____ MPH
 WEATHER CONDITION: _____ DAY WORK IN PROGRESS

A: DRIVE THROUGH

ARE MANEUVERS DIFFICULT OR UNEXPECTED?

ADEQUATE WARNING OF HAZARDS?

IS SIGNING CLEAR / UNCLUTTERED AND PROPERLY SPACED?

ARE TRAFFIC CONTROL DEVICES SUFFICIENTLY VISIBLE?

COMMENTS: _____

B: SIGNS

NEED TO BE

NEED

NEED ADDITIONAL SIGNS

CONFLICTING

NON - APPROVED SIGN SUPPORT

BLOCKED BY VEGETATION

COMMENTS: _____

C: PORTABLE CHANGEABLE MESSAGE SIGN:

APPLICATION DOES NOT MEET GUIDELINES

INAPPROPRIATE (MESSAGE)

TO MUCH INFORMATION ON P.C.M.S.

NOT DELINEATED, NO CONES / BARRELS

COMMENTS: _____

D: ARROW PANEL:

MALFUNCTION (BULB OUT, ETC.)

INCORRECT PLACEMENT

MISALIGNED BULBS

NOT DIMMED AT NIGHT

COMMENTS: _____

E: DRUMS = D / CONES = C	D	C
INAPPROPRIATE TAPER LENGTH	<input type="checkbox"/>	<input type="checkbox"/>
SPACING INADEQUATE	<input type="checkbox"/>	<input type="checkbox"/>
REFLECTIVE BANDS	<input type="checkbox"/>	<input type="checkbox"/>
ADDITIONAL DEVICES NEEDED	<input type="checkbox"/>	<input type="checkbox"/>
MISALIGN	<input type="checkbox"/>	<input type="checkbox"/>

COMMENTS: _____

F: TRAFFIC BARRIER:

IMPROPER BARRIER WALL FLARE

IMPROPER TERMINAL TREATMENT

BARRIER NEEDS TO BE

WARNING LIGHT

DELINEATORS

8" x 12" VERTICAL BARRIER PANELS

ATTENUATOR

COMMENTS: _____

1 OF 2

Figure 4.10. VDOT's work zone safety checklist form (61)

G. FLAGGING OPERATION:

NEED ADDITIONAL ADVANCE SIGNING

ARE FLAG PERSONS:

CERTIFIED?

POSITIONED CORRECTLY?

HIGHLY VISIBLE?

PROPERLY CLOTHED?

FLAGGING CORRECTLY?

COMMENTS: _____

H. PAVEMENT MARKING:

REMOVE

REPAIR

NEED ADDITIONAL

UNNECESSARY (MARKINGS / NOT ERADICATED COMPLETELY)

COMMENTS: _____

I. PAVEMENT MARKERS:

REPLACE MISSING

REMOVE

NEED ADDITIONAL

COMMENTS: _____

J. TRUCK MOUNTED ATTENUATOR:

PROPERLY POSITIONED?

PROPERLY MAINTAINED / DELINEATED?

COMMENTS: _____

K. MISCELLANEOUS:

ADEQUATE BUFFER SPACE?

IS THE WORK AREA PROTECTED?

MATERIALS PROPERLY STORED?

EQUIPMENT PROPERLY STORED?

ARE LANE CLOSURES IN ACCORD WITH ALLOWED HOURS?

ACCIDENTS:

EVIDENCE OF AN ACCIDENT

DAMAGED TRAFFIC CONTROL DEVICES

SKID MARKS DEBRIS

COMMENTS / RECOMMENDATION: _____

REVIEWED BY: _____ REVIEWED WITH: _____

(SIGN & DATE)

(SIGN & DATE)

COPY: CONTRACTOR, INSPECTOR, RESIDENT ENGINEER, OR OTHER _____

Figure 4.10. (continued)

Secondary reviews are also performed and documented by VDOT DWZSCs. The DWZSCs are experts in TTC requirements and they are sometimes able to find deficiencies in the TTC that SOs have missed because they are so close to the project. These reviews include filling out the WZSCF as well as “drive-through” video recordings of the work zone using an Eyewitness Video Recording System, which has distance measuring instrumentation (DMI). As the DWZSC drives through the work zone, he or she can observe and record the TTC and measure distances between warning signs and traffic control devices as well as taper lengths, queue lengths, work zone lengths, and flagging operations. The video recording and the recorded distances can be reviewed further by project inspection personnel or other personnel in the District’s Traffic Engineering Division. Any deficiencies found can be immediately brought to the attention of the contractor and promptly corrected.

Tertiary reviews are conducted on randomly selected projects by both Construction Quality Improvement Program (CQIP) engineers and work zone review teams composed of FHWA and VDOT Traffic Engineering Division Work Zone Safety personnel. Approximately fifteen to twenty percent of all projects within each district are reviewed in a given year. As part of the CQIP review process, engineers ensure WZSCFs are being completed, and they review the work zone traffic control for compliance with TTC plans, work contract specifications, and VAWAPM guidelines. Work zone team reviews consist of work zone drive-through, completion a WZSCF, and more in-depth face-to-face interviews with project personnel and district staff. Figure 4.11 lists the questions that are posed in these interviews. Based on these reviews, a number of recommendations may be proposed.

Night Work

VDOT is performing an increasing amount of highway maintenance and construction work at night instead of during the day. The purpose of conducting work at night is to avoid traffic congestion and the related problems that are often encountered during the higher volume daylight hours. In some cases, night work is completed in fewer days than daylight work because there are more hours in a night work shift and less interference from traffic. As more road work is being performed at night, VDOT staff and contractors have expressed concern about the hazardous conditions associated with night work, such as low visibility and more impaired and inattentive drivers. This concern has prompted some contractors to express a reluctance to bid on night work. In response, VDOT has created a Night Operations Task Force to review night work zone operations and to provide information designed to maximize the effectiveness of these activities.

VDOT / FHWA WORK ZONE SAFETY PROCESS REVIEW

_____ **District Project Review**
_____ **Project**

On _____ a review team consisting of _____ (FHWA),
_____ (FHWA), _____ (TED – VDOT), _____ (TED-
VDOT), and _____ (Hampton District TE) reviewed the _____ project.

Questions and Answers – The following items were discussed with _____ and
_____ relating to this project:

- 1) How do you Perform Flagger Training/Certification Documentation?
- 2) How do you Ensure Worker and Flagger Safety on this Project?
- 3) Do you use Work Zone Crash Reports and if so, how?
- 4) How do you Ensure Compliance to the TCP/MOT Plans?
- 5) How do you Perform Record Keeping on this Project?
- 6) Do you include the WZ Inspection Checklist Form with the Project Diary?
- 7) Any questions or comments on the Project General Provisions?
- 8) How do you Verify State Police Hours Worked?
- 9) What Type of Work Zone Safety Training Have you had?
- 10) Any Concerns with Pedestrian Access/ADA Accessibility?
- 11) Any Concerns with Trucks Traveling Through this Project?
- 12) Will there be a Post Construction Review?
- 13) How Would You Rate the Traffic Control /Maintenance of Traffic Plans?
- 14) Any Guardrail Issues on this Project?
- 15) Any Concerns with the use of Portable Changeable Message Signs?
- 16) Use of Temporary Traffic Signals?
- 17) How is the Communication Between Project and District staff?
- 18) How is the communication Between Project staff and FHWA staff?
- 19) Any Overall Comments You Would Like to Make About This Project?
- 20) Any Questions You would like to ask the Review Team?

