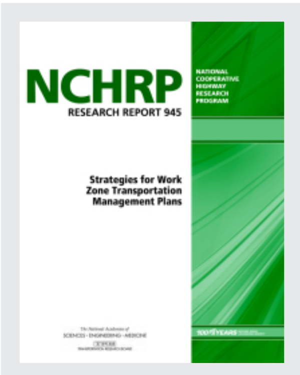


Strategies for Work Zone Transportation Management Plans (2020)

DETAILS

256 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-48178-6 | DOI 10.17226/25929

CONTRIBUTORS

Leverson Boodlal, Dileep Garimella, Kevin Chiang, KLS Engineering, LLC, Steven D. Schrock, University of Kansas, and Eric J. Fitzsimmons, Kansas State University; National Cooperative Highway Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine 2020. *Strategies for Work Zone Transportation Management Plans*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25929.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 945

Strategies for Work Zone Transportation Management Plans

Leverson Boodlal
Dileep Garimella
Kevin Chiang
KLS Engineering, LLC
Ashburn, VA

Steven D. Schrock
University of Kansas
Lawrence, KS

Eric J. Fitzsimmons
Kansas State University
Manhattan, KS

Subscriber Categories
Construction

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

The National Academies of
SCIENCES · ENGINEERING · MEDICINE
TRB
TRANSPORTATION RESEARCH BOARD
2020

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed, and implementable research is the most effective way to solve many problems facing state departments of transportation (DOTs) administrators and engineers. Often, highway problems are of local or regional interest and can best be studied by state DOTs individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration (FHWA), United States Department of Transportation, under Agreement No. 693JJ31950003.

The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine was requested by AASHTO to administer the research program because of TRB's recognized objectivity and understanding of modern research practices. TRB is uniquely suited for this purpose for many reasons: TRB maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; TRB possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; TRB's relationship to the National Academies is an insurance of objectivity; and TRB maintains a full-time staff of specialists in highway transportation matters to bring the findings of research directly to those in a position to use them.

The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments, by committees of AASHTO, and by the FHWA. Topics of the highest merit are selected by the AASHTO Special Committee on Research and Innovation (R&I), and each year R&I's recommendations are proposed to the AASHTO Board of Directors and the National Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

NCHRP RESEARCH REPORT 945

Project 03-111
ISSN 2572-3766 (Print)
ISSN 2572-3774 (Online)
ISBN 978-0-309-48178-6
Library of Congress Control Number 2020942722

NOTICE

The research report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the National Academies of Sciences, Engineering, and Medicine.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board; the National Academies of Sciences, Engineering, and Medicine; the FHWA; or the program sponsors.

The Transportation Research Board; the National Academies of Sciences, Engineering, and Medicine; and the sponsors of the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

Published research reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet by going to

https://www.nationalacademies.org

and then searching for TRB

Printed in the United States of America

The National Academies of

SCIENCES • ENGINEERING • MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.nationalacademies.org**.

The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to provide leadership in transportation improvements and innovation through trusted, timely, impartial, and evidence-based information exchange, research, and advice regarding all modes of transportation. The Board's varied activities annually engage about 8,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Learn more about the Transportation Research Board at **www.TRB.org**.

C O O P E R A T I V E   R E S E A R C H   P R O G R A M S

CRP STAFF FOR NCHRP RESEARCH REPORT 945

Christopher J. Hedges, *Director, Cooperative Research Programs*
Lori L. Sundstrom, *Deputy Director, Cooperative Research Programs*
Ann M. Hartell, *Senior Program Officer*
Jarrel McAfee, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Natalie Barnes, *Associate Director of Publications*

NCHRP PROJECT 03-111 PANEL
Field of Traffic—Area of Operations and Control

Chris Ryan Brookes, *Michigan DOT, Lansing, MI* (Chair)
Imad S. Aleithawe, *Waggoner Engineering, Inc., Jackson, MS*
Neil E. Boudreau, *Massachusetts DOT, Boston, MA*
Praveen K. Edara, *University of Missouri—Columbia, Columbia, MO*
Rochelle Hosley, *NYS Thruway Authority, Albany, NY*
Martha C. Kapitanov, *FHWA Liaison*
James W. Bryant, Jr., *TRB Liaison*

AUTHOR ACKNOWLEDGMENTS

The authors of this guidebook gratefully acknowledge the following agencies and agency representatives for providing information to support this research effort:

- Alabama Department of Transportation—Jeff Benefield
- Arizona Department of Transportation—Jesús Sandoval-Gil
- California Department of Transportation—Arvern Lofton and Marvin Guiñez
- Colorado Department of Transportation—Alvin Stamp
- Florida Department of Transportation—Gevin McDaniel
- Illinois Department of Transportation—Juan Pava
- Indiana Department of Transportation—Mischa Kachler and John McGregor
- Kansas Department of Transportation—Garry Olson
- Maricopa County, Arizona, Department of Transportation—Faisal Saleem
- Massachusetts Department of Transportation—Neil Boudreau
- Michigan Department of Transportation—Chris Brookes
- Minnesota Department of Transportation—Ted Ulven and Adam Wellner
- Missouri Department of Transportation—Daniel Smith
- North Carolina Department of Transportation—Steve Kite
- North Dakota Department of Transportation—Bernie Southam
- Ohio Department of Transportation—Duane Soisson
- Oklahoma Department of Transportation—Saad El Bakkouri
- Pennsylvania Department of Transportation—Matthew Briggs and Brian Crossley
- South Dakota Department of Transportation—Jared Pfaff
- Texas Department of Transportation—Nicholas Aiello and Jesus Valdez
- Utah Department of Transportation—Joshua Van Jura and Justin Wilstead
- Washington State Department of Transportation—Steve Haapala
- Wisconsin Department of Transportation—Erin Schoon

FOREWORD

By Ann M. Hartell
Staff Officer
Transportation Research Board

NCHRP Research Report 945 provides a practitioner-ready guidebook on how to select and implement strategies that improve safety and traffic operations in roadway construction work zones. The guidebook will be of interest to those responsible for developing and maintaining state department of transportation (DOT) work zone transportation management plans (TMPs), as well as construction contractors and those who train and supervise roadway construction workers.

According to the National Work Zone Safety Information Clearinghouse, from 2010 through 2018, an average of 679 people died each year as a result of crashes in work zones. Among the fatalities were work zone workers, pedestrians, bicyclists, and drivers and passengers in trucks, buses, and automobiles. In addition, more than 30,000 people are injured in work zone crashes each year. At the same time, construction work zones on freeways are estimated to account for nearly 24% of non-recurring delay. Travelers are also frustrated by congestion-related delays as well as unexpected road conditions and inconsistent traffic operations.

One of the ways a state DOT or other transportation agency can address work zone safety and other impacts is to develop and implement a TMP. A TMP consists of a set of coordinated strategies selected to manage the work zone impacts of a road construction project, without unreasonably compromising project constructability. TMPs outline specific strategies selected to support project goals associated with the safety of roadway users and construction workers, traffic mobility, and other operational targets during the construction period. TMPs are used to clearly define and communicate the comprehensive plan for construction project management to internal state DOT staff, contractors, the public, and the media. Because work zone impacts and issues vary, agencies must consider the mobility and safety needs of their road users, highway workers, businesses, and communities to develop an effective TMP.

NCHRP Research Report 945 describes a wide range of TMP strategies as well as how to select the most effective and cost-efficient strategy for a particular construction setting. For each strategy, the guidebook provides a brief description, conditions where the strategy is appropriate, anticipated benefits, documented effectiveness, crash modification factors (CMFs), design requirements including hardware or software needed, implementation considerations, estimated cost, and examples of its use.

The research was conducted by KLS Engineering with collaboration from the University of Kansas and Kansas State University. The research effort included a review of published literature, a survey of current practice, and a field evaluation of three strategies: truck-lane restrictions, temporary ramp metering, and reversible lanes. The field evaluations were conducted in partnership with Michigan DOT, Pennsylvania DOT, and Minnesota DOT.

The guidebook is accompanied by a set of brief fact sheets on the three evaluated strategies. The fact sheets and the report appendices can be found on the TRB website by searching for “NCHRP Research Report 945”. The contractor’s final report, which details the research activities and methods, is published as *NCHRP Web-Only Document 276* and can be found by searching the TRB website for “NCHRP Web-Only Document 276”.

CONTENTS

CHAPTER 1

Introduction

Periodic work zones are necessary to build, maintain, rehabilitate, enhance, and reconstruct this nation's roadway network. Over the course of 1 year, it was estimated that 26.5 percent of the National Highway System has at least 1 day with a work zone in place. In the peak summer months, it is estimated that 7.9 percent of the National Highway System has a work zone in place on any given workday (Ullman et al. 2018).

1.1 Work Zones' Effect on Safety

Unfortunately, work zones can mean daily changes in traffic patterns, narrowed rights-of-way (ROWs), and other construction activities that create a combination of factors resulting in crashes. According to the National Work Zone Safety Information Clearinghouse, from 2010 through 2018, an average of 680 people died each year as a result of crashes in work zones. In 2017, the last year for which complete crash data are available, work zone crashes resulted in 809 fatalities and 37,000 injuries.[1] Table 1.1 shows the work zone fatality and injury data for 2010–2018.

Additionally, work zone crashes occur in a constrained driving environment and cause congestion and excessive delays. Estimates are that work zone crashes account for 10 percent of overall congestion and 24 percent of nonrecurring freeway delays nationwide.[2]

Reducing these crashes and delays—and their negative effects on lives and the economy—requires a better understanding of the effectiveness of work zone transportation management strategies. Transportation management plans (TMPs) are coordinated strategies designed to help agencies achieve their work zone project goals related to traffic mobility, efficient system operation, motorists' and workers' safety, and other operational targets.

State departments of transportation (DOTs) and other transportation agencies currently develop and implement TMPs, which typically involve coordinated strategies related to temporary traffic control, transportation operations, and public awareness. TMPs also help road users traverse work zones safely by understanding project effects, alternatives, scheduling, and anticipated benefits.

State DOT practices, however, vary considerably with respect to what the agency considers when selecting strategies to integrate into a TMP. Practitioners can be uncertain of the effectiveness

[1] National Work Zone Safety Information Clearinghouse, *Work Zone Fatal Crashes and Fatalities*. (https://www.workzonesafety.org/crash-information/work-zone-fatal-crashes-fatalities/#national, accessed May 12, 2020).
[2] Data from congestion are from Cambridge Systematics and Texas Transportation Institute (2004); Data on nonrecurring freeway delays are from Chin et al. (2004).

Table 1.1. Work zone crash facts, fatalities, and injuries.

Year	Total Work Zone Fatalities	Total Work Zone Injuries	Total Work Zone Crashes
2010	586	36,000	87,000
2011	590	39,000	91,000
2012	619	30,000	76,000
2013	593	25,000	68,000
2014	670	31,000	89,000
2015	718	35,000	97,000
2016	782	61,000[a]	158,000[a]
2017	809	37,000[a]	94,000[a]
2018	755	NA	NA
Average	**680**	**36,750**	**95,000**

NOTE:
[a]NHTSA has redesigned the sampling process used to compute these estimates. Therefore, 2016 and later data are not directly comparable to data from 2015 and before. Data for injuries and crashes greater than 500 have been rounded to the nearest 1,000 and values less than 500 have been rounded to the nearest 100 to reflect the level of uncertainty associated with these estimates. NA = not available.

of their safety solutions and the value of their economic benefit. As a result, transportation agencies may not understand the application, its effectiveness, or the cost-efficiency of their TMP decisions.

1.2 Project Objective

NCHRP Project 03-111, "Effectiveness of Work Zone Transportation Management Plan Strategies," had two objectives:

1. Provide information in the form of a guidebook on a wide range of TMP strategies for work zone practitioners.
2. Conduct field evaluations of selected TMP strategies—truck-lane restrictions, ramp metering, and reversible lanes.

The field evaluation results are provided in the final report for NCHRP Project 03-111, which is published as *NCHRP Web-Only Document 276* and is available on the TRB website.

1.3 Guidebook Purpose

Although there is a wealth of information on transportation management planning, it is scattered among published research, DOT handbooks, manuals, and plans, as well as unpublished documentation. This guidebook is a resource that synthesizes useful knowledge from diverse sources to provide a compendium of current knowledge on work zone strategies, including suggestions on when to use, benefits, effectiveness, technical issues, design requirements, state of the practice, and cost.

1.4 Guidebook Target Audience

The intended audience for this guidebook includes transportation agency technical staff (e.g., planners, designers, construction and traffic engineers), and management and executive-level staff responsible for setting work zone policy and directing programs; FHWA staff, especially those with oversight responsibilities; and contractors, consultants, academics, and others with interest in work zone operations.

1.5 Guidebook Contents and Organization

Many work zone management strategies can be used to minimize traffic delays, improve mobility, maintain or improve motorist and worker safety, and complete roadwork promptly. The strategies presented and reviewed in this guidebook are grouped according to the FHWA TMP classification under the following three categories:

1. Transportation operations
   – Work zone safety management strategies
   – Corridor/network management (traffic operations) strategies
   – Traffic incident management and enforcement strategies
   – Demand-management strategies
2. Temporary traffic control
   – Control strategies
   – Project coordination
   – Alternative contracting and construction strategies
   – Traffic control devices (TCDs)
3. Public awareness
   – Motorist information strategies
   – Public awareness strategies

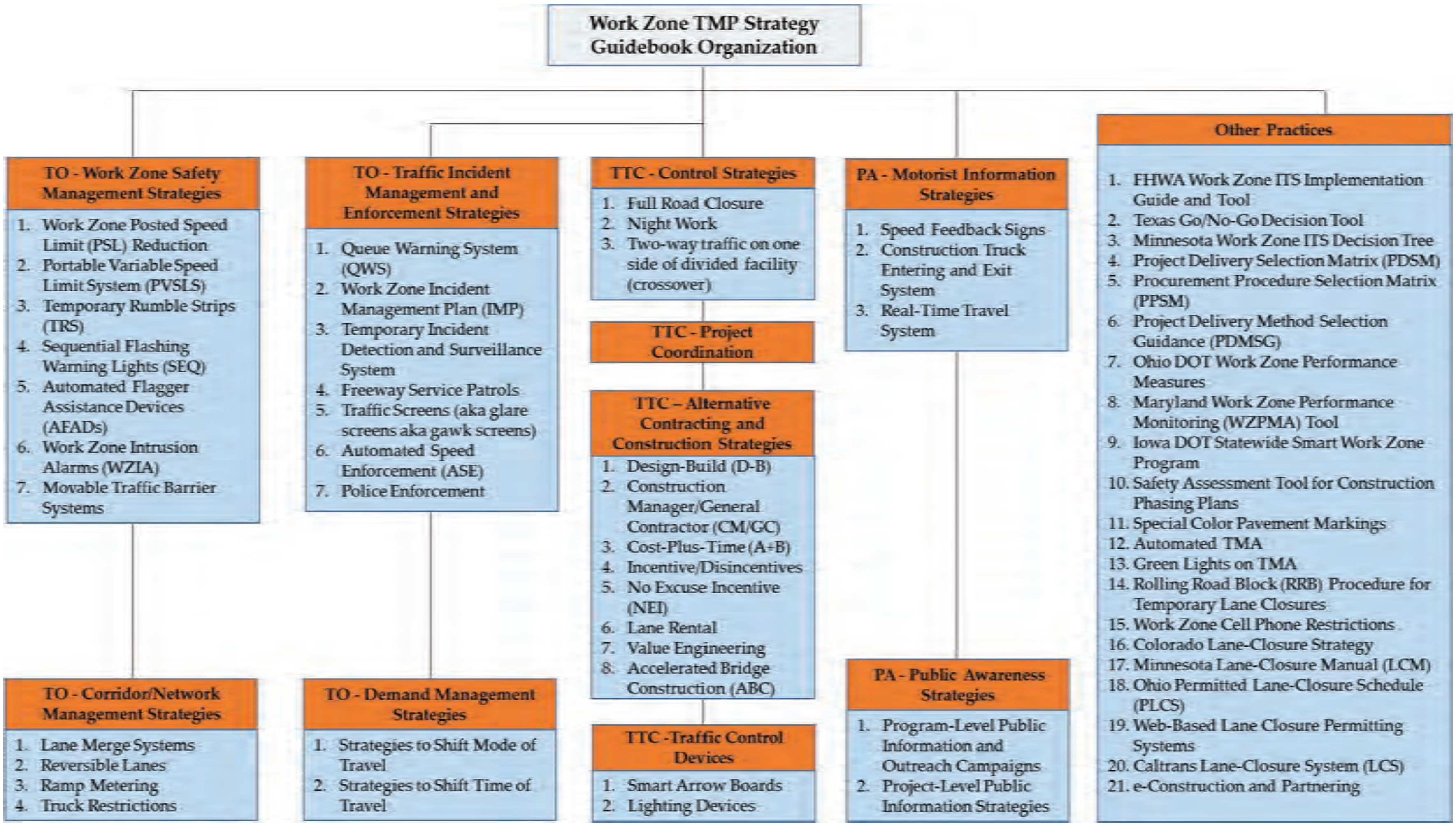
The guidebook devotes a section to each of these three major categories. The entry for each strategy is organized as follows:

- **Description.** Provides short overview and description.
- **When to Use.** Discusses conditions for use.
- **Benefits.** Discusses typical strategy benefits in terms of improving safety and mobility.
- **Expected Effectiveness.** Describes known effectiveness based on field studies.
- **Crash Modification Factor.** Presents estimated and known crash modification factors (CMFs) based on information presented in *NCHRP Research Report 869: Estimating the Safety Effects of Work Zone Characteristics and Countermeasures—A Guidebook* (Ullman et al. 2018).
- **Implementation Considerations**. Discusses how the strategy functions and if there are any installation concerns, potential difficulties, maintenance issues, and so on.
- **Design Features and Requirements.** Provides information on the appropriate design criteria, and hardware and software requirements if any.
- **State of the Practice.** Provides examples where a strategy has been used with special provisions and standard typical drawings, as applicable.
- **Cost.** Reviews estimated installation cost.
- **Resources and References.** Presents related resources and cited materials.

Figure 1.1 shows how the strategies are grouped to help users find relevant practices.

In addition to the category and subcategory designations, strategies are cross-referenced as shown in Appendix A (Appendices A through N can be found on the TRB website by searching on “NCHRP Research Report 945.”). The cross-references allow practitioners to identify these strategies based on traffic conditions in the work zone, the type of roadway involved, geographic or demographic characteristics, and when in the project life-cycle stage they are used.

Another category—best practices—was introduced to account for those strategies that do not have a measurable value for effectiveness. The best practices include emerging technologies, decision-making tools, case studies, and the successful policies and procedures of a few state DOTs.



Note: Caltrans = California Department of Transportation; DOT = Department of Transportation; ITS = intelligent transportation system; PA = public awareness; TMA = truck-mounted attenuator; TMP = transportation management plans; TO = transportation operation; TTC = temporary traffic control.

Figure 1.1. Guidebook strategy organization.

In addition, Chapter 13 provides information on the typical work zone crash characteristics, as well as methods to estimate the crashes expected to occur during a particular work zone compared with when the work zone is not present or when a particular countermeasure is included. Examples illustrate how the methods can be applied to answer different what-if questions. The chapter also includes a catalog of available work zone CMFs (WZCMFs) and presents the commonly used work zone performance measures. Information presented in this chapter is based on findings in *NCHRP Research Report 869* (Ullman et al. 2018).

1.6 Guidebook Limitations

A large number of TMP strategies were identified in a TMP guide, *Developing and Implementing Transportation Management Plans for Work Zones*, developed by FHWA in 2005. Note, however, this guidebook does not address all individual strategies listed in the 2005 TMP guide.

TCDs, such as warning signs, arrow panels, and channelizing devices, are required for all work zones, irrespective of work zone type or duration. Part 6 of the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) and state manuals govern TCD standards, guidance, and other site-specific information. Therefore, this guidebook does not address these common TCDs; however, this guidebook does cover new TCDs, revisions to the application or manner of using existing TCDs, and provisions not specifically described in the 2009 MUTCD.

Crash cushions and temporary traffic barriers have proved effective in increasing driver and worker safety in work zones, and the 2009 MUTCD and the 2011 AASHTO *Roadside Design Guide* provide guidelines for their use. Because these two strategies have proved so effective, they are not documented in this guidebook. Likewise, practices, such as project task force meetings, work zone inspections, and surveys, are also targeted to reduce effects on motorists, businesses, contractors, and other road-user groups. While DOTs use some or all of these practices on almost every project, no studies were found that documented their effectiveness quantitatively.

Likewise, control strategies, such as construction phasing/staging, lane shifts, reduced lane/shoulder widths, flagging operations, and ramp closures, are project-specific strategies and are included as part of the traffic control plans. The design of traffic control plans is governed by the 2009 MUTCD, the AASHTO Green Book, and agency manuals. Quantitative evaluations of the previously mentioned control strategies were not found in the literature.

Corridor/network management strategies, such as retiming traffic signals, parking and turning restrictions, bus turnouts, temporary traffic signals, and street improvements, are frequently used in work zones—usually with positive results. However, quantitative evaluations of these strategies were not found in the literature.

Similarly, several strategies are infrequently used in work zones, thus evaluations, whether quantitative or qualitative, are absent. Examples of these strategies include call boxes, total station units, photogrammetry, and aerial surveillance using helicopters.

Finally, to prevent duplication and using best judgment, the guidebook fits individual strategies into a single category, even though they may fall under two separate categories. For example, in the TMP guide, reversible lanes fall under both control strategy and corridor/network management strategy. However, in this guidebook, reversible lanes are included only once, under corridor/network management strategy.

1.7 Resources and References

A Policy on Geometric Design of Highways and Streets, 6th ed. AASHTO, Washington, D.C., 2011. [Green Book]
Roadside Design Guide, 4th ed. AASHTO, Washington, D.C., 2011.

Cambridge Systematics, Inc. and Texas Transportation Institute. *Traffic Congestion and Reliability: Linking Solutions to Problems*, Final Report prepared for FHWA, July 19, 2004. https://ops.fhwa.dot.gov/congestion_report_04/congestion_report.pdf.

Chin, S.M., O. Franzese, D.L. Greene, H.L. Hwang, and R.C. Gibson. *Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2*. Prepared by Oak Ridge National Laboratory, Oak Ridge, TN, November 2004. https://info.ornl.gov/sites/publications/Files/Pub57300.pdf.

FHWA. *Developing and Implementing Transportation Management Plans for Work Zones.* Rule on Work Zone Safety and Mobility, 23 Cfr 630 Subpart J. U.S. DOT, 2005. [TMP guide]

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Ullman, G. L., M. Pratt, M. D. Fontaine, R. J. Porter, and J. Medina. *NCHRP Research Report 869: Estimating the Safety Effects of Work Zone Characteristics and Countermeasures—A Guidebook*. Transportation Research Board, Washington, D.C., 2018. http://dx.doi.org/10.17226/25007.

CHAPTER 2

Work Zone Safety Management Strategies

This section includes work zone strategies and supportive technologies that transportation agencies use to address traffic safety concerns in work zones. The following strategies are covered in this section:

- Work zone posted speed limit reduction
- Portable variable speed limit system
- Temporary rumble strips
- Sequential flashing warning lights
- Automated flagger assistance devices
- Work zone intrusion alarm
- Moveable traffic barrier systems

2.1 Work Zone Posted Speed Limit Reduction

2.1.1 Description

The 2009 MUTCD, Section 1A.13, defines posted speed limit (PSL) as "a speed limit determined by law or regulation and displayed on speed limit signs."

Speed limit reduction is the process of lowering the PSL for a particular segment of a roadway resulting from changes in geometry, land use, traffic volumes, and crashes or crash potential along the highway. Work zones and school zones are two examples of where reduced speed limits are used; however, normal PSL is resumed beyond the end of the work zone.

Two types of reduced speed limits operate in work zones:

1. **Restricted speed limits** are regulatory speed limits[3] used only when the work zone and workers are in operation, typically from 9:30 a.m. to 3:30 p.m. and from 9:00 p.m. to 5:00 a.m. During periods of no activity or when the traffic controls are removed from the roadway, the speed limit signs are covered or removed. This involves installing (or uncovering) signs at the beginning of a work shift and removing (or covering) signs at the end of the shift.
2. **24/7 construction speed limits** are regulatory speed limits established for long-term projects when motorists must reduce speeds to safely navigate the work zone. These speed limits are intended for a 24-hour continuous posting so, unlike the restricted speed limits, they are not taken down at the end of the work shift.

[3] The 2009 MUTCD (Section 1A.13) defines a regulatory sign as "a sign that gives notice to road users of traffic laws or regulations."

2.1.2 When to Use

To assist in determining the need for work zone speed limit reduction, flowcharts were developed by the FHWA (Figure 2.1) and the New York State Department of Transportation (NYSDOT) (Figure 2.2).

The exact criteria used in setting work zone speed limits vary jurisdictionally. As examples of state policies and procedures, guidance on setting work zone speed limits from the Virginia DOT (VDOT), the Wisconsin DOT (WisDOT), and the Ministry of Transportation of Ontario is discussed.

2.1.2.1 Virginia

VDOT provides the following warrants for reduced speed limits on short-term (<72 hours) work zones on an Interstate or other limited-access, multilane, divided highway with a PSL of 55 mph or greater.[4]

- A lane closure resulting in congestion expected to reduce vehicle operating speeds by at least 10 mph for most of the time the work zone is in place; or
- Pavement surface conditions such as uneven, ridged, or broken pavement or potholes that destabilize vehicles for most of the work zone; or
- Workers within 2 ft of a travel lane for most of the time the work zone is in place; or
- Lane-width reductions resulting in travel lanes less than 11 ft wide for most of the work zone; or
- Work activity that reduces the sight distance available to motorists below that required at the original PSL for the majority of the time the work zone is in place.