Recommendations

Based on this review, the following recommendations are proposed:

Figure 4.11. VDOT’s work zone review team interview form (62)

Use of Virginia State Police (VASP) In Work Zones

A Federal Highway Administration 1998 report noted that the two leading causes of work zone crashes are excessive speed and driver inattention (63). Further, it was observed that the most effective way of controlling vehicular speeds in a work zone is to have a staffed police car with flashing lights stationed at the beginning of the work zone. Drivers detect the presence of police either visually or via radar detectors and reduce their speed to comply with the posted work zone speed limit. The reduced speeds and reduced speed variations result in fewer accidents. A number of other studies support these observations. As a result, the use of police enforcement in work zones is a common practice among DOT's.

VDOT fully supports this strategy and has an agreement with the State Police that provides additional funded enforcement on selected projects. VDOT and VASP have an excellent working relationship and cooperate well in meeting their mutual goal of reducing speeds and improving safety in work zones. The VAWAPM contains a mutually developed set of guidelines for the use of VASP enforcement in work zones. Police in work zones employ two main practices to reduce speeds when only one officer is assigned to a work zone. The current VDOT guideline calls for the officer to park on the side of the road at the beginning of the work zone with his or her lights flashing and radar unit on to slow motorists through the officer's presence and visibility. The officer is to stay parked most of the time, periodically stopping vehicles exceeding the posted work zone speed limit. This practice is preferred over the use of a "circulating" officer who pursues, stops, and cites speeding motorists. There is a strong feeling, however, that a minimum of two officers should be used in work zones: one stationary to slow motorists by visibility and another continuously circulating for enforcement.

Public Information & Outreach Strategies

Work zone public information and outreach strategies are used to communicate with road users, the general public, area residents, and area businesses about the nature of the work, its expected duration, possible alternate routes, and alternate modes of travel both before and after the project begins. Such programs can lead to improved driver and worker safety, reduced traffic volume, reduced traffic delay, and reduced driver frustration. An editorial posted on <http://www.Richmond.com> describes the success of a VDOT public outreach campaign during the 2005 reconstruction of the Woodrow Wilson Memorial Bridge in Alexandria (64). VDOT put extensive effort into warning motorists of the planned reduction in lanes approaching the bridge and as a result, the expected traffic jams never occurred. Web sites are an easy means of getting information about a work zone out to the public. Web sites may provide real-time or static information, but regardless of the type of information, it should be timely and accurate. In June of 2005, VDOT improved its "Dashboard" website which provides the public with information on VDOT's construction, maintenance, and business activities. VDOT also has websites specifically designed for various projects to keep the public informed. Two examples of such websites are <http://www.wilsonbridge.com/> designed for the Woodrow Wilson

Bridge project mentioned above and <http://www.springfieldinterchange.com/> designed for an interchange improvement project in Springfield, VA.

Oregon Department of Transportation (ODOT)

The 2004-2007 Oregon Statewide Transportation Improvement Program (STIP) contains over \$1.3 billion in projects and programs. Additionally, the Oregon Transportation Investment Acts (OTIA) passed in 2001 and 2002 dedicated another \$2.5 billion over a ten-year period to upgrade Oregon's highways, interchanges, and bridges. ODOT is currently scheduled to complete 160 projects with funds from OTIA by 2009. As a result, the number of work zones on the state's highways will roughly double over the next few years. As ODOT undertakes these projects, they are committed to providing the public with safe and efficient trips through its work zones.

ODOT's goal, as stated in the "2004 Oregon Traffic Safety Performance Plan", is to prevent the number of fatalities in work zones from exceeding six per year through the year 2010. In order to accomplish this objective, ODOT has been making improvements in its planning, design, construction, and maintenance practices. Additionally, \$1.8 million has been authorized for special police patrols in work zones from July 2004 through June 2007 as part of ODOT's "Work Zone Enforcement Program." ODOT also participates in a "Work Zone Education Program," which designs, distributes, and promotes work zone safety messages to the public.

ODOT's work zone management is highlighted by two separate but parallel elements at the statewide level and project level. At the statewide level, ODOT has recognized the need to manage and monitor existing work zones and to manage the scheduling of future work zones to minimize network-level impacts. To manage statewide-level activities, ODOT created Traffic Mobility Operations Center. At the project level, ODOT has created processes to ensure that work zone impacts are taken into account in the project development process.

Statewide Work Zone Planning

With several projects taking place simultaneously at the state and the local level, ODOT recognized the need for coordination of projects with the objective of managing and minimizing traffic operational impacts at the network level. For example, during the summer of 2005, ODOT had roughly 110 active work zones (65). To coordinate at the statewide level, ODOT created a new position of Statewide Traffic Mobility Manager and a new Mobility Operations Center (66). The purpose of the Center is to track current congestion in active work zones and to coordinate the scheduling of work zone lane restrictions in the future to minimize work zone induced delays. Because Oregon is a mountainous state, and there are few parallel routes, it is important to plan for network level impacts through time. All project schedules are entered into a common database by the Regions (equivalent to Districts) and the project schedules and mobility impacts are then investigated by the Mobility Operations Center, and the Center has the authority to

recommend that a project be rescheduled if a conflict results or minimum delay thresholds are violated (67).

The delay thresholds are based on corridor level travel times, and work zones should not create travel increase that exceeds ten percent more than the travel times experienced during peak traffic volumes under normal conditions. The Center also has the objective of ensuring that geometric and weight restrictions do not delay commercial traffic.

The Statewide Traffic Mobility Manager reports to a Traffic Mobility Committee. The Traffic Mobility Committee has the authority to allow exceptions to thresholds when special conditions make it costly to avoid delays above the threshold.

Project Level Work Zone Planning

ODOT has recognized that one of the most important elements of work zone safety is planning. Therefore, they have included traffic control planning within their overall PDP. Figure 4.12 depicts a generalized flow chart of ODOT's PDP which shows where traffic control planning fits in. During project scoping, a designated TCP Designer participates as a member of the Scoping Team to make general observations concerning traffic impacts and how traffic could potentially be staged around construction for each design alternative. After a design option has been selected and it is certain the design scope will not change appreciably, preliminary plans are developed. At this stage, the TCP Designer obtains more information about what will happen during construction and requests a "Work Zone Traffic Analysis" (WZTA) to determine when it is appropriate to close travel lanes within a work zone. The details of how ODOT's WZTA is conducted are described in the next section.

While the WZTA is conducted, the TCP Designer gathers information and works with all pertinent disciplines to develop a preliminary construction staging plan proportional to the scope of work being done. Once the results of the WZTA are obtained, they are incorporated into the preliminary plans. These Advance Plans include any special provisions and a complete pay item cost estimate. If any speed limit reduction is included in the TCP, a request for the reduction must be completed at this time. Approximately two weeks after the Advance Plans have been submitted, a Plans-In-Hand (PIH) meeting, attended by all members of the Project Development Team, is held to review the Advance Plans and to discuss any unresolved project issues. During this meeting, the TCP is examined closely for constructability issues related to project staging. Any alternate routes or detours are discussed at length (if being used) to ensure safe and efficient traffic flow around the work area. A Final TCP is then developed, incorporating any comments made during the PIH Meeting.

Once the Final TCP is approved, a certified Traffic Control Supervisor (TCS) is responsible for its implementation, administration, and maintenance throughout the life of the project. This includes making sure all traffic control devices are in place and working properly at all times, reporting excessive delays to ODOT project management, and

making recommendations to the contractor and ODOT regarding the function and efficiency of the TCP. A twenty-question TCS work zone safety checklist is presented in Figure 4.13. The TCS is required to document any adjustments, repairs, or incidents on a daily basis.

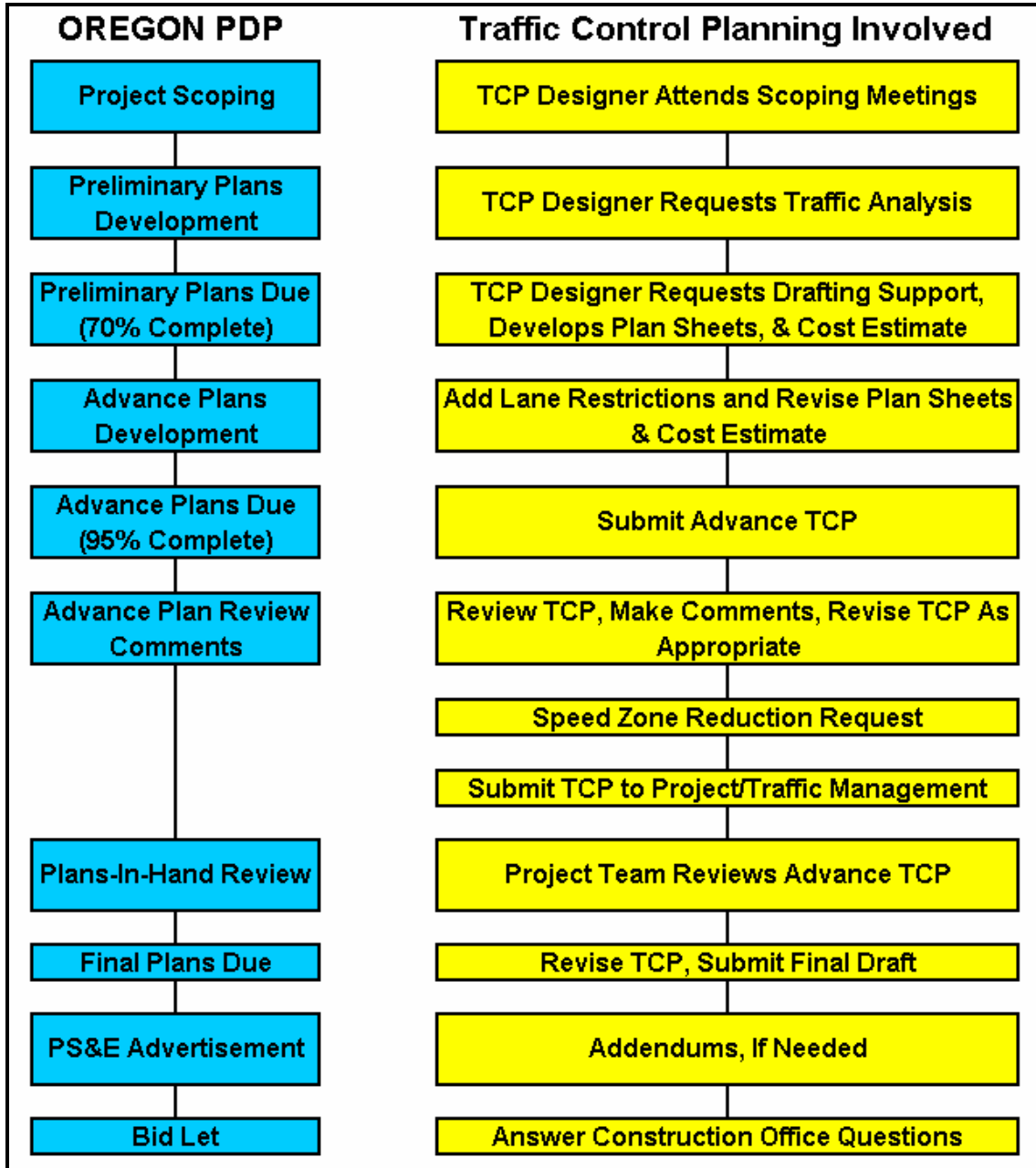


Figure 4.12. ODOT's PDP highlighting traffic control planning (68)

- 1) Does the work zone traffic control conform to the traffic control plan?
- 2) Do the work zone traffic control and the associated traffic control devices comply with the MUTCD?
- 3) Does traffic flow smoothly and safely through the work zone? Are there any “symptoms” of possible problems?
- 4) Are workers safely protected from flowing traffic?
- 5) Are provisions for pedestrians adequate? (if applicable)
- 6) Are construction equipment, materials, workers, and other vehicles kept away from flowing traffic?
- 7) Is advance warning appropriate for the work in progress?
- 8) Is the design and maintenance of temporary bypass or detour routes adequate (including posting of directional signs)?
- 9) Is traffic protected from abrupt drop-offs?
- 10) Are temporary pavement markings used effectively?
- 11) Are old pavement stripes obliterated?
- 12) Are all traffic control devices properly positioned, in sound condition, and well maintained?
- 13) Are flaggers used as needed, using appropriate equipment, and performing well?
- 14) Are permanent traffic control devices covered or turned off when they conflict with temporary traffic control in place at the work site?
- 15) Are all signs reflective and readable?
- 16) Are signs covered or removed when out of use?
- 17) Are all hazards properly shielded?
- 18) Are adequate signs and barricades in place at all intersections in the work zone?
- 19) Have provisions been made for rapid movement of emergency vehicles through or around the work area?
- 20) Have you driven through the work zone to determine if the traffic control plan works?

Figure 4.13. ODOT’s traffic control supervisor’s work zone safety checklist (69)

ODOT's Work Zone Traffic Analysis (WZTA)

Because construction projects impact traffic flow on state highways, ODOT often limits the hours that lanes and roads may be closed in work zones to reduce motorist delay and crash potential. ODOT requires a WZTA to be conducted to determine when it is appropriate to close travel lanes. Generally, a TCP Designer will submit a WZTA request form early in the PDP. A regional Traffic Analyst is then assigned to study the traffic flow patterns through the project and on any surrounding roadways which may be impacted by the construction. The goal of the WZTA is to determine how many travel lanes are required to handle the anticipated traffic volume expected to travel through the work zone during any given hour of any given day over the projected construction period. This is accomplished by comparing the projected hourly traffic volumes with the capacity of the work zone when one or more lanes are closed. Where possible, lane closures are not allowed when the projected traffic volume exceeds the work zone capacity.