VDOT's recommended guidelines for increased fines are as follows:

- Projects on limited-access highways with work duration of 60 days or more,
- Projects on non–limited access highways with a PSL of 35 mph or greater that will have a work duration of 120 days or more, and
- Projects (both limited and non–limited access highways) where safety will be improved based on the engineering judgment of the regional traffic engineer.

2.1.2.2 Wisconsin

WisDOT uses the following criteria, along with engineering judgment, to develop an appropriate work zone speed limit. The most restrictive work zone impact is used as the determining condition.[5]

- **Interstates and expressways with 70 or 65 mph speed limit**:
  - If tubular markers separate bidirectional traffic, then reduce to 55 mph.
  - If workers are present within 12 ft of live traffic without positive protection,[6] then reduce to 55 mph.
  - If the work zone is less than or equal to 0.5 mi long, with lane shifts or narrowed travel lanes and positive protection, then post warning signs with an advisory speed plaque.
  - If the work zone is less than or equal to 0.5 mi long, with no lane shifts or narrowed travel lanes and positive protection, then do not lower the speed limit.
  - If work is taking place outside the clear zone, then do not lower the speed limit.
  - Reduce all other work zones to 60 mph (70 to 60 mph or 65 to 60 mph).

---

[4] Traffic Engineering Division Memorandum Number TE-340.1: Speed Limit and Fine Signs in Work Zones, 2012.
[5] *Traffic Engineering, Operations and Safety Manual*, Section 13-5-6: Temporary Traffic Control Zones, February 2018.
[6] FHWA defines positive protection as a temporary precast concrete barrier that contains or redirects vehicles and separates workers from the active travel lanes.

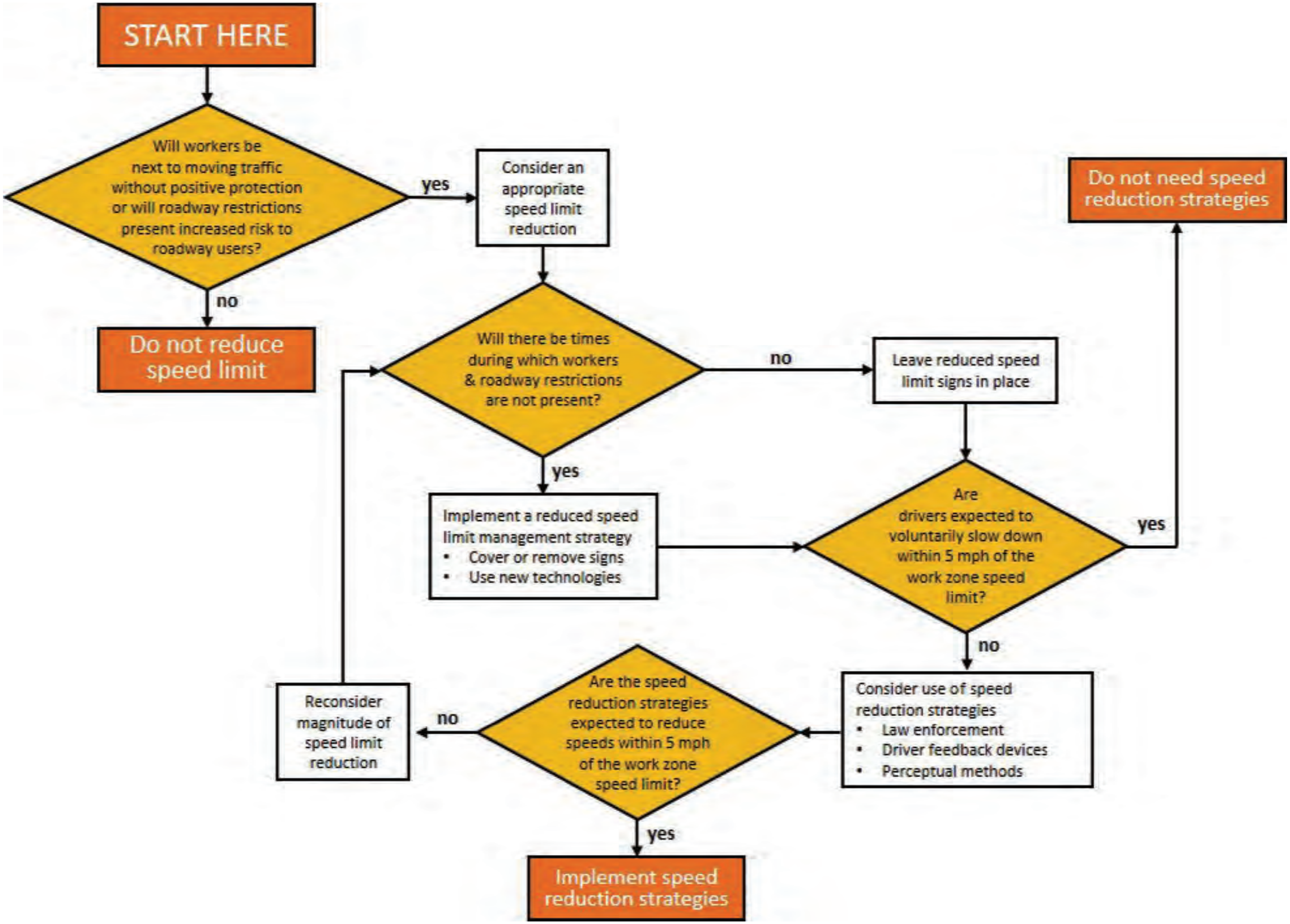


Figure 2.1. Flowchart for setting work zone speed limits (Credit: FHWA).

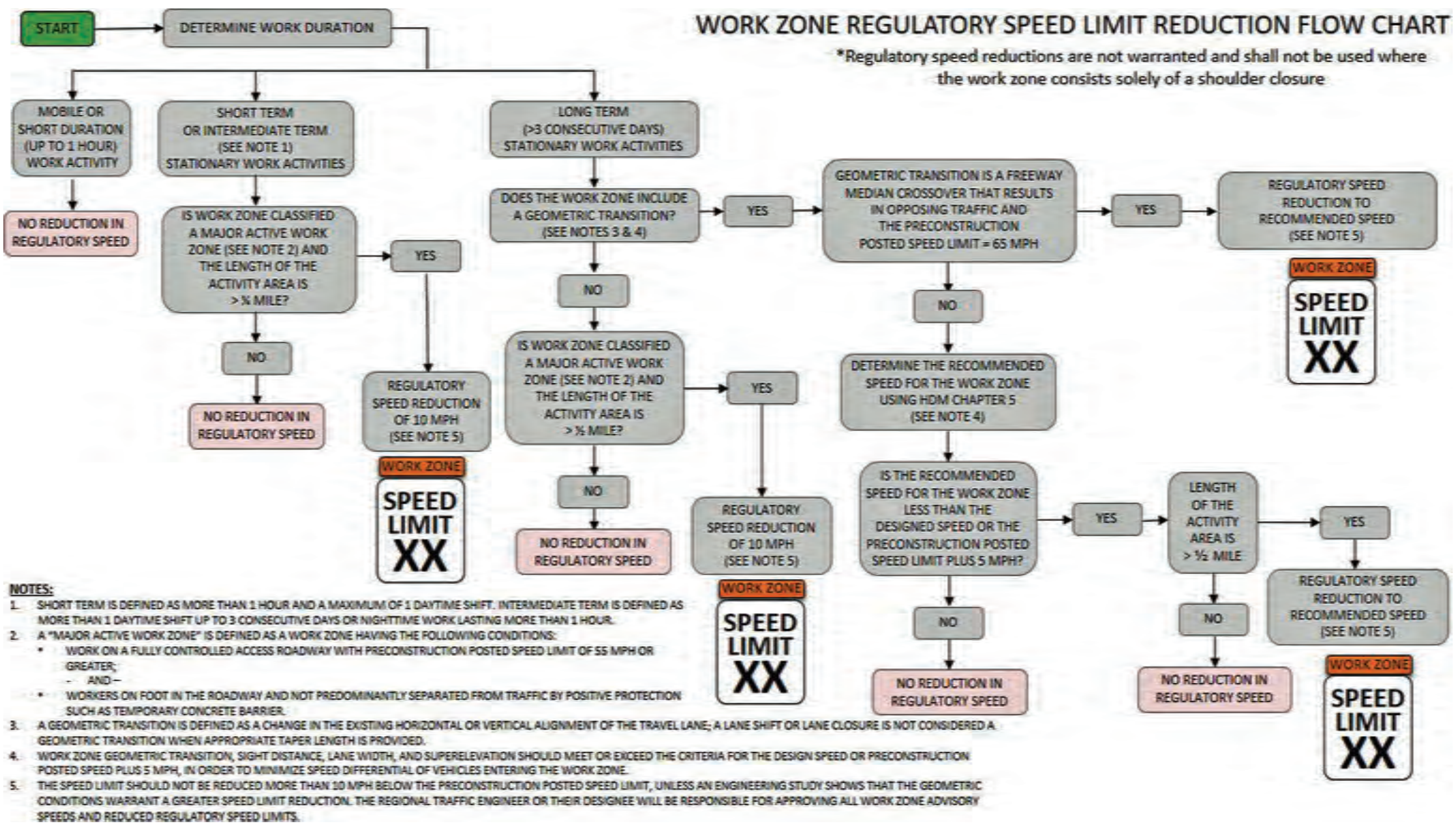


Figure 2.2. Work zone regulatory speed limit reduction flowchart (Credit: NYSDOT).

- **Expressways and other multilane highways with 55 or 50 mph speed limit.** Reduce to 45 mph only in situations that have a combination of extreme lane shifts, narrowed lanes, bidirectional traffic, or milled surfaces. Restore speed limit to normal posted speed when reduction criteria are not present.
- **Multilane highways with 45 mph speed limit.** Reduce speed limit to 35 mph only in situations that have a combination of extreme lane shifts, narrowed lanes, bidirectional traffic, or milled surfaces.
- **Two-lane rural highways with 55 mph speed limit**. Reduce to 45 mph only in situations that have a combination of extreme lane shifts, narrowed lanes, or milled surfaces. The flagging operation in itself would not typically warrant a reduced speed limit because motorists are controlled by the flagging devices.
- **Two-lane rural roadways with speed limit of 45 mph of less.** Do not reduce speed limit in typical cases, but consider a speed reduction of up to 10 mph in increments of 5 mph in situations with a combination of extreme lane shifts, narrowed lanes, or milled or gravel surfaces.
- **Two-lane urban roadways with speed limit of 40 mph or less.** Do not change the speed limit, but consider reducing it to 35 mph in situations that have a combination of extreme lane shifts, narrowed lanes, or milled or gravel surfaces.

2.1.2.3 Ontario

The January 2014 edition of the *Ontario Traffic Manual*, Book 7 (MTO 2014), provides guidelines for determining when to reduce speed limits in work zones (Table 2.1).

2.1.3 Benefits

Reducing speed limits in work zones provides the following benefits:

- Encourages speed limit compliance, thereby reducing crash potential, and
- Improves worker safety.

2.1.4 Expected Effectiveness

Hou, Edara, and Sun (2011) evaluated three speed limit scenarios on three short-term Interstate work zones in Missouri; the speed-reduction scenarios had standard speed limits of

Table 2.1. Appropriate use of speed limit reductions in work zones from the Ontario Traffic Manual, Book 7.

Method	Examples
Restricted speed limits. Used only when workers present.	• Workers on a freeway within 10 ft of a traveled lane open to traffic where no barrier is used
24/7 construction speed limits. Used for continuous public and worker safety on long-duration construction with continuous hazards, or where uninterrupted flow cannot be designed at or above the normal regulatory posted speed (substandard geometrics). Used 24 hours a day.	• Lane width less than 12 ft (3.5 m) on freeways or less than 10 ft (3.0 m) on nonfreeways • Shoulder width or offset to barriers less than 1½ ft (0.5 m) on one or both sides • Sudden lane narrowing • Substandard sightlines or stopping sight distance • Multiple lane shifts, detours, or transitions designed at less than the normal PSL, or those with no illumination • Substandard horizontal or vertical alignment • Gravel surfaces (length greater than ¼ mi, or 500 m) • Multiple lane shifts with confusing pavement markings • Partial lane shifts onto a surface different from the main roadway

Note: PSL = posted speed limit.
Source: MTO (2014).

70 mph. The scenarios involved (1) no reduction in the PSL, (2) a 10-mph reduction in the PSL, and (3) a 20-mph reduction in the PSL, respectively. The 85th percentile speeds and speed variance for the three scenarios were 81 mph and 10 mph, 62 mph and 8 mph, and 48 mph and 6 mph, respectively. The percentage of drivers who exceeded the PSL by more than 10 mph in each scenario was 15.4 percent, 4.8 percent, and 0.9 percent, respectively. The 20-mph speed limit reduction scenario proved most effective in lowering prevailing speeds and speed variance.

The Colorado DOT (CDOT) evaluated seven speed limit reduction scenarios in increments of 5 mph (i.e., 75, 70, 65, 60, 55, 50, and 45 mph). With the normal 75-mph PSL from the highway reduced to 65 mph, 85 percent of drivers complied with the lower limit (within 2 mph). This can be considered a successful speed limit that drivers respect—fewer than about 1 in 25 exceeded the limit by more than 5 mph. When the speed limit was reduced 15 mph or more, however, the number of drivers exceeding the PSL increased sharply from slightly less than 1 in 17 at a 15-mph reduction to nearly 1 in 3 at a 30-mph reduction.

2.1.5 Crash Modification Factor

The CMF for a work zone speed limit reduction appears to show a minor effect on crash risk, as shown in Table 2.2. Chapter 13 of this document provides more information on developing WZCMFs.

2.1.6 Implementation Considerations

Part 6 of the MUTCD discusses speed limit reduction for temporary traffic control (TTC) zones. Section 6C.01 of the 2009 MUTCD states,

> Reduced speed limits should be used only in the specific portion of the TTC zone where conditions or restrictive features are present.
>
> A TTC plan should be designed so that vehicles can travel through the TTC zone with a speed limit reduction of no more than 10 mph.
>
> Reduced speed zoning (lowering the regulatory speed limit) should be avoided as much as practical because drivers will reduce their speeds only if they clearly perceive a need to do so.
>
> Research has demonstrated that large reductions in the speed limit increase speed variance and the potential for crashes. Smaller reductions in the speed limit of up to 10 mph cause smaller changes in speed variance and lessen the potential for increased crashes. A reduction in the regulatory speed limit of only up to 10 mph from the normal speed limit has been shown to be more effective.

Table 2.2. CMFs for work zone speed limit reductions.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error
Lower posted speed by 5 mph					
All	All	Urban and rural freeways	Not specified	1.17	Not specified
Lower posted speed by 10 mph					
All	All	Urban and rural freeways	Not specified	0.96	Not specified
Lower posted speed by 15 to 20 mph					
All	All	Urban and rural freeways	Not specified	0.94	Not specified
Note: The CMFs were derived from past studies on non–work zone roads, so their potential applicability to a work zone situation is unclear. Use these values with caution for work zones, because reduced work zone speed limits are often connected to other changes in the roadway cross section. CMF = crash modification factor.					

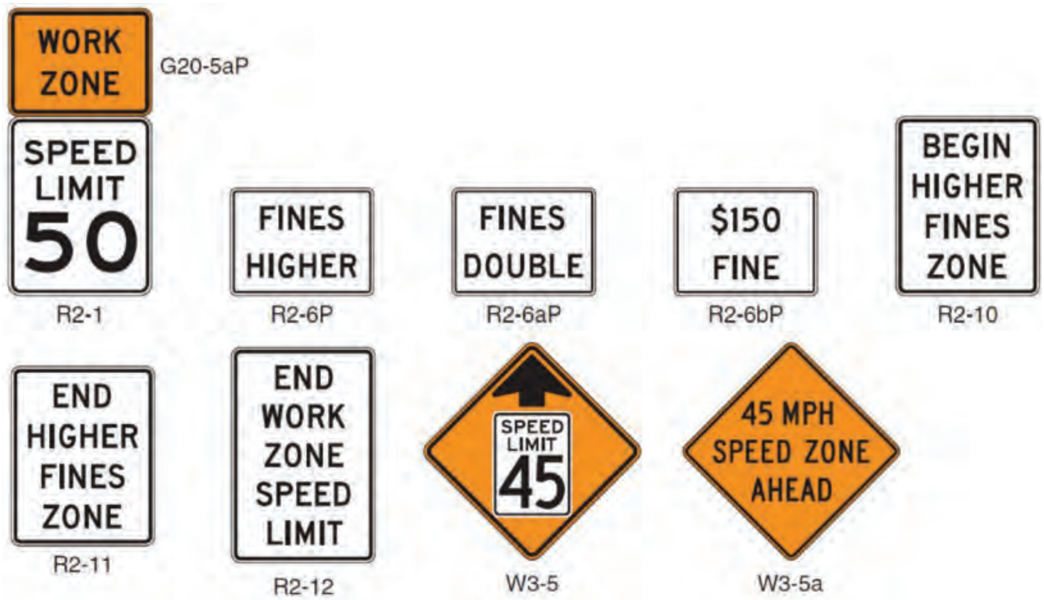


Figure 2.3. Reduced speed limit regulatory signs and plaques (Credit: 2009 MUTCD).

The MUTCD guidance corresponds with conclusions of field research such as Migletz et al. (1999) and *NCHRP Research Results Digest 192* (Transportation Research Board 1996).

In general, the original PSL and road type are important factors for DOTs to consider, as are the presence of workers, their proximity to traffic, project length, project duration, area type (i.e., urban versus rural), occurrence of night work, traffic mix (e.g., commuter, recreational, truck percentages), and geometric changes. Another important factor frequently considered is the type of separation between workers and traffic (e.g., drums versus concrete barrier).

Some state DOTs regulate work zone speed limit reductions based on worker proximity to traveled way and the presence of positive protection. For example, Michigan DOT (MDOT) does not allow a speed limit reduction when work activities, workers, materials, and equipment are more than 15 ft from the edge of the traveled way. Similarly, CDOT does not recommend speed limit reduction when the distance to the work is more than 10 ft from the edge of the traveled way, or when the work area is protected by concrete barrier and lane widths are not reduced.

2.1.7 Design Features and Requirements

Any speed limit reduction must be accompanied by the appropriate signs. Figure 2.3 shows the MUTCD-recommended regulatory signs and plaques for use with reduced work zone speed limits.[7]

2.1.7.1 Upstream of the Work Zone

- The sign must consist of a black and white SPEED LIMIT sign (R2-1) with a black and orange WORK ZONE plaque (G20-5aP) installed above the SPEED LIMIT sign.
- Use a REDUCED SPEED LIMIT AHEAD (W3-5 or W3-5a) sign to inform road users of a reduced speed zone where the speed limit is being reduced by more than 10 mph, or where

[7] The difference between a plaque and a sign is that a plaque cannot be used alone.

engineering judgment indicates the need for advance notice to comply with the PSL ahead. If used, REDUCED SPEED LIMIT AHEAD signs must be followed by a SPEED LIMIT sign (R2-1) installed at the beginning of the zone where the speed limit applies.

- If increased fines are imposed for traffic violations within the work zone, then
  - Install a BEGIN HIGHER FINES ZONE (R2-10) sign at the upstream end of a work zone where increased fines are imposed for traffic violations. Alternate legends such as BEGIN DOUBLE FINES ZONE may also be used for the R2-10 sign.
  - Mount a FINES HIGHER (R2-6P), FINES DOUBLE (R2-6aP), or $X FINE (R2-6bP) plaque below the speed limit.

2.1.7.2 Downstream of the Work Zone

- Install END WORK ZONE SPEED LIMIT (R2-12) sign.
- If increased fines are used, then install an END HIGHER FINES ZONE (R2-11) sign. Alternate legends such as END DOUBLE FINES ZONE may also be used for the R2-11 sign.

Individual signs and plaques for work zone speed limits and higher fines may be combined into a single sign or displayed as an assembly of signs and plaques.

2.1.7.3 Ohio

In September 2012, legislative changes to Ohio Revised Code 4511.98 (http://codes.ohio.gov/orc/4511) enabled the Ohio DOT (ODOT) to establish electronic speed limits in construction zones. Electronic work zone variable speed zones are permitted on multilane highways with speed limits of 55 mph or greater when workers are present for 3 or more consecutive hours, within the closed lanes or within 10 ft of the edge of the traveled way, and without positive protection. The intent of the electronic speed limit signs is to lower the speed limits "based on the type of work being conducted, the time of day when the work will be done, and any other criteria deemed appropriate by the Director of Transportation." The legislation allows the speed limit to be reduced 10 mph lower than the original non–work zone PSL.

The reduction in the PSL is conveyed to motorists through the portable, trailer-mounted digital sign displaying the speed limit for the work area. There are also flashing lights and text, WORK ZONE or WORKERS PRESENT, to notify motorists they are driving through a construction zone (Figure 2.4). The digital signs do not use radar or any other technology to

Figure 2.4. ODOT variable speed limit signs (Credit: ODOT).

record or collect speeds from passing motorists. The digital signs are only programmed to post the speed limit in a construction work zone and flash lights intermittently.

2.1.8 State of the Practice

2.1.8.1 Policy and Warrants for Work Zone Speed Reduction

NCHRP Synthesis 482: Work Zone Speed Management (Shaw et al. 2015) reports that 64 percent of state DOTs have a formal policy or guideline for determining when to reduce speed limits in work zones. In most cases, these documents also establish an agency-specific administrative process for approving speed reductions. Section 2.1.2 provides examples of states' policies and procedures on setting work zone speed limits.

2.1.8.2 State Laws to Enforce Work Zone Speed Limits

According to the Governors Highway Safety Association,[8] all U.S. states have laws that increase the penalties for speeding or committing other traffic violations while in a construction work zone. The enhanced penalty is often a doubling of the fine applicable had the same traffic violation been committed outside a construction zone. It may also be a fixed-dollar amount or a range. In many states, the enhanced penalty is applicable only when workers are present or if suitable signs are posted that notify drivers of increased fines.

- 22 states require workers and signs to be present for the increased penalties to take effect (Alabama, Arizona, Arkansas, California, Connecticut, Florida, Kentucky, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, North Dakota, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Utah, and Virginia).
- 19 states and the District of Columbia require only signs to be present for the increased penalties to take effect (District of Columbia, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, New Jersey, New Mexico, New York, North Carolina, Ohio, Rhode Island, South Carolina, Vermont, and West Virginia).

2.1.9 Cost

The costs for each static sign vary from $250 to $500, depending on the size. If a DOT is using electronic signs, such as speed display trailers, then costs may range between $8,000 and $10,000 per unit. Data-collection functionality adds an additional $5,000 per unit.

2.1.10 Resources and References

Bham, G., and M. A. Mohammadi. *Evaluation of Work Zone Speed Limits: An Objective and Subjective Analysis of Work Zones in Missouri*. MATC REPORT # 25-1121-0001-119. February 2011.

Brewer, M. A., G. Pesti, and W. H. Schneider, IV. Improving Compliance with Work Zone Speed Limits: Effectiveness of Selected Devices. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1948, 2006, pp. 67–76.

Guidelines to Establish Speed Limits in Work Zones, Michigan Department of Transportation, Bureau of Highway Instructional Memorandum 2005-16, December 2005.

Hou, Y., P. Edara, and C. Sun. Speed Limit Effectiveness in Short-Term Rural Interstate Work Zones. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Migletz, J., J. L. Graham, I. B. Anderson, D. W. Harwood, and K. M. Bauer. Work Zone Speed Limit Procedure. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1657, 1999, pp. 24–30.

Ministry of Transportation of Ontario (MTO), ed. *Ontario Traffic Manual*, Book 7, *Temporary Conditions*, Queen's Printer for Ontario, Ottawa, ON, Canada, 2014.

[8] Please see the GHSA Work Zones web page at https://www.ghsa.org/state-laws/issues/work%20zones (accessed May 12, 2020).

MnDOT. *Speed Limits in Work Zones Guidelines,* Minnesota Department of Transportation, October 2014.

NYSDOT. Engineering Instruction (EI) 08-030. *Work Zone Speed Limit Reductions*. New York State Department of Transportation, Albany, New York, September 9, 2008.

ODOT. Signs as to Increased Penalties in Construction Zones. Ohio Revised Code (ORC), Section 4511.98, Effective date September 10, 2012. http://codes.ohio.gov/orc/4511.98. Accessed March 10, 2019.

Outcalt, W. *Work Zone Speed Control*, Colorado Department of Transportation—Research, CDOT-2009-3, January 2009.

Shaw, J. W., M. V. Chitturi, W. Bremer, and D. A. Noyce. *NCHRP Synthesis 482: Work Zone Speed Management*. Transportation Research Board, Washington, D.C., 2015.

Transportation Research Board. *NCHRP Research Results Digest 192*: *Procedure for Determining Work Zone Limits*, September 1996.

WSDOT. *Speed Limit Reductions in Work Zones*, Washington State Department of Transportation, Secretary's Executive Order Number: E 1060.02, May 11, 2018.

2.2 Portable Variable Speed Limit System

2.2.1 Description

A variable speed limit (VSL) system is a type of smart work zone (SWZ) system that uses traffic detection, weather information, and road surface–condition technology to determine appropriate speeds at which drivers should be traveling, given current roadway and traffic conditions.

Sensors along the roadway collect conditions such as traffic volume, operating speeds, lane occupancy, and weather information. These data are typically transmitted to a transportation management center (TMC) and analyzed automatically with an algorithm or reviewed by agency personnel who decide the speed limit. Depending on the objectives set for the system, speed limits can be regulatory or advisory. These regulatory or advisory speeds are usually displayed on overhead electronic message boards, portable electronic speed trailers, or portable changeable message signs (PCMSs). Note that regulatory VSLs are enforceable, whereas advisory VSLs are not.