The capacity analysis methodology used by ODOT does not follow the *Highway Capacity Manual (HCM)*. Instead, several default work zone capacity ranges have been developed by ODOT through many years of work zone observations and capacity studies. The standard work zone capacities used by ODOT are shown in Figure 4.14. They are intended to represent the highest sustainable capacities per lane in work zones while restricting driver delay to less than twenty minutes. Experience has shown that this method is an effective and efficient means of determining the capacity level required to keep traffic moving safely through construction project areas.

Traffic volume data for the WZTA are obtained from multiple sources at ODOT. In most cases, data from these sources are combined to make a reasonable traffic volume projection for the WZTA. Once data are obtained, projected, and adjusted to passenger car equivalents (PCEs), they are entered into ODOT's Traffic Volume Matrix shown in Figure 4.15. A particular section of highway could potentially have four such matrices—one for each direction of travel with a set for weekdays and weekends. The volumes in each cell of the matrix are then compared with the work zone capacity as shown in Figure 4.16. The Traffic Analyst should also determine if there are any local events that will seriously impact the flow of traffic through or around the work zone and if special lane closure restrictions are necessary during those events.

Some projects may not have lane closure or construction scheduling alternatives that would lessen impacts to the traveling public. In those circumstances, the objective of the WZTA is to identify the best times of the day and months of the year for lane closures. When these situations arise, the Traffic Analyst may be called upon to provide a number of other analyses in addition to the basic work zone capacity analysis. One such examination is the investigation of queue formation, which includes projecting the speed at which queues will grow and disperse, estimating the length and duration of the expected queues, and calculating vehicle delay. The data required for the capacity analysis form the basis for these analyses and no extra data are generally required by the analyst. Under these circumstances, the Traffic Analyst should also investigate the

availability of detour routes, examine if those routes are capable of supporting detoured traffic, and assess potential strategies for traffic diversion or demand reduction.

Capacities for Two-Lane Highways:	
<ul style="list-style-type: none"> Capacity will be dependent upon the length of the section. The following tables list appropriate values for the capacity of a single lane given in Passenger Car Equivalents (PCE) for the corresponding length of the two-way, one-lane section. 	
Capacity for Two-Way, One-Lane Flagged Section:	
Closure Length of Two-Way, One Lane Section	Capacity (PCE)
Less than 0.5 mi (800 m)	1050
0.5 mi (800 m) to 1.25 mi (2 km)	900
1.25 mi (2 km) to 2.5 mi (4 km)	750
Over 2.5 mi (4 km)	550
<i>Note: Closure lengths of more than 2 miles should be avoided because they can lead to dangerous access conflicts and other unsafe situations.</i>	
Capacity for HMAC/Chip Seal Rural Preservation Projects:	
Closure Length of Two-Way, One Lane Section	Capacity (PCE)
Less than 1.25 mi (2 km)	900
1.25 mi (2 km) to 2.5 mi (4 km)	750
2.5 mi (4 km) to 5 mi (8 km)	550
<i>Note: Chip seal closure lengths of less than 1.25 mi (2 km) are not typically encountered.</i>	
Capacities for Multi-lane Highways & Freeways:	
<ul style="list-style-type: none"> Typical capacities will range from 1200 to 1600 PCE's, depending upon average driver experience and familiarity, as well as density of development. 	
Highway/Freeway Area Type	Capacity (PCE)
Rural	1200 - 1400
Urban/Suburban	1400 - 1600
NOTES:	
<ul style="list-style-type: none"> The above capacities are based on 12 foot lanes with at least 2 feet of clearance on each side. Narrower lanes or clearances will result in reduced capacities. Other factors that could reduce capacity are steep grades, poor pavement conditions, or unfamiliar drivers. These capacities assume continuous flow roadway sections. Signalized intersections and other interrupted flows are analyzed separately. Standard capacities per lane within a work zone take into account the basic uncertainty in projecting volumes with limited data, the variability of weather conditions, driver perception, driver uncertainty and experience, as well as variability in the traffic stream itself. Consequently, a range of anticipated capacities is more appropriate than one fixed value. The Traffic Analyst depends upon his or her experience and knowledge of the area to estimate the lane capacity from the above tables. In general, the above capacity values are valid, but may be modified by the Traffic Analyst for specific locations or projects. 	

Figure 4.14. ODOT's standard work zone capacities (68)

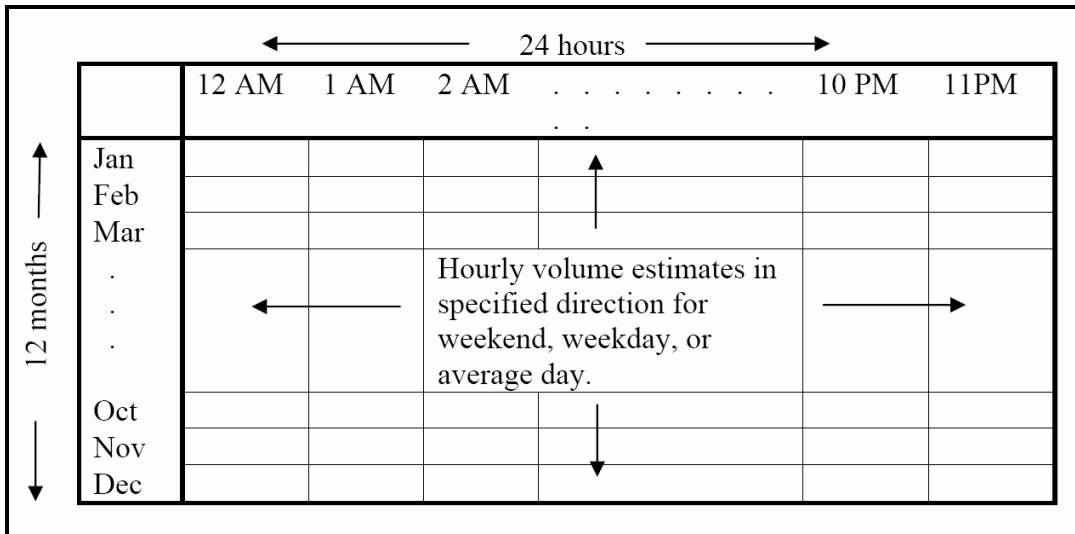


Figure 4.15. ODOT's traffic volume matrix (68)