Two common purposes for deploying VSLs are for weather-related conditions and for incident management. Recently, there has been a renewed interest in expanding VSL functionality to work zones. This section discusses the use of VSLs in work zones, here referred to as "portable variable speed limit systems" (PVSLS). Figure 2.5 shows an example of regulatory PVSLS and Figure 2.6 shows an advisory PVSLS.

Figure 2.5. Regulatory PVSLS trailer at a Utah work zone (Credit: Street Smart Rental).

Figure 2.6. Advisory PVSLS trailer at a Missouri work zone (Credit: University of Missouri).

2.2.2 When to Use

PVSLS may be considered for deployment when the following conditions are anticipated:

- Work zone will cause 10 minutes or more of additional travel time.
- Work zone queue is estimated to slow traffic at least 10 mph below the PSL.
- Traffic speeds through the project vary widely because of oversaturated conditions during the peak period, and the timing and extent of congested travel will vary significantly day to day.
- Frequent planned lane closures are expected, which will create queues that cause high speed differentials between queued and approaching traffic.
- Lower speed limits would be temporarily beneficial for the work activities that will frequently occur.

The types of construction projects and work zones considered as good candidates for PVSLS deployment have the following characteristics:

- Work duration of at least 30 days. A PVSLS is not recommended in a short-term work zone because of higher setup costs and longer testing and calibration times.
- Roadways with higher speeds (45 mph or greater).
- Four-lane divided or undivided roads (two lanes in each direction), maintaining at least a single through lane in each direction during construction.
- Work zone projects where providing positive protection is not feasible (roadway resurfacing, roadway slab replacement, bridge deck replacement, etc.).
- Roadways with sufficient traffic volume to measure (directional average daily traffic volumes between 7,500 and 25,000), but not in an area known to be frequently congested.
- Roadways that are flat and straight (simple geometries with minimal curves and elevation changes).

The following project types are unsuitable for PVSLS deployment because of the complexities involved in implementation, placement, and monitoring of conditions:

- Projects involving moving operations (striping, grinding rumble strips, etc.).
- Projects with just shoulder work (i.e., too small a traffic impact to worry about).
- Projects that use flagger control, pilot vehicles, and temporary signals.
- Projects where lane closures will require positive protection.
- Work zones too close (minimum 1 mi) to a traffic signal or other access control to eliminate external influences on the system.

2.2.3 Benefits

The goal of PVSLs is to gradually reduce speeds of vehicles approaching the lane closure in an attempt to

- Delay (and possibly prevent) congestion from forming at the lane closure.
- Reduce the speed differential between congested and uncongested traffic flow at the back of the queue, and thereby
  - Reduce the potential for rear-end crashes.
  - Reduce the crash potential associated with lane merges at lane tapers.
  - Improve motorist and worker safety.

2.2.4 Expected Effectiveness

Reported results of regulatory PVSLS studies include the following:

- With the assistance of an FHWA Accelerated Innovation Deployment demonstration grant, the Utah DOT (UDOT) initiated a PVSLS program in 2014 and evaluated the effectiveness of a PVSLS at four work zones in 2016 and 2017 (UDOT 2018). When the PVSLS was activated, compared with baseline, speeding was reduced by
  - 15.1 percent for vehicles exceeding PSL by more than 15 mph (13.3 percent to 28.4 percent),
  - 25 percent for vehicles exceeding PSL between 10 and 15 mph, and
  - 83.4 percent for vehicles exceeding PSL by less than 10 mph.
- The Texas DOT (TxDOT) evaluated the effectiveness of PVSLS in 2014 and reported speed reductions ranging between 2.5 mph and 4.2 mph when the PVSLS was active. The study also showed an increase in vehicles per hour per lane (vphpl) between 188 and 350.
- The Maryland State Highway Administration (MDSHA) found an 8 percent increase in throughput, a 34 percent reduction in travel time during the congested half hour, and a 15 percent increase in average speed (Park and Chang 2010).

Reported results of advisory PVSLS studies include the following:

- Edara, Sun, and Hou (2013) evaluated variable advisory speed limits at four work zones in Missouri and reported the following results:
  - 2.2 mph reduction in mean speeds at an urban uncongested work zone,
  - 40 percent to 58 percent decrease in average queue length,
  - 6 percent to 13 percent reduction in work zone throughput and 20 percent to 29 percent decrease in number of stops per vehicle for an urban congested work zone, and
  - 2 mph reduction in mean speeds and 85th percentile speeds at rural work zones.
- Kwon et al. (2007) reported a 25 percent to 35 percent decrease in speed variance, a 7 percent increase in throughput, and an increase in speed limit compliance during the morning peak period.

Several other field studies on both regulatory and advisory PVSLSs provided inconclusive results (Saito and Wilson 2011; Fudala and Fontaine 2010; Riffkin et al. 2008; Michigan Department of Transportation 2003).

2.2.5 Crash Modification Factor

Table 2.3 shows the CMF for a PVSLS. Chapter 13 of this document provides more information on developing WZCMFs.

2.2.6 Implementation Considerations

Most, if not all, states have a speed-zoning statute that delegates to the DOT the power to establish or change speed limits. The states that have implemented PVSLS have done so mainly under the broad authority provided in this speed-zoning provision of state law or through a special provision (e.g., South Dakota and Texas).

South Dakota House Bill 1008 (2018) states,

> The secretary of transportation may establish limited speed zones through highway work areas on the state trunk highways and on any segment of the interstate highway system based on monitored traffic, weather, or road surface conditions if the secretary of public safety and the secretary of transportation, after consultation with the director of the highway patrol, agree the limited speed zones are necessary for the protection of life and property. Differing speed limits may be established for different times of day, different types of vehicles, varying weather conditions, and any other factor that has a bearing on a safe speed.

In December 2013, the Texas Transportation Commission established Rule §25.27 of the Texas Administrative Code, authorizing and requiring TxDOT to implement a VSL pilot program to "study the effectiveness of temporarily lowering prima facie speed limits to address inclement weather, congestion, road construction, or any other condition that affects the safe and orderly movement of traffic on a roadway."

The Judicial Enforcement of Variable Speed Limits report (Hines and McDaniel 2002) addresses legal considerations for implementing and enforcing VSLs; state DOTs should refer to this guidebook for more detailed information on this topic.

DOTs can use also a commercial off-the-shelf (COTS) system to deploy PVSLS. The PVSLS could be a line item under TTC in a specification, and a COTS system could be competitively bid, thus relieving the DOT from procurement, operations, and maintenance burdens. Alternatively, the DOT could develop, procure, own, and operate the system. There are, however, many factors to consider if the DOT procures the devices for the PVSLS, such as maintenance, software development, capital replacement, deployment, personnel costs, and capital replacement concerns.

There are three basic strategies for implementing PVSLS changes to the PSLs:

- **Manual implementation**. A manually implemented operation requires an operator to change multiple electronic signs when notified, if a condition is observed through live video, or based on other alerts.

Table 2.3. CMFs for PVSLSs.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error
All	All	Urban Interstate	Not specified	0.92	0.04

Note: The CMF was developed from data from a single permanent site in Missouri using an empirical Bayes analysis. While the CMF is reliable for the corridor that was studied, analysts should consider whether the results from a permanent installation would be transferable to any specific work zone application. CMF = crash modification factor; PVSLSs = portable variable speed limit systems.

- **Semiautomated implementation.** This process would use an algorithm that collects field data (speed, volume, and occupancy) and measures against predetermined thresholds. The operator could be prompted by the software to concur or dismiss suggested changes to the VSL signs. With a semiautomated system, operators could also manually implement changes (i.e., override the system). The algorithm allows different parameters to be set and, depending on the system performance, be adjusted. With a semiautomated system, the software could also prompt operators to approve or dismiss suggested changes (i.e., override the system).
- **Fully automated implementation**. This system has all the capabilities of the previously mentioned systems but does not require any human intervention. A fully automated system would require a considerable amount of time and monetary investment. It would also require extensive instrumentation, stringent maintenance requirements, and testing to ensure the algorithm does not compromise the safety of the traveling public.

The following operational parameters should also be considered when deploying PVSLS:

- Set minimum frequency for changing speeds at 5 to 10 minutes. Set 5 minutes as the minimum, but the project may consider collecting data using a 10-minute minimum to see if the 5- and 10-minute thresholds are notably different.
- Ensure that the PVSLS has a maximum speed limit set for each project and that the maximum speed is the posted speed of the roadway before construction.
- Do not reduce speed limits in advance of taper because vehicles may need to accelerate to merge into a single lane of traffic.
- Operate the PVSLS only when workers are present and return to PSL when workers are not present.
- Use a static sign to advise drivers to return to PSL at the end of the work area.

A public information and outreach campaign must also be undertaken before implementation of the PVSLS.

2.2.7 Design Features and Requirements

PVSLS typically includes traffic sensors to collect traffic flow and speed data, several properly located electronic speed signs to display speed limits, a reliable control algorithm to compute the optimal set of speed limits at all control locations, a real-time database, and a communication system to convey information between all principal modules.

2.2.8 State of the Practice

The following states use VSLs during incident- or weather-related scenarios: Alabama, Delaware, Florida, Georgia, Maine, Maryland, Michigan, Missouri, Nevada, New Jersey, New York, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Virginia, and Washington.

Maryland, Michigan, Minnesota, Virginia, and Texas have used PVSLS on demonstration projects in work zones, but their programs are currently inactive. At the time this guidebook was written, Utah, Colorado, and South Dakota were the only states actively pursuing the use of PVSLS in work zones. The following is a brief description of their programs.

2.2.8.1 Utah

UDOT initiated its PVSLS program in 2014, with the assistance of an FHWA Accelerated Innovation Deployment demonstration grant. In 2015, UDOT developed a concept of operations that summarized the PVSLS operational parameters and limits, user and system needs, stakeholder needs and responsibilities, operational scenarios, testing/validation, data collection, performance monitoring, and safeguards, as well as the system devices needed and where they are to be deployed within the work zone.

At the time this guidebook was written, UDOT had completed 2 years of PVSLS system deployment testing in four construction work zones to evaluate the effectiveness of the system (refer to Section 2.2.4 for results). Based on the positive results from the four trial projects, UDOT created a standard drawing (Figure 2.7 and Appendix B) to help contractors to bid and deploy a PVSLS system. At the time this guidebook was written, UDOT has advertised PVSLS for three work zones for the 2019 construction season.

2.2.8.2 Colorado

CDOT developed its PVSLS concept of operations in June 2018 and deployed its first PVSLS on an 18-mi stretch of Interstate 25 from south of Castle Rock to Monument, referred to as "the Gap." It is the only four-lane section of I-25 connecting Colorado's two largest cities, Denver and Colorado Springs. CDOT deployed 22 electronic speed trailers (11 in each direction) in July 2019. Traffic conditions are monitored at the project operation center and the PVSLS adjusted based on weather conditions, crashes, congestion, or other construction-related effects. Figure 2.8 shows a screenshot of the software used to control the PVSL. These PVSLSs are enforceable and CDOT has partnered with the Colorado State Patrol to significantly expand traffic enforcement. CDOT has plans to evaluate the effectiveness of the PVSLS in 2020.

2.2.8.3 South Dakota

The South Dakota DOT (SDDOT) deployed a PVSLS as part of the I-229, exit 5, reconstruction project in Sioux Falls. The PVSLS was deployed in April 2019 and consisted of 17 electronic speed limit signs tied to a queue warning system (QWS) in advance of the work zone. When the QWS discovers slowed or stopped traffic, it lowers posted speeds for approaching traffic on the electronic speed limit signs, as well as displays an appropriate message on message boards. The PVSLS was incorporated into the QWS through a construction change order.

2.2.9 Cost

The cost for deploying a smart work zone such as the PVSLS depends greatly on the project duration and the number of devices (e.g., message boards, traffic sensors, speed trailers, cameras) used. In general, the rental cost is the same for a PCMS or a traffic sensor or camera—approximately $1,000/week/unit. For longer-duration projects, the rental costs can be substantially lower.

Equipment rental cost for the UDOT PVSLS was between $173 and $329 per day. In addition to the cost of renting the equipment, system deployment budgets were required to address equipment mobilization, training, and software configuration. It was determined that a 0.5 full-time equivalent of a field worker's time is needed to ensure the system transitions in parallel with construction activities.

The CDOT PVSLS deployment cost was about $550 per unit per month, with a one-time mobilization fee of $10,000.

The SDDOT reported a cost of about $5,700 per each sign along with a monthly maintenance fee of about $1,700 for software and modems.

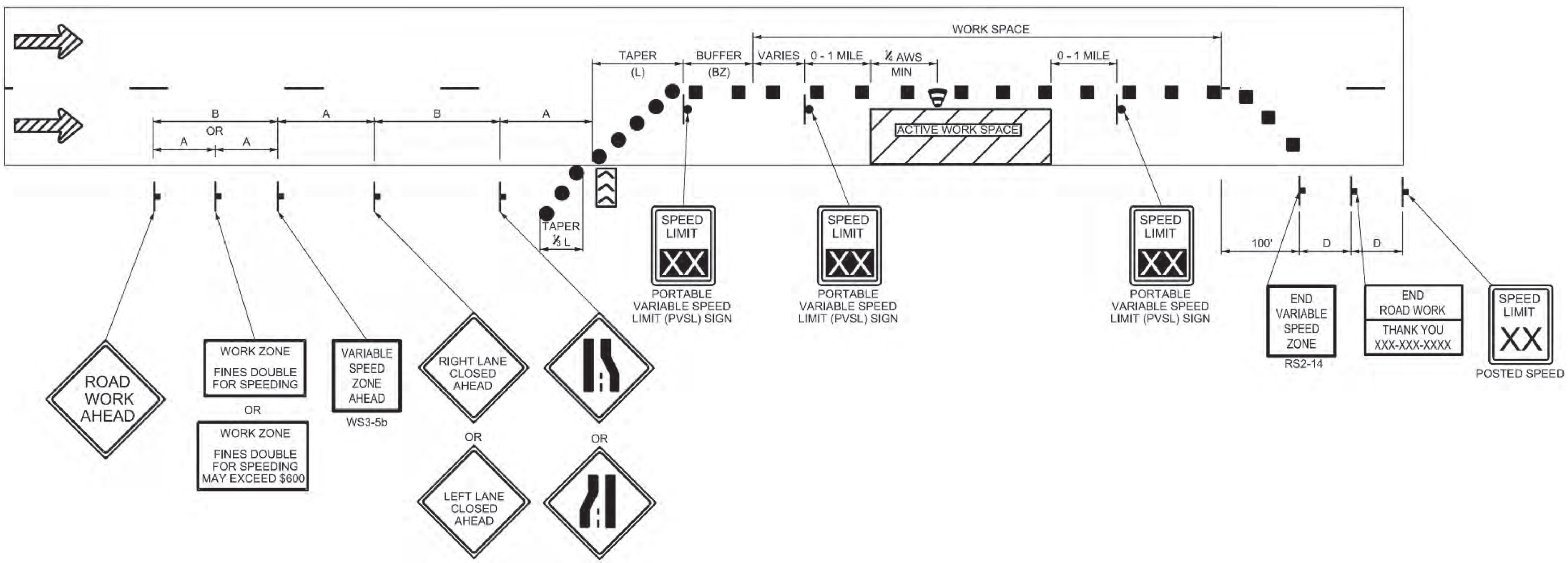


Figure 2.7. UDOT PVSLS standard drawing (Credit: UDOT).

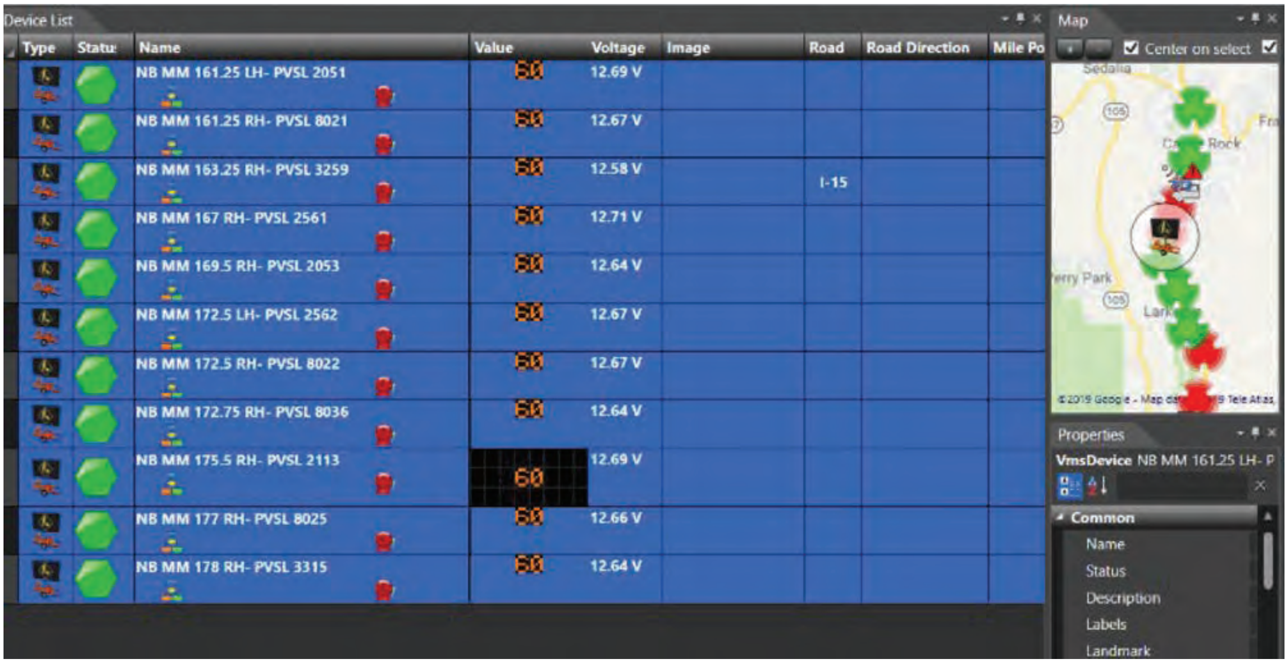


Figure 2.8. Screenshot of software used to control the PVSL (Credit: CDOT).

2.2.10 Resources and References

Edara, P., C. Sun, and Y. Hou. *Evaluation of Variable Advisory Speed Limits in Work Zones. Midwest Smart Work Zone Deployment Initiative*, Iowa Department of Transportation. InTrans Project 06-277, August 2013.

Enterprise Pooled Fund Study, *Variable Speed Limits in Work Zones: Summary of Uses and Benefits*, June 2014.

Fudala, N. J., and M. D. Fontaine. *Work Zone Variable Speed Limit Systems: Effectiveness and System Design Issues*, Virginia Transportation Research Council, Virginia Department of Transportation, FHWA/VTRC 10-R20, March 2010.

Hines, M., and J. B. McDaniel. *NCHRP Legal Research Digest 47: Judicial Enforcement of Variable Speed Limits*, TRB, National Research Council, March 2002.

Katz, B., J. Ma, H. Rigdon, K. Sykes, Z. Huang, and K. Raboy. *Synthesis of Variable Speed Limit Signs*, U.S. DOT, FHWA-HOP-17-003, May 2017.

Katz, B., C. O'Donnell, K. Donoughe, J. Atkinson, M. Finley, K. Balke, B. Kuhn, and B. Warren. *Guidelines for the Use of Variable Speed Limit Systems in Wet Weather*, U.S.DOT, FHWA-SA-12-022, August 2012.

Kuhn, B., K. Balke, R. Brydia, L. Theiss, I. Tsapakis, L. Ruback, and M. Le. *Evaluation of TxDOT Variable Speed Limit Pilot Projects*, Texas Department of Transportation. June 2015.

Kwon, E., D. Brannan, K. Shouman, C. Isackson, and B. Arseneau. Development and Field Evaluation of Variable Advisory Speed Limit System for Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2015, 2007, pp. 12–18.

Lin, P-W, K-P Kang, and G-L Chang. *Exploring the Effectiveness of Variable Speed Limit Controls on Highway Work-Zone Operations*, Intelligent Transportation Systems, 8:1–14, 2004. ISSN: 1547-2450 print/1547-2442 online.

MDOT. *Field Test of Variable Speed Limits in Work Zones (in Michigan)*, Final Report RC-1467. Michigan Department of Transportation, September 2003.

Park, S. Y. and Chang, G-L. *Applying ITS Technologies to Contend with Highway Congestion: Part-I: Variable Speed Limit Control for Recurrent Congestion*, Maryland State Highway Administration (MDSHA), MD-10-SP608B4J, December 2010.

Riffkin, M., T. McMurtry, S. Heath, and M. Sait. *Variable Speed Limit Signs Effects on Speed and Speed Variation in Work Zones*, Utah Department of Transportation Research and Innovation Division Report, No. UT-08.01, January 2008.

Saito, M., and A. B. Wilson. *Evaluation of the Effectiveness of a Variable Advisory Speed System on Queue Mitigation in Work Zones*, Utah Department of Transportation, UT-11.04, August 2011.

UDOT. *Use of Portable and Dynamic Variable Speed Limits in Construction Zones*, Utah Department of Transportation, February 2018. https://trid.trb.org/view/1494491.

UDOT. *Use of Variable Speed Limits in Construction Zones: Concept of Operations*, Utah Department of Transportation, December 2015.

Figure 2.9. Portable plastic rumble strips (Credit: Texas A&M Transportation Institute).

2.3 Temporary Rumble Strips

2.3.1 Description

The 2009 MUTCD, Section 6F.87, defines transverse rumble strips as "intermittent, narrow, transverse areas of rough-textured or slightly raised or depressed road surface that extend across the travel lanes to alert drivers to unusual vehicular traffic conditions. Through noise and vibration they attract the driver's attention to such features as unexpected changes in alignment and to conditions requiring a stop."

"Temporary rumble strips" (TRSs) refers to the use of transverse rumble strips in advance of work zones to alert drivers of conditions. TRSs are installed in work zones, are typically temporary, and are removed once the construction is complete. Two kinds of TRSs are available:

1. **Portable plastic rumble strips** that stay in place under their own weight and do not require the use of nails, adhesives, or fasteners. These strips are black. Figure 2.9 shows an example of portable plastic rumble strips.
2. **Orange polymer rumble strips with preapplied adhesive**. Figure 2.10 shows an example of this kind of rumble strip.

2.3.2 When to Use

States currently use TRSs on both freeway and nonfreeway projects in situations such as lane closures, speed reductions, flagging operations, changes in alignment, new merge patterns,

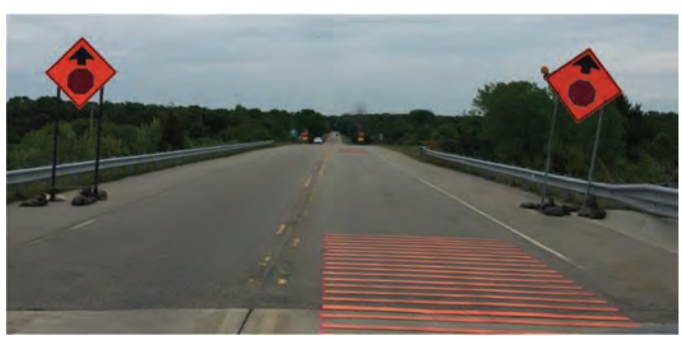


Figure 2.10. Orange polymer rumble strips with adhesive (Credit: MDOT).

visual obstructions, nighttime work zones, and more. The circumstances and the type of TRS used vary considerably, as discussed by the DOT examples to follow.

In accordance with the TxDOT *Work Zone Temporary Rumble Strip Standard Sheet Memo* (November 12, 2012), portable plastic rumble strips are to be used on

- One-lane, two-way operations using flaggers, portable signals, or AFADs with a PSL of 70 mph or less, or
- Lane closures on conventional highways with a PSL of 70 mph or less.

In accordance with the VDOT *Revised Guidelines for the Use of Portable Temporary Rumble Strips* (IIM-TE-386.1 October 2018), TRSs can be used only when the following conditions are met concurrently:

- Work operations involving flaggers, portable signals, or AFADs occur on a two-lane roadway during daylight hours.
- Work duration of the activity at a location is greater than 3 hours.
- Existing posted or regulatory speed limit is 35 mph or greater.
- Roadway has a marked centerline, indicating at least 500 vehicles per day (vpd).

Effective January 2020, WisDOT requires TRSs for all flagging operations, static or moving, in place for longer than 2 hours.

MDOT allows the use of portable plastic rumble strips on all nonfreeway projects, with a speed limit of 65 mph or less, with traffic regulators or temporary portable signal installations used to regulate traffic (Appendix C1). MDOT also developed two specifications for orange polymer with preapplied adhesive rumble strips, depending on their installation site: (1) one set of specifications detailing the rumble strips' application in advance of a STOP condition (Appendix C2), and (2) the other set when the strips are used at the approach to a work zone (Appendix C3).

TRSs should not be used on fresh seal coats, bleeding asphalt, soft pavement, heavily rutted road, or gravel surfaces. TRSs should also not be used in horizontal curves or on steep slopes. These conditions could cause excessive movement that could lead to a safety hazard for motorists.

The duration of the work zone is a key variable in deciding whether to use TRSs and, if so, which type.

- Mobile or short-duration work that moves intermittently or continuously: TRSs are not practical.
- Short-term stationary work (>1 hour within a single daylight period): portable plastic rumble strips are best suited.
- Intermediate-term stationary work (>1 daylight period up to 3 days, or nighttime work >1 hour): portable plastic rumble strips are best suited.
- Long-term stationary work (>3 days): portable plastic rumble strips or polymer/thermoplastic with preapplied adhesive are best suited.