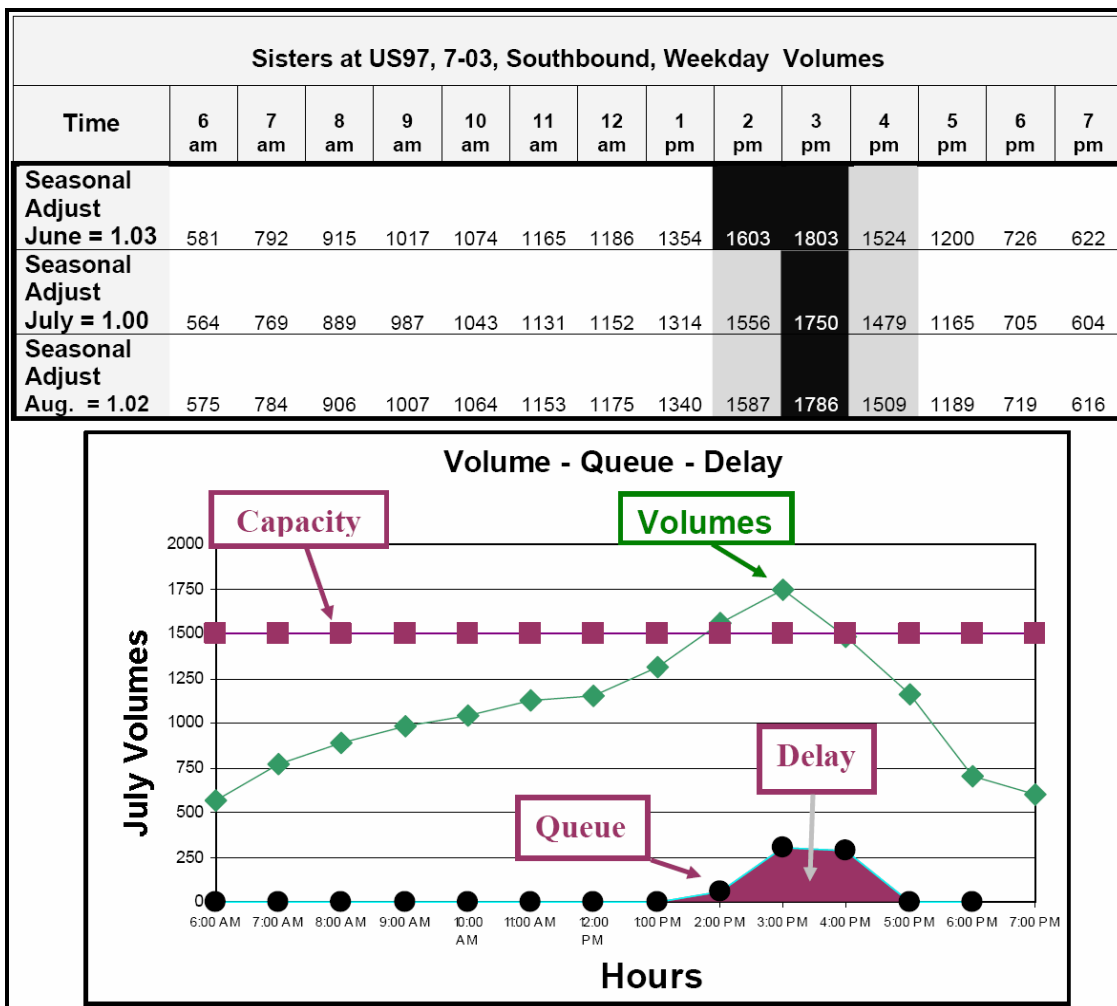


Figure 4.16. ODOT's work zone traffic analysis (volume vs. capacity) (68)

ODOT's philosophy has been to "get in, get out, and stay out". Therefore, if ODOT can significantly reduce the number of days that construction will impact a highway, they will gravitate toward the full-closure alternative first. In addition to offering maximum worker safety, full closures facilitate quicker project completion, allowing crews to work unencumbered by work zone traffic and satisfying the public by getting the route back open to regular operation as soon as possible. An example of a successful full-closure project undertaken by ODOT was the resurfacing of I-84 in Portland (70).

Incentive/Disincentive (I/D) clauses can also be added to a contract to offer a financial incentive to the contractor to complete critical work in a timely fashion, thus minimizing traffic delays and inconvenience to the traveling public. ODOT project teams are more frequently using I/D clauses for projects which have the following conditions: (1) high traffic volumes, (2) major reconstruction or rehabilitation on an existing facility that will severely disrupt traffic according to the WZTA, or (3) lengthy or inadequate detours.

ODOT's "QuickFax" Service (71)

After a 1997 flood shut down many of Oregon's major highways, ODOT tried to keep the media informed about road closures by faxing out the information to various media outlets. It took about three hours to get the information out to those who needed it. By the time the media received the information, it was already outdated. As a result, ODOT's Public Affairs Department, in cooperation with U.S. West, developed a QuickFax Service that delivers up to 50 faxes at one time. This system has since been extremely helpful in getting information out to the media regarding road closures, work zones, and other traffic congestion. Additionally, ODOT decided to use this system to inform commercial truckers of closures and traffic delays on Oregon state highways. The program has become a staple of truckers in the Oregon area. Trucking companies can subscribe to the service to get on the "QuickFax" list. ODOT then sends them up-to-the-minute information regarding immediate traffic delays related to traffic incidents, weather, or work zones. The trucking companies can then dispatch the information to their truckers so that they can take alternate routes to their destinations. According to ODOT, this service defers ten percent of traffic from a delayed area. Travelers, including truckers, can also get up-to-the-minute travel information from ODOT's Travel Advisor at <http://www.tripcheck.com/pages/>.

CHAPTER 5. CONCLUSIONS

This report looks at strategies that State Transportation Agencies (STAs) may employ to improve, manage, and monitor work zone safety and mobility. We took the approach that work zone impacts for a specific project can be examined and managed at any step of the project development process, ranging from long-range planning and policy development, all the way through the project delivery process and through follow-ups and post project reviews (postmortems). Following the steps through project development, we investigated what STAs are currently doing through a review of the literature, interviews with representatives of 30 STAs, and detailed case studies conducted with three STAs.

We first looked in the literature and, because most strategies are not commonly documented in the open literature, we did not find much that dealt directly with strategies used by STAs. Those responsible for implementation of work zone strategies are not inclined to document their strategies in the open literature. Instead, processes are developed through internal practices established over time and only a few STAs have taken the effort to fully document those practices; although, more state-level manuals covering strategies seem to be being developed by individual agencies. The Maryland State Highway Administration recently published an excellent manual on work zone strategies (72). However, the lack of any published literature documenting and comparing practices at individual STAs is the best justification for the project reported here.

This project covered many different issues and many different approaches taken by several jurisdictions, and there are many good strategies identified in the body of the text. We were, however, able to reach a few overarching recommendations/conclusions. They are discussed below.

Comprehensive Consideration of Work Zone Impacts throughout the Project Development Process

All STAs we spoke to were working on one or more strategies to reduce the impacts of work zones in one or more steps of the project development process. Generally, the respondents were very enthusiastic about the progress their agencies have made in one or more aspects of managing safety and mobility in work zones. Often, the individuals we spoke with were most familiar with aspects of work zone management that they dealt with on a day-to-day basis and were unaware of how other parts of the organization took work zone into consideration. We found that only California and Ohio (there may be more states than this, but these were the two we discovered) had really thought about work zone impacts throughout the life-cycle of project development and project delivery and had documented the roles and interactions between different offices (functional areas like planning, traffic engineering, etc.) with respect to work zone impacts during the project development and delivery process.