2.3.3 Benefits

The use of TRSs provides the following benefits:

- The sight of rumble strips can alert motorists that they are about to enter a work zone where unusual or unexpected road conditions exist.
- Audible and vibratory stimuli produced by rumble strips can increase awareness among drivers as they travel through work zones, which can be particularly helpful for inattentive,

fatigued, or sleepy drivers. An increase in driver awareness can lead to positive behavior modification in speed reduction, braking, and increased compliance with warning signs and devices—all of which are behaviors that can reduce crashes in work zones.

2.3.4 Expected Effectiveness

Nearly all rumble strip research reported an increase in driver awareness. Some findings include the following:

- 1 to 7.2 mph reduction in average speeds (WisDOT 2018).
- 10.1 percent–13.8 percent reduction in mean speeds and 8.3 percent–14.5 percent reduction in the 85th percentile speeds (Yang et al. 2013).
- 0.39 to 1 mph reduction in average speeds (Sun, Edara, and Ervin 2011).
- 4.6 to 11.4 mph mean speed reduction for automobiles and 5 to 11.7 mph for trucks (Wang et al. 2011).
- 1 to 2 mph reductions in mean speed (Fitzsimmons et al. 2009).
- 8 mph reduction in mean speed (Reddy et al. 2008).
- 2 mph mean reduction in automobile speeds and 7.2 mph for truck speeds (Fontaine and Carlson 2001).

2.3.5 Crash Modification Factor

Table 2.4 shows the CMF for TRSs. Chapter 13 provides additional information on developing WZCMFs.

2.3.6 Implementation

The following aspects should also be considered when deploying TRSs:

- TRSs do not provide drivers any indication of what action is desired. Thus, deploy TRS only in conjunction with other TCDs that help drivers identify the appropriate action.
- To make cyclists, motorcyclists, and motorists aware that the TRSs are deliberate, and to prevent erroneous drivers' responses, place a RUMBLE STRIPS AHEAD warning sign in advance of zones where TRSs are present.
- TRS can cause stability problems for motorcyclists and bicyclists. Provide breaks in the center of the lane to allow motorcycles and bicycles to avoid them if so desired. Advance warning about the presence of TRSs is also useful. The 2009 MUTCD includes a motorcycle plaque (W8-15P) that may be mounted below a warning sign indicating loose gravel, grooved pavement, metal bridge deck, or steel plates ahead if the warning is intended to be directed primarily to motorcyclists. In response to specific requirements enacted through the

Table 2.4. CMFs for TRSs.

Crash Type	Crash Severity	Facility Type	Volume Range (AADT)	CMF	Standard Error
Nighttime	All	Rural Interstate when queues **were not** present	55,000–110,000	0.890 (not significant)	0.377
Nighttime	All	Rural Interstate when queues **were** present	55,000–110,000	0.397	0.265

NOTE: AADT = annual average daily traffic; CMF = crash modification factor; TRS = temporary rumble strip.

Washington State legislature, the Washington State Department of Transportation (WSDOT) developed a MOTORCYCLES USE EXTREME CAUTION warning sign (W21-1701 in the WSDOT Sign Fabrication Manual) to be used in conjunction with other warning signs in advance of hazards to reduce motorcycle risks in work zones.

- Extend TRSs onto the shoulder to discourage drivers from making erratic maneuvers to avoid the strips.
- Avoid placing TRSs on sharp horizontal or vertical curves, soft fresh seal coat, or heavily rutted pavement.
- TRS maintenance is crucial in ensuring intended performance. Immediately replace shifting or misaligned rumble strips.

2.3.7 Design Features and Requirements

The configuration of TRSs includes interrelated factors such as their placement within the work zone, number of arrays (or sets) of TRSs used at a work zone, number of strips in a set, and spacing of strips in the set. TRSs have been tested or deployed for use in work zones in patterns ranging from 1 to 25 rumble strips, with 6 strips being a frequently used pattern in evaluations. There is a variety of practices or recommendations regarding the configuration of TRSs. Practitioners should ultimately follow state DOT specifications, traffic control plans, and manufacturer recommendations, when available.

Table 2.5 provides a sample of rumble strip configurations currently used in work zones.

2.3.8 State of the Practice

TRSs are widely used by several states that have developed their own standard specifications and traffic control plans. Examples of standard drawings from selected state DOTs are provided.

- Appendix C1 presents the MDOT special provision for TRSs (March 2018).
- Appendix C2 presents the MDOT special provision for TRSs (orange) in advance of a stop condition (February 2012).
- Appendix C3 presents the MDOT special provision for TRSs (orange) in advance of a work zone (February 2012).
- Appendix C4 presents the UDOT standard drawings for use of TRSs for freeway/divided-highway lane and shoulder closures (June 2018).
- Appendix C5 provides the CDOT portable TRS typical applications for use with one-lane, two-way operations using flaggers and for lane closures on multilane divided highways (revised May 2018).

Table 2.5. TRS spacing (in ft) by PSL.

State	<40 mph	40–49 mph	≥50 mph
Ohio	6–8	6–8	6–8
Texas	10[a]	15[b]	20[c]
Virginia	10	15	20
Iowa	10–20	10–20	10–20
Utah	40	40	40
Colorado	40	40	40

NOTE:
[a] ≤40 mph
[b] >40 mph and ≤55 mph
[c] >55 mph
Information obtained from review of state manuals and typical applications.
PSL = posted speed limit. TRS = temporary rumble strip.

2.3.9 Cost

A single portable plastic rumble strip costs about $1,500. A minimum of three strips is required to form an array (or set). Portable plastic rumble strips are reusable and normally last 3 to 5 years, depending on use.

2.3.10 Resources and References

American Traffic Safety Services Association. *Guidance for the Use of Temporary Rumble Strips in Work Zones*. 2013.

Ezekiel, Y., G. L. Hsieh, G. P. Ullman, and R. E. Brydia. Effectiveness of End-of-Queue Warning Systems and Portable Rumble Strips on Lane Closure Crashes. *Journal of Transportation Engineering*, ASCE, Part A: Systems Vol. 143, Issue 11 (November 2017).

Finley, M. D., J. D. Miles, and P. J. Carlson. *An Assessment of Various Rumble Strip Designs and Pavement Marking Applications for Crosswalks and Work Zones*, Texas Department of Transportation, FHWA/TX-06/0-4728-2, October 2005.

Fitzsimmons, E., N. Oneyear, S. Hallmark, N. Hawkins, and T. Maze. *Synthesis of Traffic Calming Techniques in Work Zones*. Iowa State University. January 2009.

Fontaine, M. D., and P. J. Carlson. Evaluation of Speed Displays and Rumble Strips at Rural-Maintenance Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1745, 2001, pp. 27–38.

Horowitz, A. J., and T. Notbohm. *Testing Temporary Work Zone Rumble Strips*. Ames, IA: Institute for Transportation, Iowa State University (Midwest Smart Work Zone Deployment Initiative), 2005.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Reddy, V., D. Tapn, D. McAvoy, and S. Pinapaka. *Evaluation of Innovative Safety Treatments—A Study of the Effectiveness of Temporary Rumble Strips in Construction Work Zones*. Florida Department of Transportation, 40502-PL-008-001, January 2008.

Schrock, S. D., V. R. Sarikonda, and E. J. Fitzsimmons. *Development of Temporary Rumble Strip Specifications*, Kansas Department of Transportation (K-TRAN: KU-14-6), February 2016.

Sun, C., P. Edara, and K. Ervin. *Elevated-Risk Work Zone Evaluation of Temporary Rumble Strips*. Missouri Department of Transportation, K-TRAN: KU-09-5. December 2011.

Virkler, M. *Removable Orange Rumble Strips.* University of Missouri, 2000.

Virkler M., M. Deepak, and K. L. Sanford Bernhardt. *Preformed Rumble Strips*. University of Missouri, 2002.

Wang, M. H., S. D. Schrock, Y. Bai, and R. A. Rescot. *Evaluation of Innovative Traffic Safety Devices at Short-Term Work Zones*, Kansas Department of Transportation. K-TRAN: KU-09-5. December 2011.

WisDOT. *Temporary Portable Rumble Strips Study*, Wisconsin Department of Transportation, Bureau of Traffic Operations, January 2018.

Yang, H., K. Ozbay, B. Bartin, and S. Chien. Evaluation of Supplementary Traffic Control Devices for Surveyor Safety Enhancement. Presented at 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

2.4 Sequential Flashing Warning Lights

2.4.1 Description

Sequential flashing warning lights (SEQ) are wireless steady-burn warning lights, mounted on channelizing devices and flashing in a sequence to clearly delineate the taper at work zone lane closures (Figure 2.11). To help drivers identify the required vehicle path, the successive flashing of the SEQ begins at the upstream end of the merging taper and ends at the downstream end of the merging taper.

2.4.2 When to Use

SEQ use is restricted to nighttime work zones with lane closures only.

The North Carolina DOT (NCDOT) allows the use of SEQ for merging tapers during nightly work activities on Interstates and freeways with speed limits greater than 55 mph and facilities with significant traffic volumes.

Figure 2.11. Sequential warning lights (Credit: University of Missouri).

The Missouri DOT's (MoDOT) practice is to use SEQ on rural work zones with a high percentage of truck traffic. MoDOT has also deployed SEQ on nighttime Interstate construction and maintenance projects.

2.4.3 Benefits

The use of SEQ provides the following benefits:

- Improving driver recognition of merging taper,
- Increasing drivers' awareness of active work zones,
- Reducing driver approach speeds,
- Maximizing traffic flow by promoting smooth lane merges,
- Reducing the incidence of last-second decisions in a taper merge maneuver (i.e., better and earlier lane discipline), and
- Offering a low-cost countermeasure with potential high returns.

2.4.4 Expected Effectiveness

Field evaluations of SEQs have reported the following results:

- Average speeds decreased on average by 2.2 mph and 85th percentile speeds decreased on average by 1 mph, which causes vehicles to merge further upstream from the taper. The benefit–cost ratio ranged from 5 to 10 (Sun et al. 2011).
- A Texas Transportation Institute study reported a "one-fourth reduction in the number of passenger vehicles and a two-thirds reduction in the number of trucks in the closed lane 1,000-ft upstream of the lane closure" (Finley, Ullman, and Dudek 2001).
- A British Highways Agency study (2005) reported that the "effect of sequential lamps is seen consistently from a point 500 m before the taper, but also has an effect at a point 600 m before the taper in half the cases."

2.4.5 Crash Modification Factor

No CMF is available for this strategy.

2.4.6 Implementation Considerations

SEQs must flash sequentially beginning with the first light and continuing until the final light and in sequence when placed on the drums that form the merging taper. SEQs should be visible on a clear night from a distance of 3,000 ft.

The number of SEQs deployed on a project depends on the PSL and the number and spacing of channelizing devices. The number of lights used in the drum taper must equal the number of drums used in the taper.

If only one or two units are knocked out or not working, the flashing sequence should continue. If more than three units are not working, all lights should be automatically turned off. Nonsequential flashing is prohibited.

The SEQ must be deactivated when lane closures are not in effect.

One potential drawback is that a small percentage of drivers became more aggressive when overtaking at the taper because the taper becomes more visible.

2.4.7 Design Features and Requirements

The SEQ must comply with the 2009 MUTCD, as defined in Section 6F.63, Channelizing Devices, and Section 6F.83, Warning Lights. Section 6F.83 further states that "each flashing warning light in the sequence shall be flashed at a rate of not less than 55 or more than 75 times per minute."

CDOT specifies "the size of each lens to be 7 in. in diameter, each lamp to have a low output steady Type C backlight to aid direction indication, utilize intelligent wireless communications and be certified as crashworthy Category 1."

2.4.8 State of the Practice

At the time this guidebook was written, Missouri and North Carolina were the only states actively pursuing the use of SEQs in work zones.

The Oklahoma Department of Transportation (OKDOT) deployed SEQ as part of the AASHTO Innovation Initiative in 2011; however, its program ended in 2012 and at the time this guidebook was written, OKDOT was no longer deploying SEQ.

2.4.8.1 Missouri

The AASHTO Innovation Initiative identified MoDOT as one of the lead states for experimental deployments. Since then, MoDOT has expanded its program and, at the time this guidebook was written, has used SEQ on more than 100 projects. MoDOT developed guidance for using SEQ in its Engineering Policy Guide (Section 616.6.83), which Figure 2.12 shows.

2.4.8.2 North Carolina

The NCDOT used SEQ on the following two projects in Forsyth and Davie Counties:

- I-0911A (Widen I-40 from Harper Road in Forsyth County to NC 801 in Davie County).
- I-5823 (I-40 pavement rehabilitation from US 601 in Davie County to Iredell County line).

2.4.9 Cost

Typical cost for SEQ is $150 per each light.

Figure: 616.6.83 Sequential Flashing Warning Light

SPEED	SIGN SPACING (ft.)		TAPER LENGTH (ft.)		OPTIONAL	CHANNELIZER SPACING (ft.)	
	Undivided (S)	Divided (S)	Shoulder (1) (T1)	Lane (2) (T2)	BUFFER LENGTH (ft.) (B)	Tapers	Buffer/ Work Areas
0-35	200	200	70	245	250	35	50
40-45	350	500	150	540	360	40	100
50-55	500	1000	185	660	495	50	100
60-70	SA - 1000, SB - 1500, and SC - 2640		235	840	730	60	100

1 Shoulder taper length based on 10 ft. (standard shoulder width) offset. 2 Lane taper length based on 12 ft. (standard lane width) offset.

This Sequential Flashing Warning Light sheet provides guidance on the placement of lights within shoulder and merge taper and operational information. Review appropriate typical applications for signs, sign spacing, taper length, buffer length, channelizer spacing, TMAs, channelizers, etc.

The sequential lights should be self-contained and placed within the merging taper and still communicate with any light within the sequence. The lights should be capable to be spaced at least 60' and may have a offset capability of at least 6'.

Pay item description: The number of sequential lights used in the merge taper will be dependent on the above table criteria based on posted speed limit. Depending on project location and intesity of lighting, the number of lights may be reduced to a minimum of 10 lights within the merge taper. Contract cost of light would be based on purchase, installing and maintaining per light.

Battery Recommendation:
6-Volt Battery: Sequential lights with one 6-volt battery were used on several projects and the lights were getting about 3 weeks of battery life. Several different types of batteries (6-volt) were used on the projects. This is based on continuous use of the light (24/7).

4 D-cell Batteries: Sequential lights with 4 D-Cell batteries with converter were used on several projects and were getting about 3 weeks of battery life. This is based on continuous use of the light (24/7).


6-Volt Batteries


4 D-Cell Batteries


Attachment of Light

Number of Batteries Used on Channelizers:

Due to weight and consistency, a 6-volt battery and 4 D-cell batteries with converter will be considered as equal. All sequential lights must be securely mounted to all channelizers.

If sequential lights are used on Drum-like channelizers, two batteries can be installed.

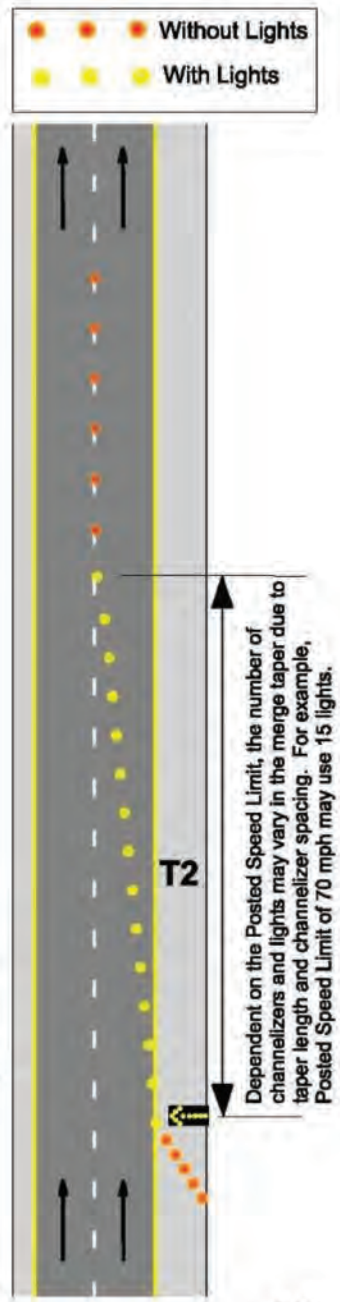
If they are mounted on a Trimline, only one battery may be installed. An extra ballast ring may be necessary to keep the trimline from tipping over.

If they are mounted on a Directional Indicator Board, only one battery may be installed.


Two Batteries


One Battery


One Battery



6/12

Figure 2.12. MoDOT SEQ guidance (Credit: MoDOT).

2.4.10 Resources and References

Finley, M. D., G. L. Ullman, and C. L. Dudek. Sequential Warning-Light System for Work-Zone Lane Closures. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1745, 2001, pp. 39–45.

Highways Agency. *Evaluation of Sequential Flashing Cone Lamps*. Trial Team: First Annual Report, Department of Transport, London, 2005.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Rea, M. S., J. D. Bullough, L. C. Radetsky, N. P. Skinner, and A. Bierman. "Toward the Development of Standards for Yellow Flashing Lights Used in Work Zones," *Lighting Research & Technology*, 50: 552–570, The Society of Light and Lighting, 2018.

Sun, C., P. Edara, Y. Hou, and A. Robertson. *Evaluation of Sequential Warning Lights in Nighttime Work Zone Tapers*. University of Missouri—Columbia. 2011.

2.5 Automated Flagger Assistance Devices

2.5.1 Description

Automated flagger assistance devices (AFADs) are TCDs that enable flaggers to be positioned out of the lane of traffic and that are used to direct traffic at lane closures on two-lane, two-way roadways. The 2009 MUTCD includes two basic types of AFADs: (1) a remotely controlled STOP/SLOW sign mounted on a trailer or moveable cart and (2) a remotely controlled red/yellow lens with a mechanically gated arm (Figure 2.13).

2.5.2 When to Use

AFADs are only to be used where there is only one lane of approaching traffic in the direction to be controlled. Most states permit use of AFADs during daytime or nighttime operations; however, if used at night, the AFADs should be illuminated in accordance with the 2009 MUTCD (Section 6E.08).

AFADs are typically used for short-term or intermediate-term lane or road closures, such as bridge maintenance, haul road crossings, guardrail repair, and pavement patching, when a flagger would normally be used. Their use is discouraged during long-term closures.

DOTs have successfully implemented AFADs on roads with a wide range of average daily traffic (ADT) counts. Although the 2009 MUTCD does not provide any limitations in this area, some states have established supplementary guidelines. For example, VDOT allows AFADs in temporary lane closures on two-way roads when the ADT is below 12,000 vpd, whereas Minnesota restricts the use of AFADs to roads with less than 1,500 ADT.

Figure 2.13. Examples of STOP/SLOW* (left) *and red/yellow* (right) *AFADs (Credit: FHWA).

2.5.3 Benefits

The primary benefit of AFADs is to enhance the safety of flaggers while also maintaining positive control of traffic approaching the work zone.

2.5.4 Expected Effectiveness

State evaluations have generally found drivers understand the red/yellow lens version better than the stop/slow version. According to a Virginia study, drivers were confused when the STOP/SLOW version was accompanied by signs reading WAIT ON STOP and GO ON SLOW. Many drivers interpreted them to mean they should pause at the STOP sign before proceeding slowly, rather than wait until the sign changed to SLOW before moving (Cottrell 2006). There were significantly more violations of the STOP/SLOW version in Texas than of the red/yellow lens version, although STOP/SLOW violations dropped to levels similar to the red/yellow lens when a mechanical gate arm was added to the device (Finley 2013). Surveys of work zone crews in Maine, Missouri, and Virginia have found enthusiastic approval of AFADs (ATSSA 2012).

2.5.5 Crash Modification Factor

No CMF is available for this strategy.

2.5.6 Implementation Considerations

While AFADs are a method of improving the safety of flagging operations, they do not eliminate the need for trained flaggers. AFAD operators must be certified flaggers trained on operating the device correctly; the operator must be able to manually control the lane closure in the event an AFAD malfunctions.

It is preferable to place the AFAD within the shoulder of the road; however, if the shoulder is not adequate, the AFAD is permitted to encroach on the travel lane, provided the appropriate sight distance is available. If this is the case, the gate arm must not extend into the adjacent lane.

Most states limit the distance between flagging stations to 800 ft, although some (e.g., Minnesota) permit their use in 1,000-ft work zones if each device has its own operator.

On work zones with a long activity area, intermediate regulators need to know the direction of traffic flow, especially for traffic on side roads.

2.5.7 Design Features and Requirements

All AFAD applications must abide by the specific standards set forth in the MUTCD (Section 6E.04). Section 6E.05 provides detailed specifications for STOP/SLOW AFADs; similarly, Section 6E.06 lists detailed specifications for red/yellow AFADs. In accordance with *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* (Ross, Sicking, and Zimmer 1993) and the AASHTO *Manual for Assessing Safety Hardware*, AFADs must satisfy applicable crashworthiness standards based on device weight.

There are two methods for using AFADs in a work zone. The first method employs an AFAD at each end of the work zone; the second method employs an AFAD at one end and a flagger at the other end. Two separate flaggers are commonly used to operate in either method; however, a single flagger may remotely control two flagging stations, provided that the flagger has a clear view of each station and of approaching traffic in both directions. In accordance with

Figure 2.14. Missouri AFAD with changeable message sign (Credit: University of Missouri).

the 2009 MUTCD and crashworthiness standards, advanced warning signs must alert traffic in both directions of an impending stop. When not in use, AFADs need to be removed from the clear zone and advanced warning signs covered.

When an AFAD is used, the advance warning signing should include a ROAD WORK AHEAD (W20-1) sign, a ONE LANE ROAD (W20-4) sign, and a BE PREPARED TO STOP (W3-4) sign.

2.5.8 State of the Practice

Currently, 11 states have standards for using AFADs: Alabama, Florida, Illinois, Kansas, Minnesota, North Carolina, Ohio, Oregon, Virginia, Washington, and Wisconsin.

MoDOT developed a new AFAD system that uses STOP/SLOW paddles and flashing red/yellow lights (Brown et al. 2018). In addition, a changeable message sign (CMS) was installed to display a series of four messages. As Figure 2.14 shows, the CMS alternated between an image of a STOP sign and the word STOP every 2 seconds during the stopped interval. The CMS alternated between an image of SLOW and the words GO ON SLOW every 2 seconds during the GO interval. The AFAD was built onto a truck-mounted attenuator (TMA) unit. The truck integration obviates the need to tow and deploy trailer-mounted AFADs.

2.5.9 Cost

The average cost for AFADs ranges between $25,000 and $30,000, excluding flagger costs. Rental prices vary between $3,000 and $3,500 per month, but these rates vary by geographic location, season, and number of units rented.

2.5.10 Resources and References

Brown, H., C. Sun, S. Zhang, and Z. Qing. *Evaluation of Automated Flagger Assistance Devices*. Missouri Department of Transportation. February 2018.

Cottrell B. H., Jr. *Evaluation of the AutoFlagger in Virginia*, Report Number VTRC 07-R12, Virginia Transportation Research Council, Charlottesville, Virginia, 2006.

Finley, M. Field Evaluation of Automated Flagger Assistance Devices in Work Zones on Two-Lane Roads. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2337, 2013, pp. 1–8.

Finley, M., B. Ullman, N. Trout, and E. Park. *Studies to Determine the Effectiveness of Automated Flagger Assistance Devices and School Crossing Devices*. Report No. FHWA/TX-12/0-6407-1. Texas Department of Transportation, 2012.

Guidance on the Use of Automated Flagger Assistance Devices, ATSSA (American Traffic Safety Service Association), 2012.

Manual for Assessing Safety Hardware, 2nd ed. AASHTO, Washington, D.C., 2016. [MASH16]

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

MoDOT. *Evaluation of Automatic Flagger Assistance Devices*, Missouri Department of Transportation Organizational Results Division, 2008.

MoDOT. *Lane Closure on Two-Lane Highways Using Automated Flagger Assistance Devices (AFAD) with Red and Amber Signal System*, Missouri Department of Transportation, 2012.

Odell, W. Automated Flagger Assistance Devices (AFADs): Saving Lives. Presented at 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

Ross, H. E., Jr., D. L. Sicking, and R. A. Zimmer. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.* TRB, National Research Council, Washington, D.C., 1993.

2.6 Work Zone Intrusion Alarm

2.6.1 Description

A work zone intrusion alarm (WZIA) is equipment that provides highway workers with additional warning of unauthorized vehicles and errant motorists that enter a work zone. WZIA uses vehicle-detection technology and audible, visual, or tactile alarms to alert workers to intrusions while giving them enough reaction time to move away from the hazardous location.

The first WZIAs were developed under the Strategic Highway Research Program and used microwave, infrared, and pneumatic tubes for vehicle detection. Most previous WZIAs have been decommissioned for several reasons, including low demand (small market), persistent false alarms, high cost, difficulty to deploy, and limited range of alarm. Since the development of these first-generation WZIAs, manufactures have used other technologies to develop other similar devices. The COTS WZIAs, available at the time of this writing, are described here and shown in Figure 2.15.

- Worker Alert System (WAS), by Astro Optics, LLC, is a pneumatic microwave-based system with an auditory, visual, and haptic alarm that is wirelessly triggered when a vehicle crosses over a pneumatic hose positioned in a work zone. The audio alarm is 80 dB at 50 ft.
- SonoBlaster, by Transpo Industries, is a kinematic system comprising of a disposable carbon dioxide (CO_2) cartridge and an alarm unit. When the CO_2 cartridge is punctured, the escaping gas produces sounds through an air-pressure horn. The device can be mounted on traffic cones, drums, delineators, and other barricades. The audio alarm is 90 dB at 50 ft.
- Intellicone, by Highway Resource Solutions (United Kingdom), is a lamp-integrated motion sensor attached to a traffic cone that can detect being hit by a vehicle and when vehicles cross between cones. When triggered, the unit signals a visual and a three-tone audio alarm. Intellicone also wirelessly sends an alert to a web portal to enable automated online reporting (communication features are currently unavailable in the United States). The audio alarm is 75 dB at 50 ft.