Although work zone planning, development, and operation are just part of the entire project development process, STAs need to develop work zone strategies that mesh with

the larger program. In fact, most of the work zones strategies applied by the Ohio DOT are embedded in the overall 14-step project development process. Whether as part of the larger project development process, or as stand-alone procedure, steps in the project development process and the work zone impacts of decisions made throughout the project development process need to be examined and understood by the involved offices.

Policy and Policy Plan Level Direction on Work Zone Impacts

The new federal work zone safety and mobility rule states that “states shall implement a policy for the systematic consideration and management of work zone impacts on all federal-aid projects.” Therefore, STAs will develop agency-level policies to address work zones. When we interviewed representatives from STAs, very few told us about agency policies regarding work zones or that work zones were addressed in policy plans. Clearly, this is an area where STAs are going to need to create policies emphasizing work zones safety and mobility. This is an issue where FHWA and/or AASHTO should be involved in educating top and upper management in the need to address work zones in agency strategic plans, long-range plans, agency business plans, and other agency policy documents.

Performance Measurement, Data Collection, and Data Standards

Most agencies we interviewed lacked objective performance data, although many described processes where they have experts review and evaluate work zones on a periodic or continuous basis. Although related to one another, safety performance and mobility performance are measured through different attributes and, therefore, they are discussed separately.

Safety performance. Although crash data are, more or less, collected automatically through crash reports filled-out by officers or submitted by individuals involved in crashes, even these data tend to be unreliable and, for some agencies, difficult or impossible to obtain within a reasonable time period. For example, Ruab et al. examined 110 crashes that were located in and around work zones in Northern and Western Illinois (73). Out of the 110, seven would have occurred whether the work zone was there or not and, therefore, 103 were work zone related. Of the 103 crashes, the reporting officer failed to check the box for work zone on 47 of these crash reports (46 percent). A new Model Minimum Uniform Crash Criteria guideline has been published since Ruab et al. completed their study, and more information is collected on work zones on the new model crash record for those jurisdiction that have adopted the new model crash record format. Regardless of whether the new form is used, many work zone crashes go unreported or miss-reported. Although Ruab et al. found that officers failed to code work zone-related crashes even when the crashes were within the lane closure area, we suspect that many crashes get unreported as being work zone related when they occur well upstream of the work zone and are a result of queuing upstream from work zone lane restriction.

The new National Model for collecting crashes information, Traffic and Criminal Software (TraCS), involves locating crashes with digital maps and GPS and compiling crash reports on in-vehicle computers and sending records to a statewide database immediately or shortly after the crash (the end of the officer's work shift) (74). This system provides the promise of obtaining accurate crash data in a relevant time frame, but only 21 states are participating in the TraCS program and, in those states, not all police agencies are participating. STAs like the Ohio DOT are making the best of what is available from existing record keeping systems (see Ohio case study in Chapter 4), but even they have to wait for paper records to flow into the Ohio Department of Motor Vehicles and then DOT staff make paper copies of the relevant records every other week and enter the data into a separate work zone-specific database (see Figure 4.6).

The institutions and technology used to collect crash information are unique in each state, and STAs will have to develop their own unique methods for establishing methods for collecting, performing quality assurance, managing, and analyzing work zone crash data. However, as was found in Ohio, this information is valuable for making operational decisions at current work zones and is available to make safety performance comparison between and among work zones.

Mobility performance. Modern ITS devices used to help manage traffic typically contain technology to measure speeds and flows and detect queues and other traffic flow attributes. The objectives of the measurements are not generally to collect and report mobility performance data, but they do illustrate that technology is available to collect mobility performance information. There is a need for devices to process, store, and compare performance through time and between work zones.

As an illustration of mobility performance data collected by automated traffic control, the figure below shows data collected on an urban freeway in Baltimore, Maryland. The Maryland State Highway Administration (SHA) installed two portable Changeable Message Signs (CMS) that displayed an alternating message when vehicles approached. The CMS flashed the speed of the approaching vehicles in MPH and then "Obey Speed Limit 50 MPH." The two CMSs were placed up-stream from the work zone lane restriction—the first one was nearly a mile upstream and the second one was placed 1,200 feet upstream. Plotted in the Figure 5.1 are the average speeds at the second device immediately before and after deployment and after the CMS was removed. The figure illustrates the ability of the device to collect mobility performance data. The data also show that the device had an initial impact (novelty affect) and reduced average speeds but as drivers became more familiar with the device tends to have less impact on speed.

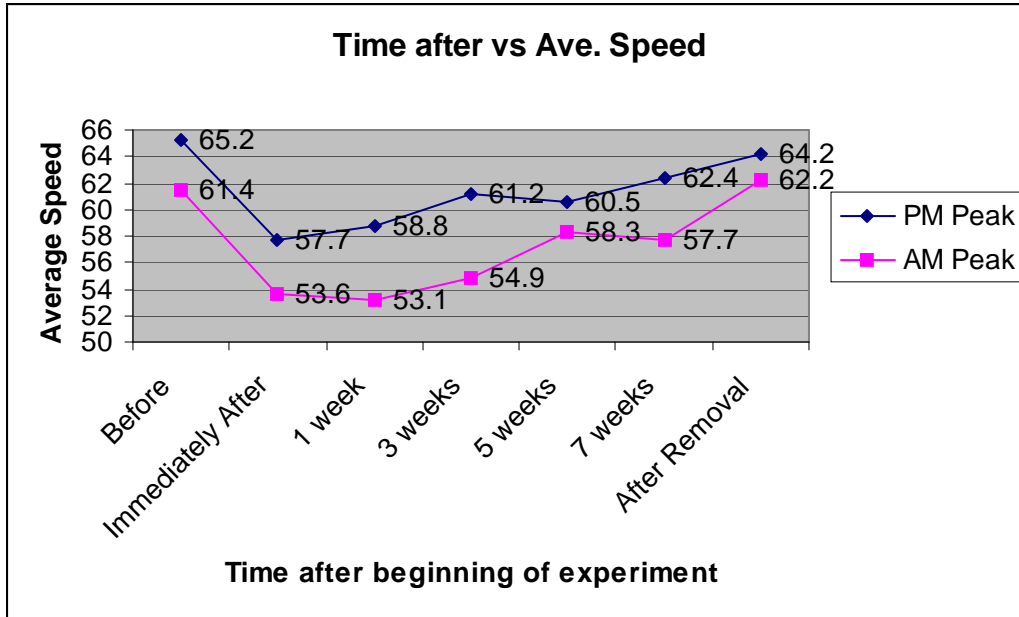


Figure 5.1. Average speeds at the second device

REFERENCES

1. Scriba, T., and J. Seplow. "Making Work Zones Work Better: The Final Rule on Work Zone Safety and Mobility," *ITE Journal*, April, 2005, 38–42.
2. Battles, S.L., and J.W. Trombly. "Results of 2002-2003 Work Zone Self Assessment." Institute of Transportation Engineers Annual Meeting, Seattle, Washington, August 24–27, 2003.
3. *Meeting the Customer's Needs for Mobility and Safety During Construction and Maintenance Operation*. Washington, DC: Office of Program Quality Coordination, Federal Highway Administration, 1998.
4. *Work Zone Operations Best Practices Guidebook*. Publication No. FHWA-OP-00-010. Washington, DC: Federal Highway Administration, 2000.
5. Minnesota Department of Transportation. Metropolitan District Lane Closure Manual. 2003. <http://www.dot.state.mn.us/metro/trafficeng/laneclosure/index.html>.
6. *Transportation Asset Management Case Studies: Highway Economic Requirements System, the Oregon Experience*. Washington, DC: Office of Asset Management, Federal Highway Administration, U.S. Department of Transportation.
7. Office of Transportation Safety. Work Zone Safety. Salem, Oregon: Oregon Department of Transportation. http://egov.oregon.gov/ODOT/TS/docs/03_PPP_Workzone.pdf.
8. *Highway Project Development Process Handbook: Overview*. St. Paul, Minnesota: Minnesota Department of Transportation. 1999. <http://www.dot.state.mn.us/tecsup/xyz/plu/hpdp/book1/overview/overview.pdf>.
9. Transportation Management Plan Guidelines. Traffic Operations Program, Office of Systems Management Operations, California Department of Transportation, Sacramento, California, 2004.
10. Krammes, R.A., G.L. Ullman, G.B. Dresser, and N.R. Davis. *Travel impacts of Urban Freeway Reconstruction Projects in Texas*. Report FHWA/TX 91/1108-3. College Station, Texas: Texas Transportation Institute, 1990.
11. Dalzeill, E., and A. Nicholson. "Risk and Impact of Natural Hazards on a Road Network," *Journal of Transportation Engineering* 127, no. 2 (2001): 159–165.
12. Cairns, S., C. Hass-Klau, and P. Goodwin. *Traffic Impact of Highway Capacity Reductions: Assessment of the Evidence*. Prepared for London Transport and The Department of the Environment, Transportation and the Regions, London, England, 1998.

13. Saag, J.B., *Project Development Methodologies for Reconstruction of Urban Freeways and Expressways*. National Cooperative Highway Research Program, Synthesis of Highway Practice 273. Washington, DC: Transportation Research Board, 1999.
14. Federal Highway Administration. *Traffic Safety in Highway and Street Work Zones. Federal-Aid Policy Guide, Par 630J*. Washington, DC: Federal Highway Administration, 1991.
15. Graham, J.L., and J. Migletz. *Synthesis of Highway Practice 208: Development and Implementation of Traffic Control Plans for Highway Work Zones*. NCHRP 208. Washington, DC, 1994.
16. Conger, S.M. *Winter Highway Operations: A Synthesis of Highway Practice*. NCHRP 344. Washington, DC: Transportation Research Board, 2005.
17. Fischer, T.M.. “Nebraska’s Smart Work Zone Initiative.” Presentation made at the WASHTO annual meeting, Omaha, Nebraska, July, 2005.
18. Horowitz, A.J., I Weisser, and T. Notbohm. *Diversion from a Rural Work Zone Owing to a Traffic-Responsive Variable Message Sign System*. Center for Urban Studies, University of Wisconsin Milwaukee, 2003.
19. Zwahlen, H.T. and A. Russ. “Evaluation of Real-Travel Time Prediction System in a Freeway Construction Work Zone.” Proceedings of the Transportation Research Board Annual Meeting. Washington, DC. 2002. CD-ROM.
20. Pigman, J.G., and K.R. Agent. *Evaluation of Traffic Information and Prediction System (TIPS) as work Zone Traffic Control*. Report KTC-04-10/FR128-03-1F. Kentucky Transportation Center, University of Kentucky, 2004.
21. “Work Zone Safety Inspection Checklist” Washington, DC: Federal Highway Administration. <http://www.fhwa.dot.gov/construction/revzone6.htm>.
22. Maze, T.H, S.D. Schrock, and K.S. VanDerHorst. *Traffic Management Strategies for Merge Areas in Rural Interstate Work Zones*. Ames, IA: Center for Transportation Research and Education, Iowa State University, 1999.
23. Dixon, K.K., and J.E. Hummer. *Capacity and Delay in Major Freeway Construction*. Report 23241-94-8. Center for Transportation Engineering Studies, North Carolina State University, 1995.
24. Memmott, J.L., and C.L. Dudek. *A Model to Calculate the Road User Cost at Work Zones*. Report FHWA/TX-83/20+292-1. Austin, TX: Texas Transportation Institute, 1982.

25. Dixon, K.K., J.E. Hummer, and N.M. Rouphail. "Comparison of Rural Freeway Work Zones Queue Length Estimation Techniques: A Case Study," Presented to Transportation Research Board Annual Meeting, Washington, DC, 1998.
26. Schnell, T., and F. Aktan. *On the Accuracy of Commercially Available Macroscopic and Microscopic Traffic Simulation Tools for Predication of Workzone Traffic*. Report FHWA/HWA-2001/08. Final Report Submitted to the OH/DOT, May 2001.
27. Benekohal, R.F., A. Kaja-Mohideen, and M.V. Chitturi. *Evaluation of Construction Work Zones Operational Issues: Capacity, Queue, and Delay*. Project IVA-H1, FY – 00/01. Report No. ITRC FR 00/01-4. Champaign, IL: Illinois Transportation Research Center, University of Illinois, 2003.
28. Al-Kaisy, A., and F. Hall. "Guidelines for Estimating Capacity at Freeway Reconstruction Zones." *Journal of Transportation Engineering* 129, no. 5(2003): 572–577.
29. Kim, T., D.J. Lovell, M. Hall, and J. Paracha. "New Methodology to Estimate Capacity for Freeway Work Zones." Presented at the Annual meeting of the Transportation Research Board, Washington, DC, January, 2001.
30. Dudek, C.L. and S.H. Richards. "Traffic Capacity through Urban Freeway Work Zones in Texas." *Transportation Research Record* 869, 1982.
31. Krammes, R.A., and G.O. Lopex. *Updated Short-Term Freeway Work Zone Lane Closures Capacity Values*. Report No. FHWA/TX-92-/1108-5. College Station, TX: Texas Transportation Institute, 1992.
32. Agarwal, M., T.H. Maze, and R.R. Souleyrette. *Impact of Weather on Urban Freeway Flow Characteristics and Facility Capacity*. Ames, IA: Center for Transportation Research and Education, Iowa State University, 2005.
33. Sullivan, E.C. *Accident Rates During Nighttime Construction*. UCB-ITS-RR-89-11. Berkeley, California: Institute of Transportation Studies, University of California Berkeley, 1989.
34. McDonald, T., B. Storm, and M.E. Anderson-Wilk. *Effectiveness of Extra Enforcement in Construction and Maintenance Work Zones*. Ames, IA: Center for Transportation Research and Education, Iowa State University, 2003.
35. CORSIM was developed by the Federal Highway Administration and can be purchased through traffic software service center like McTrans at the University of Florida. <http://mctrans.ce.ufl.edu/index.htm>.