2.6.2 When to Use

WZIA should be used primarily where adding a positive protection system such as concrete barrier is not feasible, worker safety is of particular concern, crash rates upstream of the merge

Figure 2.15. Commercially available WZIA systems (Credit: Caltrans).

taper are high, and sight distance is limited. A study conducted for Alabama DOT (Marks et al. 2017) recommended

- Intellicone for work zones longer than 1 day, tapers longer than or equal to 1,500 ft, or both.
- WAS for work zones less than 1 day, tapers shorter than or equal to 1,500 ft, or both.

2.6.3 Benefits

Intrusion alarms improve safety by allowing workers time to move out of harm's way from an errant vehicle, reducing the potential for a work zone vehicular related injury.

2.6.4 Expected Effectiveness

Limited studies have been conducted to evaluate and compare the available WZIA technologies, as the following describes.

- *WAS.* Gambatese, Lee, and Nnaji (2017) evaluated the effectiveness of WAS, SonoBlaster, and Intellicone on three paving projects over 10 weeks. The study found the duration of the WAS alarm to be consistently 6 seconds. WAS produced the loudest sound when the alarm was oriented toward the sound meter. A lag time of no more than 1 second was observed between the time the pneumatic tube is pressured and the alarm is triggered. The indistinct alarm was a concern because it might not alert workers working closely to noisy equipment.
- *SonoBlaster*
  - A study conducted by Novosel (2014) for the Kansas DOT (KSDOT) found the SonoBlaster alarm duration to be inconsistent, ranging from 3 to 80 seconds. Irrespective of the orientation, the peak sound level occurred within the first second of firing and subsequent sound levels dropped off unevenly. A major concern with the SonoBlaster system was that in cold weather and after the first activation, the compressed CO_2 cartridge can become cold enough during firing that ice condenses on the cartridge. Novosel found that accumulated ice between the CO_2 cartridge and the firing pin prevented the system from working properly. Furthermore, replacing the CO_2 cartridge in cold or wet weather may bring moisture in contact with the nozzle.

- The study conducted by Gambatese, Lee, and Nnaji (2017) found similar results to the Novosel study. The SonoBlaster yielded false negatives (i.e., the system triggered but the alarm did not activate) and produced shorter bursts of sound after it had been used and the cartridge had been replaced.
- FHWA disseminated SonoBlaster intrusion alarm devices to several states for a demonstration project (Kuta 2009). The demonstration participants began field-testing the units in 2008. FHWA synthesized the evaluations (forms, e-mailed comments, or phone calls) into a demonstration project interim report issued in July 2009. The evaluations led to retooling the device to improve sound, set up, and mounting aspects. FHWA then made the retooled units available to original and new participants for testing and evaluation.
- The New Jersey Department of Transportation (NJDOT) was one of the state agencies nationwide to test the SonoBlaster. NJDOT used a retooled version of an earlier unit distributed by FHWA. Problems with quality control and reliability, combined with the cost of the alarm, raised doubts about the desirability of and potential benefits to be gained from deploying the device on NJDOT maintenance jobs. The NJDOT decision was that conducting additional test deployments would not substantially change the conclusions.

• *Intellicone.* Gambatese, Lee, and Nnaji (2017) found the sound to be louder when two speakers were oriented toward the sound meter. The maximum range between a lamp and the alarm was 250 feet, and the alarm duration was consistent at 32 seconds. Similarly, Novosel (2014) found that even though engine and mechanical noises from construction vehicles in a work zone were louder than the Intellicone alarms, the sound could be distinguished because of its high frequency and three tones (Novosel 2014). However, distinguishing the alarm sound from the inside of a work zone vehicle (a backhoe) at 100 to 200 feet away was difficult. The maximum sound level was around 90 dB at 10 feet and decreased to around 55 to 60 dB at 400 feet. Workers found the audible alarm on the Intellicone system difficult to hear because of its low volume (Novosel 2014).

In addition to the COTS available technologies, some prototype WZIAs were developed and tested as follows:

- Hayden (2013) evaluated the sDrum system effectiveness and deployment. The system consists of 28 orange traffic drums (called smart drums or sDrums) positioned adjacent to the orange cones marking the work zone lane closure. When the system detects a speeding vehicle approaching, the orange lights on top of the drums produce synchronous flashes that warn the driver to slow down and alert workers of a speeding vehicle. If the vehicle speed is above a set trigger speed, the system activates a pager system that warns the workers of the speeding vehicle. A Caltrans research team deployed the pilot system for 4 weeks near Los Banos with inconclusive results.
- Hourdos (2012) developed and tested a low-cost rapidly deployable intelligent drum line prototype that sends an audible warning to alert motorists traveling at dangerous speeds near highway work zones. The intelligent drum line system is comprised of two instrumented work zone drums. The sensor subsystem measures the speed of the oncoming vehicles and detects the location of the vehicle with respect to each drum. The audible warning system is comprised of a powerful air horn mounted inside the drum and designed to direct the sound force mainly toward the roadway; sound is suppressed in all other directions. Researchers tested the system only under simulated conditions and not in conjunction with actual work zone operations.

2.6.5 Crash Modification Factor

No CMF is available for this strategy.

2.6.6 Implementation Considerations

The following guidelines should be considered for using WZIAs (Gambatese, Lee, and Nnaji 2017):

- **Sound level.** Sound alarms produced by the work zone intrusion alert technology should be at least 110 dB when the alarm is located 50 ft away from workers and above 95 dB when the alarm is 100 ft away. Researchers preferred types of sounds, such as a screeching noise or one emitted by an emergency vehicle siren, that differ from the noises heard during the operation (e.g., diesel engine noise from equipment, truck backup alarm, passing automobile). In addition, agencies should avoid short-burst alarms. Alarms that provide longer, continuous sound improve the possibility of capturing workers' attention.
- **Transmission distance.** The minimum transmission distance should be 400 ft when the 85th percentile work zone speed is 35 mph. For work zones with historically higher vehicle travel speed, higher maximum work zone speed limits, and greater expected distances between workers, the transmission distance can be increased.
- **Haptic alarms.** Any haptic or vibration feature included with the alarm technology should be mobile, portable, and wearable either on the worker's arm or on the hard hat. A patterned vibratory signal lasts for approximately 14 seconds and creates a vibration frequency of 150 Hz.

2.6.7 Design Features and Requirements

The California Department of Transportation (Caltrans) conducted pilot testing of WAS, SonoBlaster, and Intellicone systems at its Maintenance Equipment Training Academy testing facility, which is a controlled environment (closed to live traffic). All tests were conducted in November 2018 (*Task Number 3038, Evaluation of Work Zone Intrusion Alarms*).

Based on the results of operational and range tests conducted, Caltrans developed recommended deployment plans for WAS (Figure 2.16) and Intellicone (Figure 2.17).

Figure 2.16 shows recommended and maximum distance between components of the WAS at which the evaluation trials produced 100 percent successful results. Caltrans recommends a

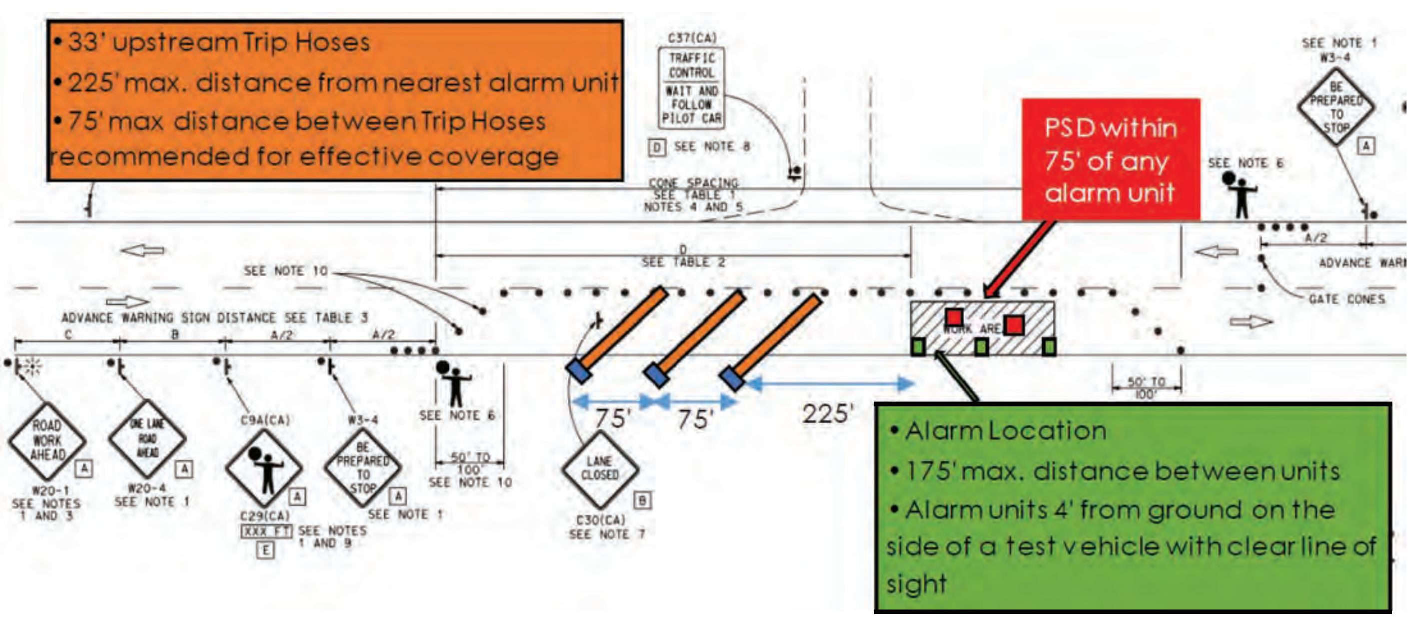


Figure 2.16. Caltrans WAS recommended deployment plan (Credit: Caltrans).

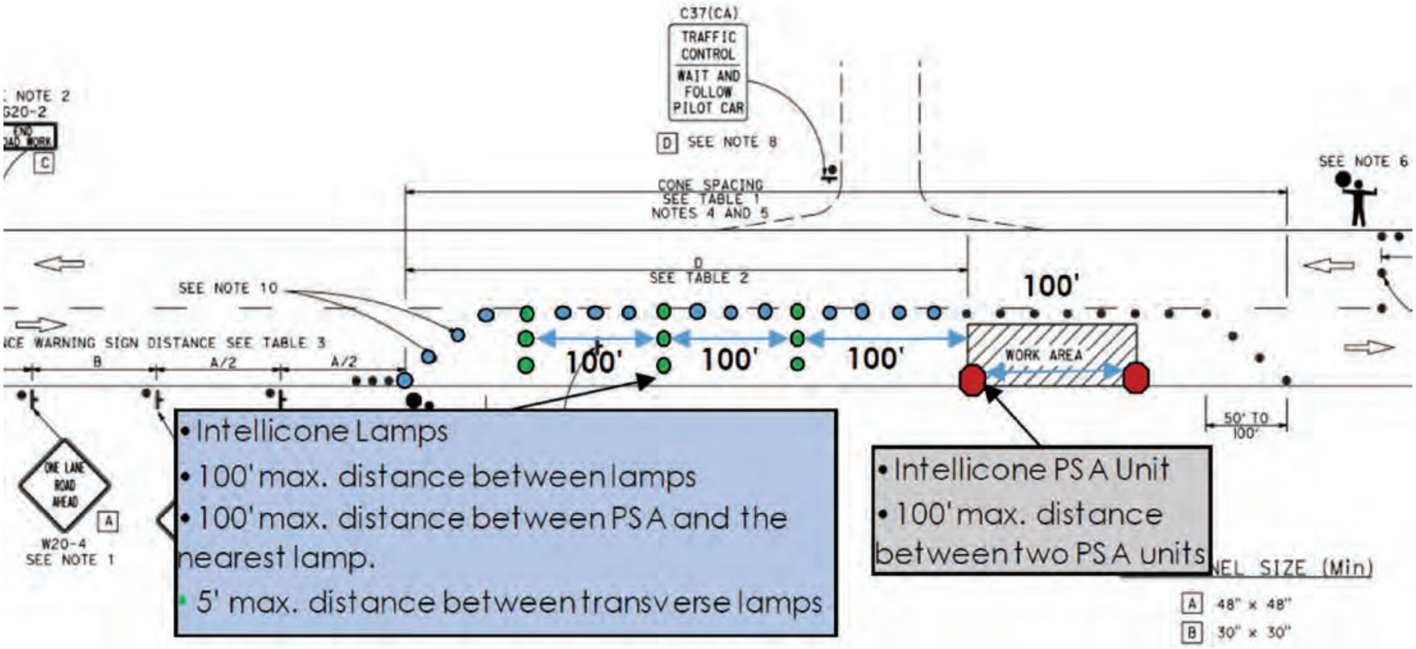


Figure 2.17. Caltrans Intellicone recommended deployment plan (Credit: Caltrans).

maximum distance of 225 feet between the first alarm unit and the nearest trip hose. Additional trip hoses upstream of the first trip hose are recommended to increase the coverage area in the work zone. Although Figure 2.16 shows three trip hoses, a recommendation on the specific number of trip hoses is not provided since that would depend on the length of the work zone and the number of available devices. Instead, a maximum of 75 feet between the trip hoses is recommended based on discussions and feedback from maintenance workers during supplemental testing, as this distance provided effective coverage with minimum gaps for intruding vehicles to miss a trip hose. Based on this recommendation, the total number of trip hoses can be calculated given the length of a work zone.

It is also recommended to lay out the trip hoses diagonally at an approximate angle of between 45 to 70 degrees to improve the coverage area. Multiple alarm units should be placed, ideally, at the start, middle, and end of the work area, ensuring the maximum distance between the alarm units does not exceed 175 ft with a clear line of sight. Also, the units should be placed at least 4 ft above the ground. The speaker on the alarm unit should be oriented toward the workers during daytime and the light source should be oriented toward the workers during nighttime operations.

Figure 2.17 shows Intellicone lamps on the taper and tangent cones with spacing as required by the Caltrans standard traffic control plan tables. The maximum distance between the lamps, between the portable site alarm and the nearest lamp, and between two PSA units must be at most 100 ft, at which the evaluation trials in this research produced 100 percent successful results. For effective coverage, additional cones with lamps are recommended to be deployed transverse to the traffic flow, as shown in Figure 2.17. Two cones are recommended, with a maximum spacing of 5 ft. This configuration should be repeated every 100 ft, starting from the work area and going upstream in the work zone. It is recommended to deploy as many cones with lamps as available to increase the coverage area of the system in a work zone. Based on the work zone speed and spacing between the cones, the number of cones required for a specific work zone can be calculated. Lamps of all sensitivities except “very high” are recommended to be used in the presence of heavy vehicles and speeds exceeding 35 mph. For other speeds, the very high sensitivity lamp should be used.

The Pennsylvania DOT (PennDOT) also developed WZIA standard drawings for use on conventional highways and on freeways and expressways, as shown in Figure 2.18.

2.6.8 State of the Practice

Current literature suggests that work zone intrusion alert systems are not widely used. At the time this guidebook was written, only Pennsylvania had deployed intrusion alarms in active work zones. California and Oregon conducted testing in controlled environments (closed to live traffic) to better understand system deployment, practical implementation, capabilities, and limitations.

2.6.8.1 Pennsylvania

PennDOT purchased 16 WASs in 2018 and distributed them to districts for an evaluation that lasted until June 30, 2019. Each PennDOT district was asked to evaluate the system for at least 1 month. Districts with more than six counties were given an extra intrusion alarm to allow all counties to use the devices for at least 1 month. By tracking where and when the devices were used and evaluations by the field staff, PennDOT intends to issue recommendations for further purchases.

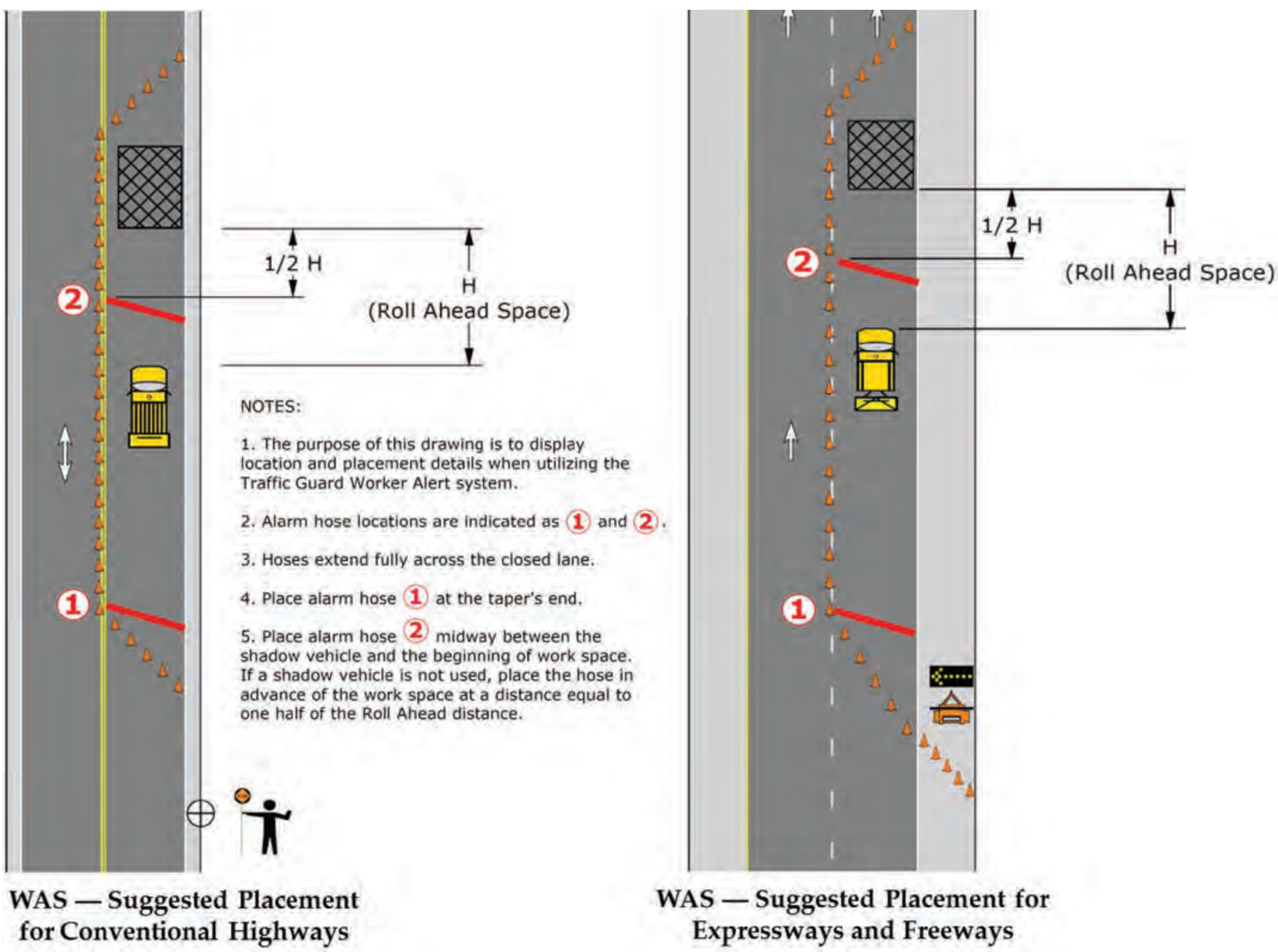


Figure 2.18. PennDOT-suggested WAS placement (Credit: PennDOT).

2.6.8.2 Advanced Warning and Risk Evasion

In addition to the intrusion alarm systems listed previously, Oldcastle Materials recently introduced Advanced Warning and Risk Evasion (AWARE) alert technology. The system relies on position and orientation sensors and radar to constantly monitor the work zone. AWARE was piloted during a paving project for the Minnesota Department of Transportation (MnDOT) in May 2018. Overall, the pilot was successful in illustrating the potential of the AWARE system to detect vehicle intrusions into workspaces and to warn both intruding motorists and work crews. The AWARE system is undergoing more field-testing and is not currently commercially available.

2.6.8.3 Minnesota

MnDOT has developed a concept of operations for a work zone intrusion warning system to support enhanced work zone safety (MnDOT 2015). The system requirements were derived from the needs identified in the concept of operations and address the functional aspects of the system. Figure 2.19 shows a screenshot of the system requirements.

2.6.9 Cost

Caltrans estimated costs for a hypothetical half-mile closure on a two-lane road with 12-ft wide lanes, PSL of 25 mph (channelizing device spacing of 25 ft in taper and 50 in tangent section resulting in a total of 63 channelizing devices), and activity area of 500 ft as follows:

- *WAS.* \$4,630 assuming the use of 10 personal safety devices, three alarm units, six 33-ft trip hoses with chargers, and a single handheld remote trigger.
- *SonoBlaster.* \$5,670 for 63 units with one CO_2 cartridge per unit (or unit price of about \$90).
- *Intellicone.* \$11,100 for 63 units and two PSAs (or unit price of approximately \$150 to \$200).

ID #	Needs	ID #	High Level Requirements	ID #	Detailed System Requirements
1	Workers in a work zone need an alert when a vehicle enters a restricted area.	1.1	WIWS shall detect all unauthorized vehicles entering a work zone.	1.1.1	WIWS shall detect unauthorized vehicles entering a work zone with at least XX% accuracy.
Considerations: This should cover all components needed for the system to function at a rate which is acceptable by the agency.					
				1.1.2	WIWS shall send notification within XX seconds of vehicle entering restricted area.
Considerations: The specified time should include all latency between devices and include data processing needed to generate the notification to the alert system.					
				1.1.3	WIWS shall provide a means to disable detection in the field manually to allow authorized vehicles to enter work zone.
		1.2	WIWS shall alert workers when a vehicle enters a work zone.	1.2.1	WIWS alert may be audible, visual, sensory (e.g. vibration) or a combination of any or all of these alerts.
				1.2.2	WIWS alert shall be activated within XX seconds of vehicle entering a restricted area.
Considerations: The specified time should include all latency between devices and include data processing needed to receive the notification to the alert system.					
				1.2.3	WIWS shall only alert workers in danger, in the vehicle's path.
Considerations: In the attempt to reduce de-sensitization of the alerts only those workers in immediate danger should be notified with alert (proximity of intrusion and downstream workers).					

Figure 2.19. Minnesota work zone intrusion warning system requirements (Credit: MnDOT).

2.6.10 Resources and References

Brown, H., C. Sun, and T. Cope. "Evaluation of Mobile Work Zone Alarm Systems," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2485, pp. 42–50, 2015.

Caltrans. *Task Number 3038, Evaluation of Work Zone Intrusion Alarms*. Division of Research, Innovation and System Information, 2019.

Fyrie, P. "Work Zone Intrusion Alarms for Highway Workers," AHMCT Research Center. University of California at Davis, 2016.

Gambatese, J., H. Lee, and C. Nnaji. *Work Zone Intrusion Alert Technology: Assessment and Practical Guidelines*, Oregon Department of Transportation, 2017.

Hayden, L. *Pager Performance for the Western Transportation Institute's Augmented Speed Enforcement Project*. California Department of Transportation (Caltrans) Division of Research. CA13-2062E. 2013.

Hourdos, J. *Portable, Non-Intrusive Advance Warning Devices for Work Zones with or without Flag Operators,* University of Minnesota, Minnesota Traffic Observatory, MN/RC 20-26, October 2012.

Krupa, C. *Work Zone Intrusion Alarm Effectiveness*, NJ-2010-004, New Jersey Department of Transportation, September 2010.

Kuta, B. *Work Zone Intrusion Alarm Demonstration Interim Report—SonoBlaster*, FHWA Resource Center, U.S. DOT, August 2009.

Marks, E., S. Vereen, and I. Awolusi. "Active Work Zone Safety Using Emerging Technologies 2017," UTCA Report Number 15412, 2017.

MnDOT. *Work Zone Intrusion Warning System: System Requirements*, Minnesota Department of Transportation, 2015.

Novosel, C. *Evaluation of Advanced Safety Perimeter Systems for Kansas Temporary Work Zones*. Ph.D. dissertation, University of Kansas, 2014.

PennDOT. *Ways to Stop Work Zone Intrusions*, PennDOT District 12, Progress Report, Volume 1, Issue 8, 2018.

Theiss, L., G. L. Ullman, and T. E. Lindheimer. *Closed Course Performance Testing of the AWARE Intrusion Alarm System*, Texas A&M Transportation Institute, College Station, TX, 2017.

Ullman, G. L., and L. Theiss. *Personal Warning Sensor for Road Construction Worker*, Texas A&M Transportation Institute, College Station, TX, 2019.

Ullman, G. L., N. D. Trout, and L. Theiss. *Driver Responses to the AWARE Intrusion Alarm System*, Texas A&M Transportation Institute, College Station, TX, 2016.

Zhang, F., and J. Gambatese. "Highway Construction Work-Zone Safety: Effectiveness of Traffic-Control Devices." *Practice Periodical on Structural Design and Construction*, 22(4), 04017010, 2017.

2.7 Moveable Traffic Barrier Systems

2.7.1 Description

Moveable or mobile traffic barrier systems protect workers by isolating short-duration work zones from live traffic. At the time this guidebook was written, the two tractor trailer–mounted mobile barrier systems used in the United States are the Balsi Beam developed by Caltrans and the proprietary Mobile Barrier Trailer (MBT-1) system developed by Mobile Barriers LLC.

2.7.2 When to Use

Short-term freeway maintenance projects, such as shoulder repair, guardrail replacement, bridge deck repairs, bridge joint maintenance, median barrier repair, and pavement patching, that require maintaining high-speed, multilane traffic, are the most common category for potential moveable barrier use.

The most common method for using moveable barriers is as a shoulder application. During peak traffic hours, the barrier is on the shoulder protecting equipment, materials, drop-off, and the like, but does not encroach on traffic lanes. During off-peak hours, adjacent lanes can be closed and the moveable barrier positioned into the closed lane to provide a larger protected work area or a work/haul vehicle-access lane.

Some other work activities warranting moveable barriers are

- Pothole filling,
- Overnight slab replacement,
- Light bulb changes on highways,
- Joint seal replacements,
- Work required on medians,
- Bridge rehabilitation,
- Culvert replacements,
- Guardrail replacements, and
- Pavement distress surveys.

2.7.3 Benefits

Moveable barriers allow field crews to safely and quickly create a work space that is physically separated from moving traffic and then quickly remove the device from the roadway when the work activity is completed, restoring normal traffic flow.

For road crews, the mobile barrier protects against work zone intrusions, reduces the vehicles and equipment otherwise needed on site, and improves lighting and ambient conditions. With less worker fatigue and fewer delays, crews have reported productivity gains of 60 to 80 percent.

2.7.4 Expected Effectiveness

Moveable traffic barrier systems have reduced mean speeds by 4 to 6.2 mph (Gambatese and Tymvios 2013).

2.7.5 Crash Modification Factor

A CMF is not available for this strategy.

2.7.6 Implementation Considerations

Moveable barrier systems should be considered for use in the following situations:

- Time-of-day restrictions for lane closures limit available work time.
- Work activity is short term or can be broken into a series of short-term closures.
- Exposed work hazards require positive protection.

In addition, with the barrier in place, limited space is available to travel to and from the worksite on the same side.

2.7.7 Design Features and Requirements

2.7.7.1 Balsi Beam

Caltrans developed the tractor trailer–mounted mobile worker protection device Balsi Beam in 2003 (Mortazavi 2010, Figure 2.20). The trailer consists of two telescoping high-strength steel beams whose width can be extended to as much as 12 ft. Using hydraulic power, each beam can rotate to either side of the roadway (left or right), depending on which side requires protection; stacking both beams on the same side will create a 3-ft-high wall. The trailer can be extended to provide a work area up to 30 ft long. The trailer beams act as a rigid obstacle that deflects any vehicle that attempts to penetrate the work area from the side; a TMA is attached to the rear of the trailer. *NCHRP Report 350* Level 2 crash testing was successfully completed in 2003.

Figure 2.20. Balsi Beam (Credit: Caltrans).

2.7.7.2 MBT-1

Similar to the Balsi Beam, the proprietary MBT-1 barrier consists of a 5-ft-tall smooth steel wall that protects the work zone from the side, combined with an attenuator at the rear (Figure 2.21). Adding wall sections can increase the length of the work area from 42 ft to 102 ft. By swapping the positions of the semi-tractor and the rear wheels, workers can reconfigure the device for placement on the left or the right side of the road. The system was certified as *NCHRP Report 350* Test Level 3 and *Manual for Assessing Safety Hardware* (MASH16) compliant for Test Level-2 and Test Level-3 for use on the National Highway System.

2.7.8 State of the Practice

Mobile barriers are used frequently in California, Florida, Oregon, and Washington.

2.7.9 Cost

The estimated cost of a mobile barrier can be upwards of $300,000 depending on the vehicle options selected.

2.7.10 Resources and References

Arico, M. C., and B. Ravani. *Balsi Beam Deployment Support.* CA09-0981, AHMCT Research Center, University of California at Davis. October 30, 2008.

Bligh, R. P., N. M. Sheikh, W. L. Menges, and R. R. Haug. *Portable Concrete Traffic Barrier for Maintenance Operations,* FHWA/TX-05/0-4692-1, Texas A&M Transportation Institute, May 2005.

Burkett, G., V. Her, and S. A. Velinsky. *Development of New Kinds of Mobile Safety Barriers.* CA09-0920, AHMCT Research Center, University of California at Davis, February 28, 2009.

Gambatese, J. A., and N. Tymvios. *Evaluation of a Mobile Work Zone Barrier System*. Oregon State University. FHWA-OR-RD-14-05. August 2013.

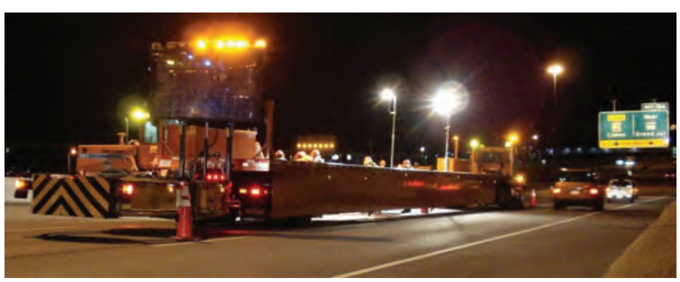


Figure 2.21. MBT-1 (Credit: Mobile Barriers LLC).

Lohse, C., D. A. Bennett, and S. A. Velinsky. *Temporary Barrier Usage in Work Zones.* CA07-0915, AHMCT Research Center, University of California at Davis, June 30, 2007.

Manual for Assessing Safety Hardware, 2nd ed. AASHTO, Washington, D.C., 2016. [MASH16]

Mortazavi, A. *Balsi Beam: Technology Transfer and Deployment.* CA10-1653, California Center for Innovative Transportation, University of California at Berkeley, July 2010.

Portable Positive Protection: A Guide for Short Duration and Short Term Work Zones, American Traffic Safety Services Association (ATSSA), September 2015.

Price, G. C. *Cost-Benefit Analysis & Justification: Mobile Barriers MBT-1,* June 2017.

Ravani, B., J. Wong, P. Fyhrie, and R. Bosler. *Scientific Evaluation of the ArmorGuard Mobile Barrier System.* CA11-1842, AHMCT Research Center, University of California at Davis. June 17, 2011.

Ross, H. E., Jr., D. L. Sicking, and R. A. Zimmer. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.* TRB, National Research Council, Washington, D.C., 1993.

Theiss, L., and R. P. Bligh. *Worker Safety During Operations with Mobile Attenuators,* FHWA/TX-13/0-6707-1, Texas A&M Transportation Institute, May 2013.

CHAPTER 3

Corridor/Network Management Strategies

This section includes strategies to optimize traffic flow through the work zone corridor and adjacent roadways using various traffic operations techniques and technologies. The following strategies are covered in this section:

- Lane merge systems
- Reversible lanes
- Ramp metering
- Truck-lane restrictions

3.1 Lane Merge Systems

3.1.1 Description

Lane merge systems refer to the lane-use instructions that inform motorists of the merge point location during a lane closure. The two types of lane merge systems are

- **Early merge** (Figure 3.1). Encourages drivers to merge into the open lane sooner than they would with the conventional merge.
- **Late merge** (Figure 3.2). Encourages drivers to remain in their lanes until they reach the merge point at the lane closure taper and then alternate (take turns) moving into the open lane, which effectively doubles the queue storage capacity. The late-merge strategy is also known as a zipper merge.

The decision regarding which system to use is based on traffic demand and lane congestion.

3.1.2 When to Use

Early merge is effective on roadways with high traffic volume and lower average speeds, usually related to congestion. For example, early merge should be used when peak hour traffic demand is between 2,000 and 3,000 vehicles per hour (vph) for a two-to-one lane closure and between 3,000 and 3,800 for a three-to-two lane closure (Enterprise Pooled Fund Study 2014).

Late merging works best for roadways with lower traffic—between 1,200 and 1,800 vph, with the most common implementation volume set at 1,500 vph (Sperry et al. 2009; Grillo, Datta, and Hartner 2008; Datta, Hartner, and Grillo 2007; MnDOT 2004).

According to the MnDOT Intelligent Work Zone Toolbox (2019 edition), late merge should be considered in the following situations:

- Traffic volumes exceed 1,500 vph to sustain a queue that is caused by merging lanes.
- Estimated queue lengths may encroach beyond an upstream intersection or interchange operations.

Figure 3.1. Illustration of early-merge concept (Credit: FHWA).

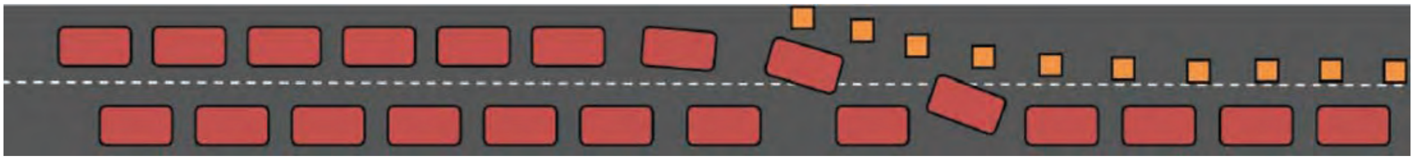


Figure 3.2. Illustration of late-merge concept (Credit: FHWA).

- Speeds and lane occupancy volumes are anticipated to vary unpredictably and cause the motorist to have trouble identifying the best lane-use practice, such as using both lanes versus moving into the continuous thru-lane.

Figure 3.3 shows a flowchart developed by ATSSA (2012) to help DOTs decide when to use static merging strategies (early or late) or a dynamic combination of early and late strategies.

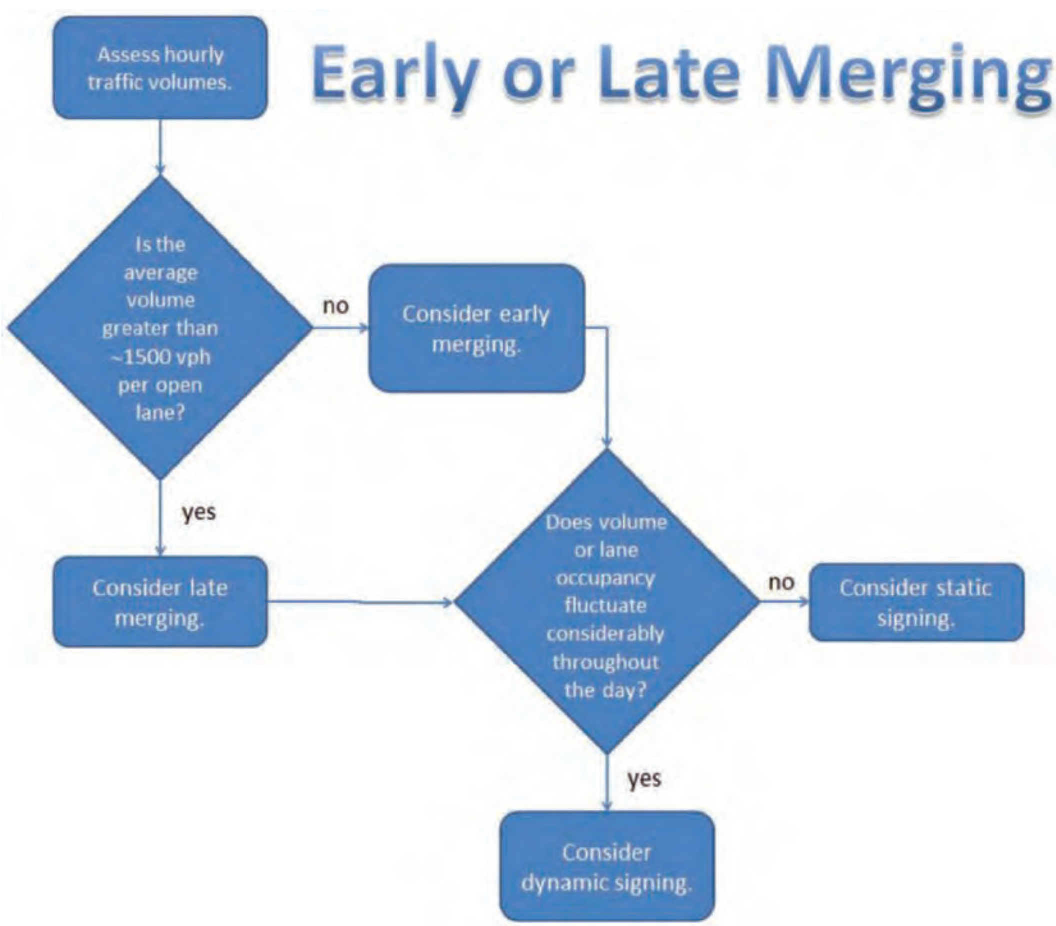


Figure 3.3. Lane-merging decision-making flowchart (Credit: ATSSA).

3.1.3 Benefits

The use of an early-merge system provides the following benefits:

- Reduces aggressive driving and unsafe merge maneuvers.
- Provides significant advanced warning to allow drivers adequate distance to merge.
- Gives positive instructions on lane usage.
- Improves vehicle throughput slightly.

The use of a late-merge system provides the following benefits:

- Maximizes available storage upstream of work zone for reducing total queue length.
- Increases overall vehicle throughput.
- Reduces the differential speed between lanes by using both traffic lanes, because both lanes travel at approximately the same speed.
- Reduces aggressive driving and possibly reduces crashes.

3.1.4 Expected Effectiveness

Compared to the early merge, the late-merge strategy has been studied more extensively with the following results:

- Reduction of 3- to 24-minute delays (FHWA 2015)
- 38.5 percent reduction in average travel time for every 10,000 ft of travel per vehicle, 61.3 percent increase in average speed, 22 percent increase in capacity, and 16 percent reduction in percentage of vehicles merging at taper (Datta, Hartner, and Grillo 2007)
- 29.8 percent increase in work zone capacity (Qin, Noyce, and Chen 2006)
- 17.8 percent increase in vphpl and a 15 percent reduction in maximum queue length (Kang et al. 2006)
- 30 percent to 40 percent increase in percentage of drivers using the discontinuous lane near the taper point during peak congestion times (MnDOT 2004)
- 35 percent reduction in queue length (MnDOT 2003)

3.1.5 Crash Modification Factor

No CMF is available for this strategy.

3.1.6 Implementation Considerations

Agencies can implement early- and late-merging methods in a static (passive) or dynamic (active) manner.

Static merging systems use static signs to instruct motorists on where to merge. The static signs may have flashing lights that are activated at certain times of the day. Figure 3.4 shows an example of static late merge.

A dynamic lane-merging system (DLMS) is a type of SWZ system that collects real-time traffic information (e.g., speeds, volume, occupancy) and switches between early and late merge depending on traffic conditions. An example of dynamic late merge is shown in Figure 3.5.

Aspects to consider before DLMS deployment include sign spacing, PCMS messaging, and public outreach.

Sign spacing needs to be modified according to the geometry of the road, the expected queue length, and the average expected speed of the vehicles. Additionally, drivers' familiarity with the roadway and whether entrance or exit ramps are near the merging area needs to be considered.

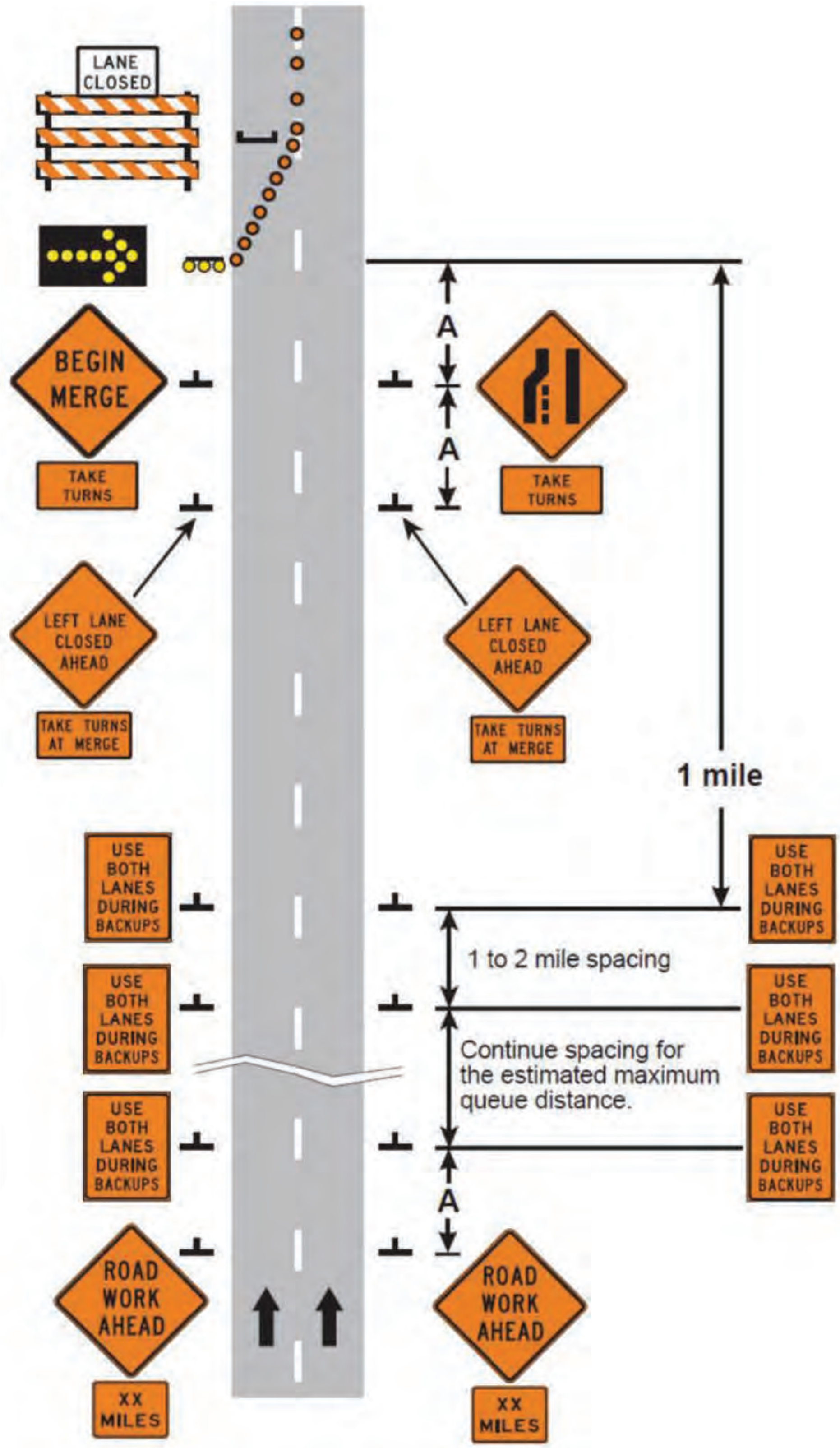


Figure 3.4. Static (passive) zipper merge layout (Credit: MnDOT).

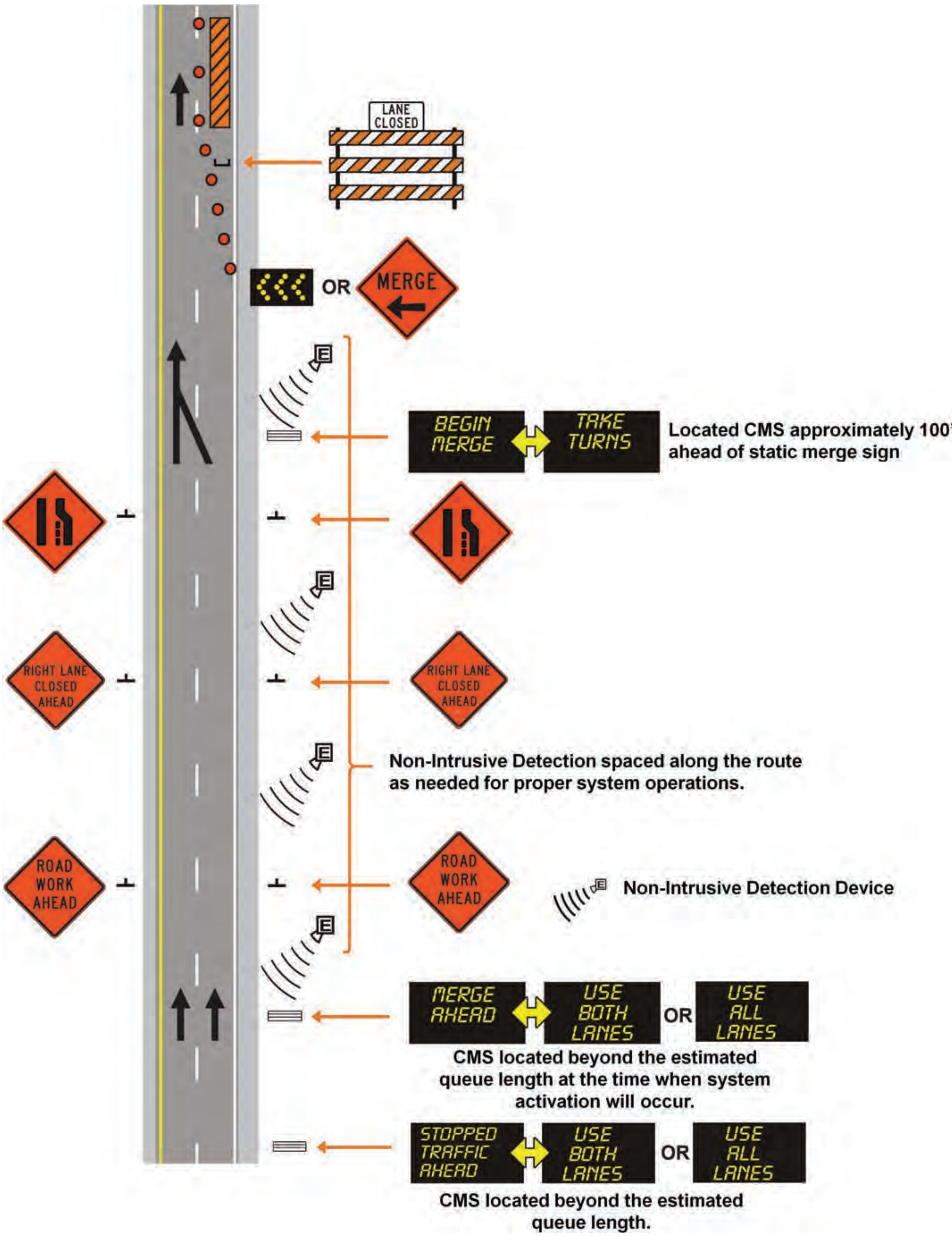


Figure 3.5. Dynamic late-merge (i.e., zipper merge) system layout (Credit: MnDOT).

It is pertinent to ensure that the PCMS is displaying reasonable messages. The PCMS should be located in advance of the lane closure as determined by the engineer based on estimated queue lengths and geometry. An example PCMS display for late merge follows:

- PCMS located beyond estimated maximum queue length: STOPPED TRAFFIC AHEAD (Phase 1), USE BOTH LANES (Phase 2).
- Intermediate PCMS located beyond estimated queue length at the time when DLMS activation will occur: MERGE AHEAD (Phase 1), USE BOTH LANES (Phase 2).
- PCMS located at point of merge shall display: MERGE HERE (Phase 1), TAKE TURNS (Phase 2).

Accomplishing a successful, safe DLMS will require a public outreach campaign to help motorists understand how to navigate safely through the merge system.

3.1.7 Design Features and Requirements

A DLMS typically involves portable traffic sensors that detect real-time traffic characteristics (speeds, occupancy, etc.), a series of PCMSs to display messages to motorists upstream of the work zone, and an automated traffic system that stores the data and uses algorithms to turn the system on and off. When speeds drop below the default speed threshold, a series of PCMSs are activated, encouraging the motorists to stay in their lanes and take turns to merge at a designated location, thus improving traffic flow, reducing the queue, and improving overall safety. Once the congestion dissipates, the PCMSs are deactivated and motorists follow the early-merge process.

3.1.8 State of the Practice

A DLMS is one of the technology applications promoted by the FHWA's SWZ, during Round 3 of the Every Day Counts (EDC) initiative.[9] The National Work Zone Safety Information Clearinghouse website (https://www.workzonesafety.org/swz/) provides resources including bid specifications, deployment plans, and case studies. Examples of DLMS deployments follow.

3.1.8.1 Minnesota

MnDOT first introduced the zipper merge in the early 2000s and has deployed it on several projects. The department also created video tutorials and conducted extensive public service announcements on radio and TV stations, news websites, and highway billboards. MnDOT uses both passive (static signs) and active (intelligent work zone) systems to implement the zipper merge and developed standard layouts (Appendix D1).

3.1.8.2 Kansas

KSDOT implemented a dynamic late lane merge system (i.e., zipper merge) in association with a bridge deck repair project in Overland Park from July 7 to November 1, 2016.

Appendix D2 shows the layout of the system. System performance was evaluated using the duration of the traffic queues during any given day for the first 12 weeks of the project. During the first 3 weeks of the project, a vehicle queue extended to the furthest sensor approximately 4.5 mi away from the merge point for only 68 minutes. For weeks 4–6, that sensor saw

[9] Information on the FHWA promotion of SWZs is found on the Every Day Counts Initiative: Smarter Work Zones, Technology Applications: Dynamic Lane Merge web page: https://www.workzonesafety.org/swz/swztechnology-application/types-of-applications/dynamic-lane-merge/.

queues for only 35 minutes, and for weeks 7–9, that location saw queues for 76 minutes. Data for weeks 10–12 was skewed because of another work zone operation that involved a lane closure.

To help motorists navigate the system, KSDOT conducted an extensive education effort that included news releases, interviews, public meetings, a project website, and a video (https://www.youtube.com/watch?v=8wgSjstvsPc). The video was used to educate the driving public about the dynamic late merge and address several of the major criticisms about late merging.

After the zipper merge was started the week of July 5, 2016, several local TV stations did stories that featured elements of the video. Ultimately, the video was viewed almost 200,000 times between YouTube and Facebook.