36. SimTraffic was developed and sold by Trafficware, Ltd., PO Box 499, Sugar Land, TX 77487.
37. Anderson, M.D., and R.R. Souleyrette. "Simulating Traffic for Incident Management and ITS Investment Decisions." Proceedings of Crossroads 2000. Ames, IA, 1998, 7–11.
38. Schnell, T., J.S. Mohror, and F. Aktan. "Evaluation of Traffic Flow Analysis Tools Applied to Work Zones based on Flow Data Collected in the Field." Proceedings of the Annual Meeting of the Transportation Research Board, Washington, DC, 2002.
39. Chitturi, M.V., and R. Benekohal. "Comparison of Queue Length Estimates from QUEWZ, FRESIM, and QuickZone with Field Data." Institute of Transportation Engineers 2005 Technical Conference and Exhibit, Las Vegas, Nevada, February 2005.
40. Rakha, H., M. Van Aerde, L. Bloomberg, and X. Huang. "Construction and Calibration of a Large-scale Micro-Simulation Model of the Salt Lake Area." Proceedings of the Annual Meeting of the Transportation Research Board, Washington, DC, 1999.
41. Algiers, S. and others. *Review of Micro-Simulation Models*. SMARTTEST Project Deliverable No. 3. European Commission DGVII, Brussels, 1997.
42. Micro-Simulation Web Pages maintained by Dr Ken Fox, a Senior Consultant at Halcrow. <http://www.microsimulation.drfox.org.uk>.
43. Anderson, S., T. Kane, and M. Jha. "Use of Advanced Microscopic Traffic Simulation for Transportation Planning in Des Moines Area." Proceedings of the Mid-Continent Transportation Symposium, Ames, Iowa, 2003.
44. California Department of Transportation. *Transportation Management Plan Guidelines*. California: Traffic Operations Program, Office of Systems Management Operations, 2004.
45. "Award of Excellence in Infrastructure: 1- A+B+C Project, Reserve Relief Canal," McGraw Hill Construction, Louisiana Contractor, http://louisiana.construction.com/projects/02_Bestof/02_AwardOfExcInf.asp.
46. Lambert, M.A. "Fixin It First: Targeting Infrastructure Investments to Improve State Economies and Invigorate Existing Communities." Washington, DC: NGA Center for Best Practices, National Governors Association.
47. Kamyab, A, and T.H. Maze. *Iowa's Evaluation of the Wizard CB Alert System*. Washington, DC: Work Zone Mobility and Safety Program, Office of Operations, FHWA. <http://ops.fhwa.dot.gov/wz/workshops/accessibile/Maze.htm>.

48. Keenan, C. "Work Zones that Work." *Public Roads* 68, no 3 (2004).
49. Ohio Department of Transportation. *Project Development Process Manual*. Columbus, OH, November 2004, p. 6.
50. Ohio Department of Transportation. *Project Development Process Manual*. Columbus, OH, November 2004, Appendix H.
51. Ohio Department of Transportation. *Traffic Engineering Manual*. Columbus, OH, June 2004, Section 630-5.
52. Holstein, David. "How One State DOT is Addressing Work Zone Impacts." Transportation Research Board Annual Meeting Presentation Session 476, Washington, DC, January, 2005.
53. Ohio Department of Transportation. "Permitted Lane Closure Calculation." Columbus, OH.
https://dotaw100.dot.state.oh.us/plcm/plcm_calculations_standardizatio.htm.
54. Schnell, T., J.S. Mohror, & F. Aktan. "Evaluation of Traffic Flow Analysis Tools Applied to Work Zones Based on Flow Data Collected in the Field." *Transportation Research Record 1811*. Washington, DC: Transportation Research Board, 2002, 57–66.
55. "Ohio Keeps Motorists & Road Rehabilitation Moving Forward." Washington, DC: Federal Highway Administration, Office of Operations, Summer 2003.
<http://ops.fhwa.dot.gov/wz/practices/factsheets/factsheet8.htm>.
56. FHWA. "Final Rule on Work Zone Safety & Mobility." *Federal Register* 69, no. 174 (2004). http://www.ops.fhwa.dot.gov/wz/docs/wz_final_rule.pdf.
57. Holstein, D. "23 CFR 630 Subpart J: Work Zone Safety & Mobility—The ODOT Way." Presentation Made at the Smart Work Deployment Meeting, Davenport, IA, July 2005.
58. Joint Legislative Audit and Review Commission. *Review of Construction Costs and Time Schedules for Virginia Highway Projects: A Report in a Series on Transportation Issues in Virginia*. House Document No. 31. Richmond, VA, January 2001.
59. Virginia Department of Transportation. "Milestones in the Project Development Process." Construction Division Memorandum. Richmond, VA.
60. The information in this section was obtained from David B. Rush, VDOT Work Zone Safety Coordinator.

61. Virginia Department of Transportation. *Virginia Work Area Protection Manual: Standards & Guidelines for Temporary Traffic Control*. May 2005.
www.extranet.vdot.state.va.us/forms/Converted/TE-97001.pdf.
62. Email attachment received from David B. Rush, Virginia Department of Transportation, Work Zone Safety Coordinator, September 7, 2005.
63. Federal Highway Administration. *Meeting the Customer's Needs for Mobility & Safety during Construction & Maintenance Operations*. HPQ-98-1. Office of Program Quality Coordination, U.S. Department of Transportation, September 1998.
64. Holland, R. "Communication at Work: VDOT Shows How It's Done." July 26, 2005.
http://www.richmond.com/business/output.aspx?article_ID=3796413&Vertical_ID=2&tier-1&position=2.
65. "Mobility Center tracks road, bridge projects." *Quarterly Oregon Motor Carrier News*. Oregon Department of Transportation, 2005.
66. "Randal Thomas—Keeping Oregon's Traffic on the Move." *Inside ODOT* (internal news letter of the Oregon Department of Transportation), December 2004.
67. "Traffic Mobility Operations Room Allows Statewide Project Monitoring." *Inside ODOT*, May 2005.
68. Oregon Department of Transportation. *Traffic Control Plans Design Manual*, 2005.
http://www.oregon.gov/ODOT/HWY/TRAFFIC/Traffic_Control.shtml.
69. Oregon Department of Transportation. *Traffic Control Safety Workbook*. p. 54.
<http://www.cbs.state.or.us/external/osha/pdf/workshops/305w.pdf>.
70. Kuennen, T. "Stay Out: Portland I-84 Speed of Construction." *Hot Mix Asphalt Technology*, December 2002, 12–15.
71. Federal Highway Administration, Office of Operations. *Oregon's "QuickFax" Service*. FHWA Publication No. FHWA-OP-00-022, July 2000,
<http://www.ops.fhwa.dot.gov/wz/practices/factsheets/factsheet1.htm>.
72. Maryland State Highway Administration. *Work Zone Safety Toolbox*. Baltimore, MD, 2005.
73. Raub, R.A., O.B. Sawaya, J.L. Schofer, and A. Ziiaskopoulos. "Enhanced Crash Reporting to Explore Workzone Crash Patterns." Proceedings of the Annual Meeting of the Transportation Research Board, Washington, DC, January 2001, CD-ROM.
74. The National Model for the Statewide Application of Data Collection & Management, Iowa DOT, Des Moines, Iowa, <http://www.dot.state.ia.us/natmodel/>