3.1.8.3 North Carolina

NCDOT implemented the dynamic late merge (zipper merge) on an I-85 work zone in Vance and Warren Counties just south of the Virginia state line. NCDOT implemented the zipper merge during the first week of October 2016. Using the zipper merge setup decreased travel time by 1 minute, which equates to an 11-mph increase in mean speed. The greatest improvement related to implementing the zipper merge was in safety; after implementing zipper merge, fewer vehicles entered the shoulder to merge.

3.1.8.4 Massachusetts

As part of its I-91 Springfield Viaduct reconstruction project, the Massachusetts DOT (MassDOT) implemented a zipper merge system to improve traffic flow and increase safety where the lanes on I-91 south dropped from two to one. The DLMS was in effect from October 2016 to March 2018. At the time this guidebook was written, MassDOT is still evaluating the effects of the DLMS.

3.1.8.5 Wisconsin

WisDOT implemented its first dynamic late-merge system as part of the Zoo Interchange project in 2016. Implementing the zipper merge was preceded by an extensive public campaign that included developing an instructional fact sheet (Appendix D3) and an instructional video (https://www.youtube.com/watch?v=FhKZKmS2Ag4).

3.1.8.6 Colorado

The CDOT has developed a standard layout for zipper merge (Appendix D4) and a public relations late-merge video (https://www.codot.gov/library/traffic/work-zone-safety-and-work-zone-traffic-operations/work-zone-traffic-operations-strategies/travel-demand-management/late-merge-work-zone-traffic-control-strategy/CDOT-Late-Merge-newLogo.mp4).

3.1.8.7 Michigan

MDOT has deployed zipper merge on several projects:

- US-2 bridge over the Escanaba River, Delta County (October–November 2018)
- I-96 concrete joint repairs, Lowell (May–September 2014)
- I-196 bridge work near Grand Rapids (April–July 2013)

3.1.9 Cost

The cost to deploy an SWZ such as the dynamic merge system depends on the project duration and the number of devices used (e.g., message boards, traffic sensors, speed trailers, cameras).

In general, the rental cost is the same for a PCMS or a traffic sensor or camera—approximately $1,000 per week. For longer-duration projects, the rental costs can be substantially lower.

MnDOT reported the cost estimate, based on 2018 MnDOT rental prices, for an active zipper merge project using two PCMS and six sensors at $7,000 per week, or $13,000 per month, or $58,000 per 6 months.

3.1.10 Resources and References

American Traffic Safety Services Association (ATSSA). *Guidance for the Use of Dynamic Lane Merging Strategies*, U.S. DOT, Washington, D.C., 2012.

Beacher, A. G., M. D. Fontaine, and N. J. Garber. Evaluation of the Late Merge Work Zone Traffic, VTRC 05-R6, Virginia Transportation Research Council, Charlottesville, VA, 2004.

Beacher, A. G., M. D. Fontaine, and N. J. Garber. Guidelines for Using Late Merge Traffic Control in Work Zones: Results of a Simulation-Based Study. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1911, 2005, pp. 42–50.

Datta, T. K., C. Hartner, and L. Grillo. *Evaluation of the Dynamic Late Lane Merge System at Freeway Construction Work Zones*, Wayne State University. Research Report RC-1500. September 2007.

Enterprise Pooled Fund Study. *Dynamic Merge Systems in Work Zones: Summary of Uses and Benefits*, June 2014.

FHWA Every Day Counts (EDC) Initiative: Smarter Work Zones, Technology Applications: Dynamic Lane Merge web page. https://www.workzonesafety.org/swz/swztechnology-application/types-of-applications/dynamic-lane-merge/.

FHWA. Smart Work Zone Webinar Series. *Webinar #6: SWZ Case Study: Variable Speed Limit and Dynamic Lane Merge*, November 12, 2015. https://www.workzonesafety.org/swz/webinars/.

Grillo, L. F., T. K. Datta, and C. Hartner. Dynamic Late Lane Merge System at Freeway Construction Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2055, Vol. 1, 2008, pp. 3–10. https://doi.org/10.3141/2055-01.

Ishak, S., Y. Qi, and P. Rayaprolu. "Safety Evaluation of Joint and Conventional Lane Merge Configurations for Freeway Work Zones," *Traffic Injury Prevention*, 13(2), pp. 199–208.

Kang, K. P., G. L. Chang, and J. Paracha. Dynamic Late Merge Control at Highway Work Zones: Evaluations, Observations, and Suggestions. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1948, 2006, pp. 86–95.

McCoy, P. T., and G. Pesti. Dynamic Late Merge-Control Concept for Work Zones on Rural Interstate Highways. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1745, 2001, pp. 20–26.

MnDOT. *Dynamic Late Merge System Evaluation, Initial Deployment on US-10*. Minnesota Department of Transportation, 2003.

MnDOT. *Evaluation of 2004 Dynamic Late Merge System*, Minnesota Department of Transportation, December 2004.

MnDOT. *Intelligent Work Zone Toolbox,* 2019 edition, Minnesota Department of Transportation.

Qin, X., D. A. Noyce, and Y. Chen. *Evaluation of Dynamic Late Merge System in Highway Work Zones. Traffic Operations and Safety*, (TOPS) Laboratory, Wisconsin Department of Transportation, July 2006.

Radwan, E., R. Harb, and S. Ramasamy. *Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida*, 2009.

Sperry, R., T. McDonald, S. Nambisan, and R. Pettit. *Effectiveness of Dynamic Messaging on Driver Behavior for Late Merge Lane Road Closures*, CTRE Project 08-327, Iowa Department of Transportation, 2009.

Tapan D., K. Schattler, P. Kar, and A Guha. *Development and Evaluation of an Advanced Dynamic Lane Merge Traffic Control System for 3 to 2 Lane Transition Areas in Work Zones*, Wayne State University. Research Report RC-1451, January 2004.

Tarko, A., and S. Venugopal. *Safety and Capacity Evaluation of the Indiana Lane Merge System*, Joint Transportation Research Program, Purdue University. HWA/IN/JTRP-2000/19. February 2001.

Vaughan, C., C. Cunningham, S. Warchol, D. Findley, C. Carnes, S. Sallade, G. Oyler, D. Coble, and B. Kearns. *The Effects of Late Lane Merges on Travel Times*, North Carolina Department of Transportation (FHWA/NC/2015-08), 2018.

Zaidi, Z., E. Radwan, and R. Harb. *Evaluating Variable Speed Limits and Dynamic Lane Merging Systems in Work Zones: A Simulation Study*. Orlando, Florida: Hindawi Publishing Corporation, 2012.

3.2 Reversible Lanes

3.2.1 Description

A reversible roadway is one in which the direction of traffic flow in one or more lanes or shoulders is reversed to the opposite direction for some period of time. Its utility is derived by taking advantage of the unused capacity of the minor-flow direction to increase capacity in the major-flow direction, thereby negating the need to construct additional lanes.

3.2.2 When to Use

Reversible lanes are particularly useful in work zones with a directional imbalance in excess of 65 percent to 35 percent during weekday peak hours, when the number of lanes is reduced and the cost to provide additional capacity would be high. The cost of ROW limitations may even make the cost of reversible lanes too high to implement.

3.2.3 Benefits

The primary benefit of reversible lane operation is reducing congestion during periods of high and unbalanced directional travel demand. Their utility results from using the reduced capacity of the minor-flow direction lanes to increase the directional capacity in the major-flow direction. Another significant benefit is the reduction in construction time, which translates into a lower road-user cost (RUC).

3.2.4 Expected Effectiveness

Most reversible lane systems were developed and managed based primarily on experience, professional judgment, and empirical observation. Formal analyses of the effects of work zone reversible lane operations are limited.

- A work zone reversible lane system was implemented for 2 months (August–October 2014) on Autobahn A-3 southeast of Frankfurt, Germany, and analysis identified almost 400,000 vehicle hours saved compared with a permanent lane reduction in one direction (Waleczek et al. 2016).
- As part of this project (NCHRP 03-111), the effectiveness of reversible lanes was studied at two work zones in Michigan and at another work zone in Minnesota. The results indicated that implementing the reversible lane operation improved travel time between 5.6 percent and 15 percent. The capacity-reduction factor for reversible lane operation appears to be 0.90 to 1.20 per lane, the latter occurring when the reversible lane operation is within barriers and not affected by ramps and other merging traffic. The NCHRP Project 03-111 final report, which details the findings of the reversible lane field evaluations, is published as *NCHRP Web-Only Document 276* and is available on the TRB website. MDOT estimated an RUC savings of $30 million at one test site.
- The $29 million I-75 Linwood to Pinconning project in Bay County, Michigan, was originally scheduled in 2012 to take 2 years. Instead, MDOT finished reconstructing 32 lane-miles of I-75 in less than 1 year using reversible lanes.

3.2.5 Crash Modification Factor

Table 3.1 shows the CMF for work zone reversible lanes. Chapter 13 of this document provides more information on developing WZCMFs.

Table 3.1. CMFs for work zone reversible lanes.

Crash Type	Crash Severity	Facility Type	Volume Range (AADT)	CMF	Standard Error
All	Fatal, serious and minor injury	All	<100,000	1.029	0.2

NOTE: The CMF was derived from three test sites. CMF = crash modification factor; AADT=annual average daily traffic. While the CMF is reliable for the corridors that were studied, analysts should consider whether the results are transferable to any other specific work zone application.

3.2.6 Implementation Considerations

The ITE *Traffic Engineering Handbook* (7th edition) recommends that DOTs examine the following criteria before implementing reversible lanes:

- The traffic congestion problem under investigation should be both periodic and predictable.
- The ratio of a major-to-minor traffic count should be at least 2:1, and preferably 3:1.
- ROW (or the ability to acquire it) to construct additional lanes should be limited.

Enforcement and incident management are other considerations to control and manage reversible roadways. Because one primary motivation of reversible lane use is to limit the overall cross section width of a road, shoulders along many segments are often narrow or absent. This situation eliminates the ability to use roadside traffic enforcement vehicles. It also greatly limits the ability of vehicles to make emergency stops and of service vehicles to respond to incidents.

3.2.7 Design Features and Requirements

The design criteria used for reversible lanes, such as turning radii, sight distances, taper lengths, lanes widths, and so on, are similar to those for conventional highways and should meet the standards and policies set forth in the 2018 AASHTO *Green Book*, the 2009 MUTCD, and applicable state-specific documents.

Agencies should pay particular attention to the design of the termini transitions, as these areas confuse drivers the most. Agencies should also consider the control of pedestrian movements across reversible lanes.

Work zone reversible lane applications are controlled in the following ways:

- Lane-use control signals (LUCS) indicate which lanes of a reversible roadway are available (or not available) for use in a particular direction. LUCS are distinguished by placing special signal faces over a certain lane or lanes of the roadway and by their distinctive shapes and symbols. The 2009 MUTCD (Chapter 4M) provides standards and guidance for LUCS use.
- Channelizing devices such as drums, tubular markers, cones, and vertical panels can be used to separate the opposing traffic. Given a typical twice-daily peak period application, using conventional channelizing devices is labor and time intensive because the devices must be moved into and out of position at different times of the day.

  A more-innovative barrier system, and one that is gaining in popularity, is the moveable barrier. Moveable barriers have been used on both a permanent basis for roadways and bridges and a temporary basis within construction zones where unbalanced directional flows occur. Moveable barriers can be repositioned laterally by using a transfer vehicle that travels along the barrier. The appearance and performance of moveable concrete barriers are similar to those of fixed concrete barriers and the ends are protected with crash cushions. The 2009

MUTCD (Figure 6H-45) shows a typical application using moveable barriers for a temporary reversible lane.

A swift gate can also be used in conjunction with the moveable machine barrier. A swift gate is an automated lane closure system used for repetitive lane closures. This system consists of tapered gates that pivot from a stored to a deployed position to channel motorists into the correct traffic configuration. The swift gate can be deployed from a handheld device, saving time and money and reducing worker exposure.

- The 2009 MUTCD guidelines for reversible lane pavement markings require that "each side of reversible lanes shall consist of a normal broken double yellow line to delineate the edge of a lane in which the direction of travel is reversed from time to time, such that each of these markings serves as the center line markings of the roadway during some period" (2009 MUTCD, Section 3B.03).
- The 2009 MUTCD (Section 2B.26) presents the most current standards for design and placement of regulatory signs for reversible roadways. The 2009 MUTCD requires that agencies use all post-mounted signs only as a supplement to overhead signs or LUCS.

3.2.8 State of the Practice

The following examples demonstrate how state DOTs have used reversible lanes in work zones.

3.2.8.1 District of Columbia

Rehabilitation of the Whitney Young Memorial Bridge (2019, expected completion 2020). The Whitney Young Memorial Bridge (also known as the East Capitol Street Bridge) carries approximately 45,000 vehicles daily over the Anacostia River and Kingman Lake in southeast Washington, D.C., near RFK Stadium. The north structure of the bridge carries three lanes of westbound traffic, plus a pedestrian sidewalk. The south structure of the bridge carries three lanes of eastbound traffic, plus a pedestrian sidewalk. The bridge was originally constructed in 1955, and repairs were needed to the bridge deck, concrete abutments, and steel-girder system. Construction is accomplished by closing one bridge structure at a time. The project will maintain three lanes of traffic by using a reversible middle lane; this allows for two lanes of inbound traffic during morning peak hour and two lanes of outbound traffic during evening peak hour traffic. Traffic is separated by drums, which are moved before and after each peak traffic period (Figure 3.6).

Rehabilitation of the Arlington Memorial Bridge (2018, expected completion 2020). The National Park Service and the FHWA are rehabilitating the Arlington Memorial Bridge, which connects the Lincoln Memorial Circle with the Arlington National Cemetery near Washington, D.C. During construction, the six travel lanes that carry about 55,000 vehicles daily are reduced to three travel lanes. Traffic is being maintained under the reversible lane concept. The three travel lanes consist of one eastbound lane, one westbound lane, and one reversible lane (center lane). The reversible lane is reconfigured daily, except weekends and national legal holidays, to carry eastbound traffic from 5:00 a.m. to 9:30 a.m. and westbound traffic from 2:30 to 7:00 p.m. Traffic in these lanes is controlled by overhead LUCS. Space constraints preclude physical separation between opposing traffic (Figure 3.7).

3.2.8.2 Michigan

MDOT has used a moveable barrier wall to create reversible lanes on several work zone projects.

- **US-131 between 10 Mile and 14 Mile roads near Rockford, Kent County (2018).** The project involved reducing the four lanes to three lanes and using a reversible lane to accommodate

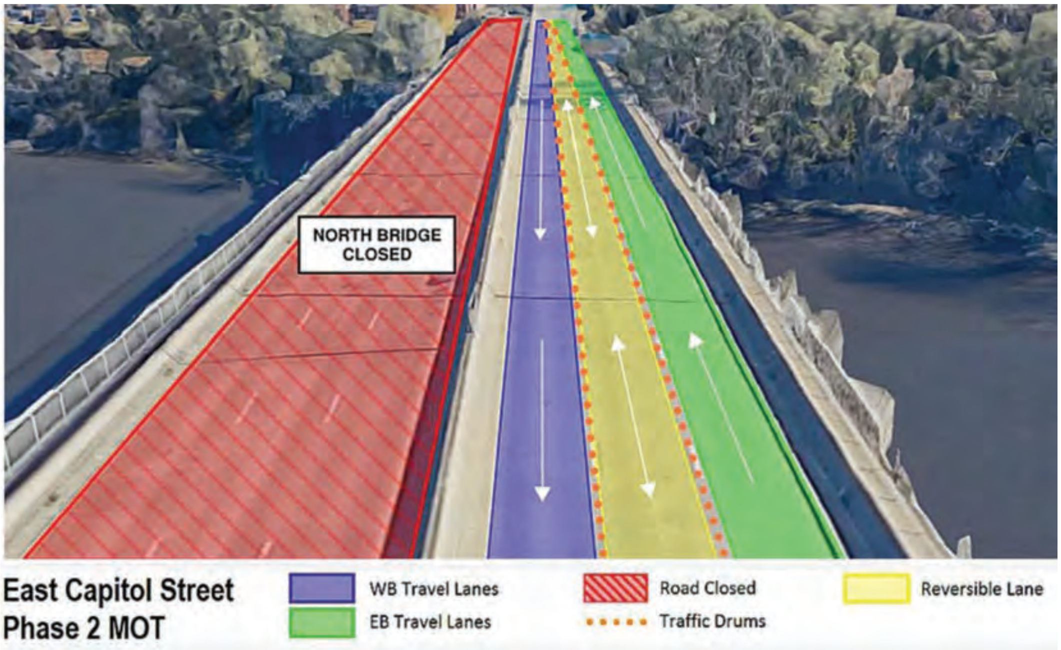


Figure 3.6. East Capitol Street Bridge reversible lane concept (Credit: DDOT).

peak hour traffic. The moveable barrier was moved twice daily, which allowed contractors to maintain two open lanes of travel during peak volumes (two lanes southbound in the morning and two lanes northbound in the afternoon). The addition of the moveable barrier allowed construction to be completed within one season as opposed to two seasons, which resulted in cost savings over the original estimate. In addition, separating construction traffic from the traveling public has improved safety.

- **Reconstruction of I-75 from Dixie Highway to Hess Road, Saginaw County (2015 and 2016).** The busy five lanes in each direction of I-75 encounter heavy weekend tourist traffic, so repair work on a 3.8-mi section could easily have brought traffic to a standstill and seriously affected Michigan's tourism industry. Using traditional contraflows with temporary concrete

Figure 3.7. Reversible lane operations on Arlington Memorial Bridge using lane-use control signals (Credit: Dave Dildine/WTOP).

barriers to separate directional traffic would mean restricting traffic to a 3/2 pattern through the duration of the $46 million project. Instead, MDOT used a reversible lane to keep three lanes open in the peak direction at all times while retaining positive barrier protection between opposing traffic lanes. The reversible lane provided three lanes north Wednesday through to Saturday, and three lanes south Sunday through Tuesday (Figure 3.8). Switching from one configuration to the other took about 30 minutes without the need to stop traffic during the switchover. The reversible lanes were in operation during the reconstruction of both the northbound roadbed (May–July 2015) and the southbound roadbed (May–July 2016). After the project finished in September 2016, MDOT estimated using reversible lanes saved $30 million in user delay.

- **I-75 Linwood to Pinconning project in Bay County (2012)**. This $29 million project was originally scheduled to take 2 years to complete. Instead, MDOT finished repairing and reconstructing 32 lane-miles of I-75 in less than 1 year. Using reversible lanes was one innovation that helped accelerate the construction schedule, which was the key component to the success of this project. All traffic was switched over to one side of the highway, and a wall of moveable barrier was deployed to separate the northbound and southbound traffic. The wall was moved twice each week to keep two lanes open for heavy tourist traffic in one direction (northbound on Fridays and Saturdays, southbound on Sundays). This helped mitigate the potential traffic congestion and allowed the contractor full access to one side of the freeway for better-quality repairs and an accelerated construction schedule.

3.2.8.3 Minnesota

I-94 between East 7th Street in Saint Paul and Hwy 120/Century Avenue in Maplewood, Minnesota (2017). Construction took place in two phases—westbound pavement in 2016 and

Figure 3.8. I-75 reversible lane setup (Credit: Lindsay Corporation).

eastbound pavement in 2017. During the 2017 season, a reversible lane using moveable barriers allowed contractors to maintain four lanes of travel open during peak volumes (four lanes westbound in the morning and four lanes eastbound in the afternoon).

3.2.8.4 Maryland

MD-140 Westminster Pike/Baltimore Boulevard Bridge Reconstruction, Maryland (2015). To avoid excessive traffic backups resulting from lane reduction on the bridge from four to three, MDSHA used a moveable barrier and signal system to provide a reversible lane. The zipper barrier extended 0.5 mi along the middle of the bridge, and the center lane was reversed from 5:00 to 9:00 a.m. and from 3:00 to 7:00 p.m. During each traffic switch, sometime between 9:00 a.m. and 3:00 p.m. and again between 7:00 p.m. and 5:00 a.m., only one lane was maintained in each direction for 30–45 minutes. MDSHA used overhead signals with green arrows and red X lane controls to guide the drivers through the work zone (Figure 3.9). The reversible lane and signals were in place during spring and fall 2015.

3.2.8.5 Wisconsin

In the late fall 2013, WisDOT began construction on the Daniel Hoan Bridge as part of a larger $278 million I-794 Lake Freeway project. WisDOT determined that the most efficient way to retrofit the bridge was to close one side completely and move all traffic to the three lanes on the other side. If WisDOT had used traditional construction barriers to separate the three lanes, more than 40,000 vpd would have been stuck in a 2/1 traffic pattern for the duration of the job. To mitigate traffic congestion, WisDOT installed a reversible lane with a moveable median barrier and a swift gate arm (Figure 3.10) to give two lanes to the peak traffic direction at all times.

3.2.9 Cost

When using LUCS and channelizing devices to separate traffic (<0.5 mi), costs range from $300,000 to $500,000. The cost for a moveable machine barrier, without a swift gate, can exceed $1 million (1 mi). Exact costs depend on project duration and length. The cost difference for moving the moveable machine barrier once a week versus twice a day is minimal, considering that the only extra resources necessary are fuel and personnel.

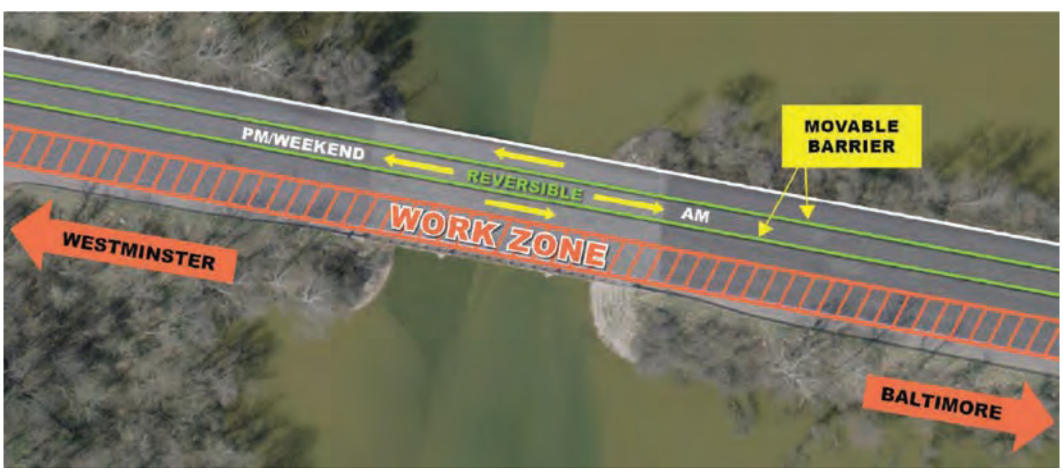


Figure 3.9. Reversible lane operations on MD-140 using moveable barrier (Credit: MDSHA).

Figure 3.10. Reversible lane operations using moveable barrier and swift gate (Credit: WisDOT).

3.2.10 Resources and References

CDOT. *I-70 Mountain Corridor CSS, I-70 Reversible Lane—Phase II Feasibility Study*, Colorado Department of Transportation, February 2011.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Metropolitan Planning Organization. *Reversible-Flow Lane Study, SR 5/US 1/South Dixie Highway, From SW 40th Street/SR 976/Bird Road to Interstate 95 (I-95)*, Miami-Dade County, December 3, 2007.

A Policy on Geometric Design of Highways and Streets, 6th ed. AASHTO, Washington, D.C., 2011 [Green Book].

Waleczek, H., J. Geistefeldt, D. Cindric-Middendorf, and G. Riegelhuth. "Traffic Flow at a Freeway Work Zone with Reversible Median Lane," *Transportation Research Procedia*, Vol. 15, 2016, pp. 257–266.

Wolshon, B., and A. Pande. Institute of Transportation Engineers, *Traffic Engineering Handbook*, 7th ed., Wiley, 2016.

Wolshon, B., and L. Lambert. *NCHRP Synthesis 340: Convertible Roadways and Lanes.* Transportation Research Board of the National Academies, Washington, D.C., 2004.

3.3 Ramp Metering

3.3.1 Description

"Ramp metering" refers to the traffic signals located on on-ramps to maintain safe and smooth freeway operations by controlling the entry of vehicles onto the roadway. Ramp metering has traditionally been viewed as a permanent active freeway management technique used to mitigate and reduce the effect of recurring congestion. Recently, however, agencies have begun to use ramp metering on a temporary basis to mitigate the effects of nonrecurring congestion related to highway construction activities.

The ramp-metering system uses temporary signal heads, wireless radar detectors mounted on portable trailers for data collection, and temporary signing. Figure 3.11 illustrates the typical setup of a work zone ramp-metering system.

3.3.2 When to Use

Agencies should base their decision to deploy a temporary ramp-metering system on whether local traffic conditions, including anticipated traffic volumes during construction, warrant such measures. An agency should also consider the following when deciding whether to implement a temporary ramp-metering system during highway construction:

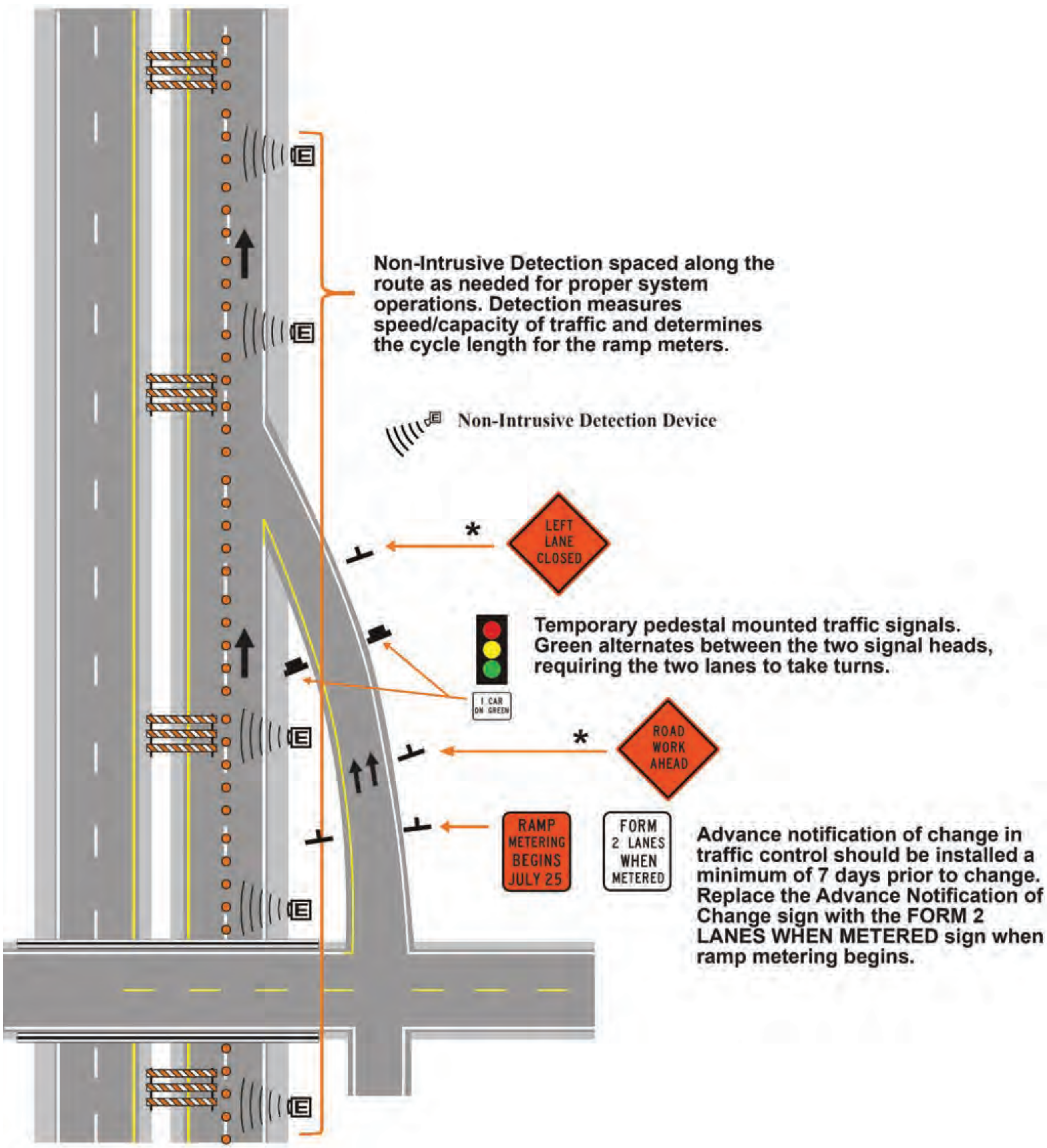


Figure 3.11. Temporary ramp-metering layout (Credit: MnDOT).

- Main-line congestion resulting from highway construction activities (i.e., temporary reduction in main-line capacity resulting from either a lane or a shoulder closure, or reduced lane width causing traffic backups during peak periods).
- Safety issues at merge points and on the main line (i.e., increase in crash risk within the construction zone related to merging volume conflicts).
- A temporary increase in volume caused by detoured traffic exceeds the capacity of through lanes.

For the work zone ramp meter to be effective, the recommendation is that the combined vehicular volume on the main line and the ramp not exceed 1,600 vphpl (ramp volumes not to exceed 400–600 vphpl).

3.3.3 Benefits

The use of ramp metering provides the following benefits:

- Reduces main-line congestion and overall delay, while increasing mobility through the freeway network and traffic throughput. Travel times, even when considering time in queue on the ramp, are generally reduced when ramp metering is implemented.
- Improves safety by breaking up vehicle platoons and controlling the rate at which vehicles enter the main line from the ramp. This allows vehicles to merge smoothly onto the main line and reduces the need for vehicles on the main line to reduce speed.
- Reduces the effect of geometric conditions that cause problems under high-speed or high-volume ramp conditions and heavy main-line volumes because the ramp speeds are likely to be lower and there is less disruption from vehicle platoons vying for limited main-line gaps.

3.3.4 Expected Effectiveness

Formal analyses of the effects of work zone ramp-metering operations are limited and, at the time this guidebook was written, there are only two known studies.

- As part of this project (NCHRP 03-111), the effectiveness of ramp metering was studied at two work zones in Minnesota and Pennsylvania. The final report for NCHRP Project 03-111, which details the findings of the ramp-metering field evaluations, is published as *NCHRP Web-Only Document 276* and available on the TRB website.
  - **Fixed-cycle length ramp metering**. 8.6 mph increase in main-line vehicular speeds.
  - **Variable cycle length ramp metering.** 5.18 mph increase in main-line vehicular speeds.
- **Ramp speeds**. 19.5 percent decrease in mean speeds and 19 percent to 24 percent reduction in total (main line plus ramp) delay (Edara Sun, and Zhu 2012).

3.3.5 Crash Modification Factor

Table 3.2 shows the CMF for work zone ramp metering. Chapter 13 of this document provides more information on developing WZCMFs.

3.3.6 Implementation Considerations

Key geometric issues that agencies should consider when investigating ramp metering include inadequate acceleration length, main-line weaving problems caused by closely spaced ramps, and limited sight distances on a horizontal or crest vertical curve.

Table 3.2. CMFs for work zone ramp metering.

Crash Type	Crash Severity	Facility Type	Volume Range (AADT)	CMF	Standard Error
All	Fatal, serious and minor injury	All	<100,000	0.847	0.544

Note: The CMF was derived from two test sites. CMF = crash modification factor; AADT=annual average daily traffic. While the CMF is reliable for the corridors that were studied, analysts should consider whether the results are transferable to any other specific work zone application.

Ramp geometry is often a barrier to implementing ramp metering. Agencies should ensure the acceleration lane and storage can accommodate queues resulting from a metered traffic setup.

A public outreach campaign, proactively disseminating information about and clearly communicating the benefits of ramp metering, is suggested to familiarize the public and encourage their support.

3.3.7 Design Features and Requirements

The overall functionality of the temporary ramp-metering system remains unchanged from that of a permanent deployment. The system uses essential components and equipment, including the following, to maintain functionality:

- Temporary signal heads with either green and red signal heads or green, yellow, and red signal heads to control the flow of traffic from the ramp onto the main line.
- Detectors to measure traffic conditions (speed, occupancy, etc.) on the main line and occupancy and queue length on the ramp.
- Signing at the start of the ramp to warn vehicles of upcoming conditions and near the signal head to instruct drivers to exit the ramp only on a green signal.

Ramp-metering systems operate under either static, fixed timing or variable timing to dynamically respond to main-line traffic conditions. When operating under fixed timing, the system is activated during a predetermined period (peak hours, special events, etc.) and meters traffic to the main line at a predetermined rate. When operating on variable timing, the system uses main-line traffic data to activate only when warranted by main-line occupancy and speed, and meters traffic at a rate that is also adjusted based on main-line traffic conditions. When and if the ramp becomes congested, the ramp signal can discharge vehicles at a faster rate, alleviating ramp congestion and preventing vehicles from queuing on the adjacent roadway.

3.3.8 State of the Practice

Current deployment of ramp meters under peak period work zone conditions is limited to the following known instances:

- MN Route 52 Bridge Deck Replacement Project, Rochester, Minnesota (April 18–July 1, 2016).
- I-279 Parkway North Improvement Project, Ohio Township, Allegheny County, Pennsylvania (April 23–August 26, 2018).

As part of this project (NCHRP 03-111), the effectiveness of ramp metering was studied at the previously mentioned locations. The final report for NCHRP Project 03-111, which details the findings of the ramp-metering field evaluations, is published as *NCHRP Web-Only Document 276* and is available on the TRB website.

In addition, Missouri deployed ramp meters at seven work zones in urban Columbia during off-peak conditions. These two-to-one lane closures were located near five different ramps on either I-70 or US-63 (Edara, Sun, and Zhu 2012).

3.3.9 Cost

The cost for a single ramp meter system, including the temporary traffic signal, the signal controller, and three traffic detection sensors varies between $50,000 and $75,000.

3.3.10 Resources and References

Arnold, E. D., Jr. *Ramp Metering: A Review of the Literature.* Virginia Transportation Research Council, Virginia Department of Transportation, Charlottesville, VA, December 1998.

Edara, P., C. Sun, and Z. Zhu. *Evaluation of Temporary Ramp Metering for Work Zones.* InTrans Project 06-277. Midwest Smart Work Zone Deployment Initiative, Iowa Department of Transportation, November 2012.

Horowitz, A., J. Wu, J. P. Duarte, A. Drakopoulos, M. Patrabansh, and G. Vergou. *Evaluation of Ramp Meter Effectiveness for Wisconsin Freeways, A Milwaukee Case Study.* #SPR-0092-45-17. University of Wisconsin, Milwaukee, Marquette University, Milwaukee. October 2004.

Ishak, S., J. Codjoe, O. Osman, M. Russell, and J. Rodriguez. *Measuring the Effectiveness of Ramp Metering Strategies on I-12.* FHWA/LA.08/507, Louisiana State University, October 2013.

KSDOT and MoDOT. *Ramp Metering, 2011 Evaluation Report,* Kansas and Missouri Departments of Transportation. March 2011.

Magalotti, M. J. *Freeway Ramp Management in Pennsylvania,* FHWA-PA-2011-005-PIT007. University of Pittsburgh, March 31, 2011.

Managed Lanes and Ramp Metering Manual Part 4: Ramp Metering Performance Measurement Plan, Nevada Department of Transportation, December 2013.

Mizuta, A., K. Roberts, L. Jacobsen, and N. Thompson. *Ramp Metering: A Proven, Cost-Effective Operational Strategy—A Primer,* FHWA-HOP-14-020, FHWA, U.S. DOT, October 2014.

MnDOT. *Ramp Meter Evaluation, Phase II Evaluation Report*, Minnesota Department of Transportation, May 10, 2012.

MnDOT. *Twin Cities Ramp Meter Evaluation, Final Report,* Minnesota Department of Transportation. February 1, 2001.

MnDOT. *Twin Cities Ramp Meter Evaluation, Evaluation Plan*, Minnesota Department of Transportation, September 25, 2000.

Wu, J., M. McDonald, and K. Chatterjee. *A Detailed Evaluation of Ramp Metering Impacts on Driver Behaviour,* Transportation Research Group, University of Southampton, UK. June 9, 2006.

3.4 Truck-Lane Restrictions

3.4.1 Description

Truck-lane restrictions refer to imposing restrictions on truck travel through the work zone (Figure 3.12). This ensures that at least one lane is used only by passenger vehicles. A restricted vehicle, however, is allowed to use any lane, including the restricted lane, to pass another vehicle and to enter and exit the highway. Lane restrictions can be designated on a 24-hour or peak period-only basis.

Figure 3.12. Work zone truck-lane restriction (Credit: KLS Engineering).

3.4.2 When to Use

Conditions most conducive to favorable application of truck-lane restrictions are

- Roadways with two or more lanes in each direction.
- Interchanges spaced more than 2 mi apart with low ramp volumes.
- Trucks being greater than 10 percent of the total traffic stream and less than 20 percent of the total truck traffic using the lane to be restricted.
- Roadway sections at least 6 mi long.
- Higher than average truck/auto crash pattern.

Truck-lane restrictions should also be considered when traffic is shifted onto patched shoulders that may result in pavement or other structural deficiencies.

3.4.3 Benefits

The use of truck-lane restrictions in work zones provides the following benefits:

- Improves traffic flow and provides a lane free of truck–automobile passenger car interaction, which reduces the number of lane changes and the passing movements of passenger vehicles.
- Improves safety by reducing crash potential.

3.4.4 Expected Effectiveness

As part of this project (NCHRP 03-111), the effectiveness of restricting trucks to the left lane was studied at three work zones in Michigan. The final report for NCHRP Project 03-111, which details the findings of the truck-lane restriction evaluations, is published as *NCHRP Web-Only Document 276* and available on the TRB website.

- Truck use of the left lane for all sites combined increased by 234.96 percent while decreasing by 59.36 percent in the right lane.
- Overall average truck speeds reduced by approximately 3 mph (5 percent) with the truck-lane restrictions.

3.4.5 Crash Modification Factor

Table 3.3 shows the CMF for work zone truck-lane restrictions. Chapter 13 of this document provides more information on developing WZCMFs.

3.4.6 Implementation Considerations

Compliance requires routine enforcement by regular traffic patrols; specialized, dedicated truck enforcement units; or both. A targeted public information campaign should also be conducted to inform the public and the trucking community about the restriction.

Table 3.3. CMFs for work zone truck-lane restrictions.

Crash Type	Crash Severity	Facility Type	Volume Range (AADT)	CMF	Standard Error
All	Fatal, serious and minor injury	All	<100,000	0.928	0.081

NOTE: The CMF was derived from three test sites. CMF = crash modification factor; AADT=annual average daily traffic. While the CMF is reliable for the corridors that were studied, analysts should consider whether the results are transferable to any other specific work zone application.

3.4.7 Design Features and Requirements

Truck-lane restrictions are typically achieved by using stand-alone static signs (TRUCKS USE LEFT/RIGHT LANE [2009 MUTCD R4-5]). The static signs may be supplemented with PCMS.

A modified R4-5 sign (from black lettering on white background to black lettering on orange background) should also be considered if using the regulatory R4-5 sign (black and white) requires a state law. States can also develop alternative R4-5 signs, as prepared by Texas (2014 Texas MUTCD, Section 2B.31A). The Texas R4-5 sign series, shown in Figure 3.13, is meant for use only on freeways.

The number of signs installed and their placement is important to reinforce the restrictions and ensure trucks follow them. Static signs should be installed on both sides of the roadway.

A minimum of two static signs or a single static sign combined with a PCMS is suggested in advance of the work zone. The frequency of signs within the work zones will depend on the length of the work zone, but installing signs in 1-mi increments is typical. Agencies can adjust sign placement and frequency downstream of any high truck-volume merging-ramp traffic.

3.4.8 State of the Practice

The 84th Texas Legislature in 2015 passed House Bill 3225 giving TxDOT the authority to restrict large truck traffic to a specific lane in a work zone that is on the state highway system. The lane restrictions only apply when signs are installed. This legislation went into effect September 1, 2015. I-35 in Waco District became the first location in the state to act on new legislation and improve work zone safety by restricting trucks to the left lane.

MDOT used truck-lane restrictions on the following projects:

- Reconstruction of 5.6 mi of I-75 from Dixie Highway to I-275 to prevent trucks traveling on the patched shoulders and drain grates. Trucks were restricted to using the left lane and restrictions were in place during the reconstruction of both the northbound roadbed (March–October 2015) and the southbound roadbed (April–September 2016). (Trucks made up 30 percent of the traffic composition.)
- Reconstruction of a 10-mi section of US-23 within Livingston and Washtenaw Counties from the west US-23/M-14 (tri-level) interchange (Exit 45) north to the Silver Lake Road interchange (Exit 55). In Spring 2017, when traffic was shifted to the outside (right) shoulders, the shoulders began to fail. MDOT initially repaired the areas that failed and started restricting

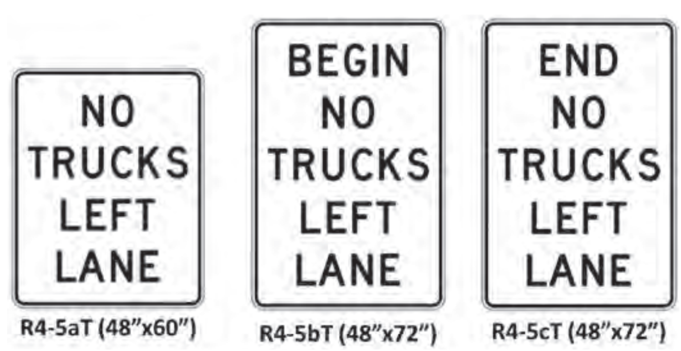


Figure 3.13. Truck-lane-restriction signing (Credit: TxDOT).

truck use to the left lane to keep trucks off shoulders that were not repaired. Trucks were restricted to left-lane use in both the northbound and the southbound directions. The project was not set up originally for trucks to use only the left lane.

In both projects, DOTs used multiple static signs and PCMSs to enforce truck-lane restrictions.

3.4.9 Cost

The cost for a static sign ranges between $500 and $1,000 depending on size. A PCMS costs approximately $8,000 (or a rental cost of $1,000 per week).

3.4.10 Resources and References

Borchardt, D. W., D. L. Jasek, and A. J. Ballard. *Monitoring of Texas Vehicle Lane Restrictions*, Texas Department of Transportation, September 2004.

Design and Operation of Work Zone Strategies to Improve Large Truck Safety, ARTBA Work Zone Safety Consortium, Washington, D.C., 2016.

Fontaine, M., L. Dougald, and C. Bhamidipat. *Evaluation of Truck Lane Restrictions in Virginia: Phase II*, Virginia Transportation Research Council, Charlottesville, VA, October 2009.

Lord D., D. Middleton, and J. Whitacre. Does Separating Trucks from Other Traffic Improve Overall Safety? *Transportation Research Record,* No. 1922, 2005, pp. 156–166.

Middleton, D., S. Venglar, C. Quiroga, D. Lord, and D. Jasek. *Strategies for Separating Trucks from Passenger Vehicles: Final Report*, Texas A&M Transportation Institute, November 2006.

Mussa, R. Safety and Operational Evaluation of Truck Lane Restriction, *Journal of the Transportation Research Forum*, 43(2), 2004, pp. 117–127.

Mussa, R., and G. Price. Quantify the Effects of Raising the Minimum Speed on Rural Freeways and the Effects of Restricting the Truck Lanes Only in the Daytime, *Safety and Operational Evaluation of Truck Lane Restriction on Interstate 75*, Vol. 2, Florida Department of Transportation. Project No. BC-352, May 2004.

Mwakalonge, J. *Evaluation of Truck Lane Restriction on Non–Limited Access Urban Arterials*. Florida State University, 2007.

Qi, Y., S. Ishak, B. Wolshon, C. Alecsandru, and X. Sun. Effect of Truck Lane Restriction and Differential Speed Limit on Traffic Characteristics of Four-Lane Rural Freeways. Presented at 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.

TxDOT. *Texas MUTCD: Manual on Uniform Traffic Control Devices*, Revision 2, Texas Department of Transportation, October 2014.

Yang, C. H., and A. C. Regan. Impacts of Left-Lane Truck Restriction on Urban Freeways. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.

CHAPTER 4

Traffic Incident Management and Enforcement Strategies

This section includes various strategies to manage work zone traffic operations strategies to provide adequate enforcement of traffic regulations in work zones. The following sections are covered:

- Queue warning systems
- Work zone incident management plans
- Temporary incident-detection and surveillance systems
- Freeway service patrols
- Traffic screens (a.k.a. glare screens, a.k.a. gawk screens)
- Automated speed enforcement
- Police enforcement

4.1 Queue Warning Systems

4.1.1 Description

A QWS is a type of SWZ system that detects downstream stop-and-go traffic and alerts motorists further upstream of the congestion ahead. These systems are also referred to as "congestion warning systems," "stopped traffic warning systems," "real time traffic control systems," "traffic merge warning systems," and "end of queue warning systems" (EQWS).

A QWS is based on algorithms and uses a series of traffic sensors to detect real-time traffic conditions (e.g., vehicle speeds, lane occupancy). When traffic speeds drop below a preset threshold, the QWS remotely activates PCMSs or warning lights on static signs to display messages to motorists upstream of the work zone beyond the maximum queue. The QWS is deactivated when the sensors indicate that the queue has dissipated and speeds are back to the preset free-flow speeds. Figure 4.1 shows the layout of a typical QWS.

4.1.2 When to Use

A QWS should be considered for use under the following conditions:

- Estimated queue lengths vary greatly, day by day and hour by hour, and cause 10 minutes or more of additional travel time.
- Queue lengths may encroach upstream sooner than a motorist has reasonable expectations for stopped traffic, and the geometrics (terrain) may cause poor visibility for end-of-traffic queues, shorten motorists' reaction times, and cause panic stopping.
- Vertical grades, horizontal curves, or poor illumination restrict with sight distance.

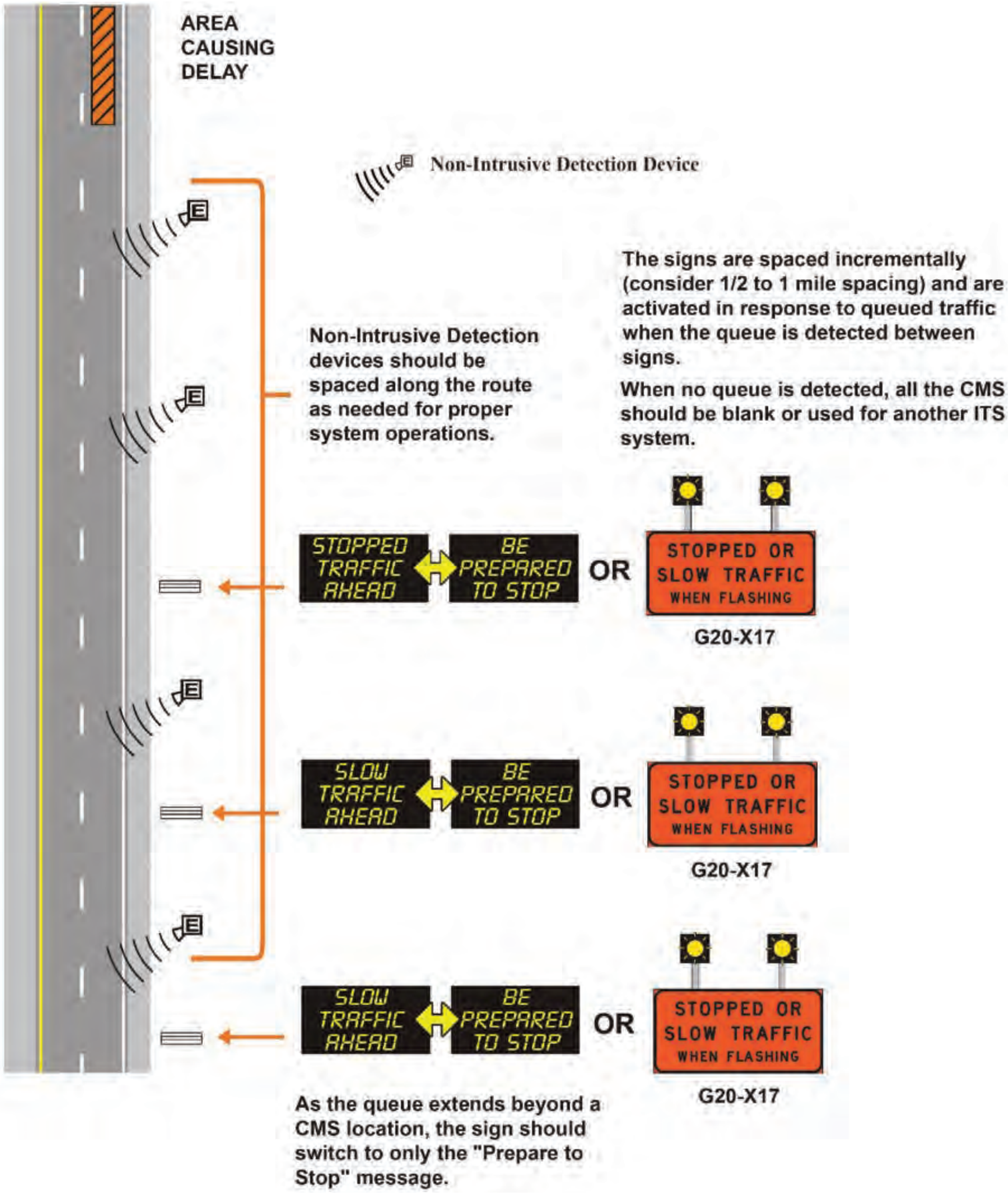


Figure 4.1. Queue warning system layout (Credit: MnDOT).

- Estimated queues initiated on crossroads could cause traffic conflicts or delays on the main-line road, such as backups beyond the length of ramps, through or around turns in intersections, or other hazardous congestion situations.
- The project and queue area has a history of crashes.

4.1.3 Benefits

The use of QWS provides the following benefits:

- Reduces primary and secondary crashes by alerting drivers to congested conditions.
- Delays the onset of congestion, improving smooth and efficient traffic flow and trip reliability.
- Provides environmental benefits through decreased emissions, noise, and fuel consumption.

4.1.4 Expected Effectiveness

WisDOT deployed a QWS in 2017 as part of the I-43 improvement project in Manitowoc County. A crash analysis conducted with and without the QWS reported a 15 percent reduction in queuing-related crashes and a 63 percent reduction in injury crashes. The QWS reduced queue-related work zone crash costs by 13 percent. The change in average speeds as drivers reacted to the first PCMS varied for each scenario: STOPPED TRAFFIC AHEAD and SLOW TRAFFIC AHEAD resulted in an increase of 3.8 mph and a decrease of 45.6 mph, respectively. However, many variables influenced these results, including visible brake lights downstream, proximity to the start of the lane closure, the number of PCMS boards activated and the corresponding messages, and the location where vehicle speeds were measured.

KSDOT used a QWS in conjunction with the Five-Bridges construction project located along route I-235 in Wichita between Spring 2016 and Fall 2017. Although the QWS was not operating as intended until early June 2016, it operated within specification nearly 100 percent of the 2017 season. Results included a 59.8 percent reduction in total crashes and 70.1 percent reduction in rear-end crashes. Estimated reduced crash cost was $8,700 per day.

TxDOT used a QWS in combination with TRSs to reduce the risk of crashes on the I-35 expansion project and reported the following results:

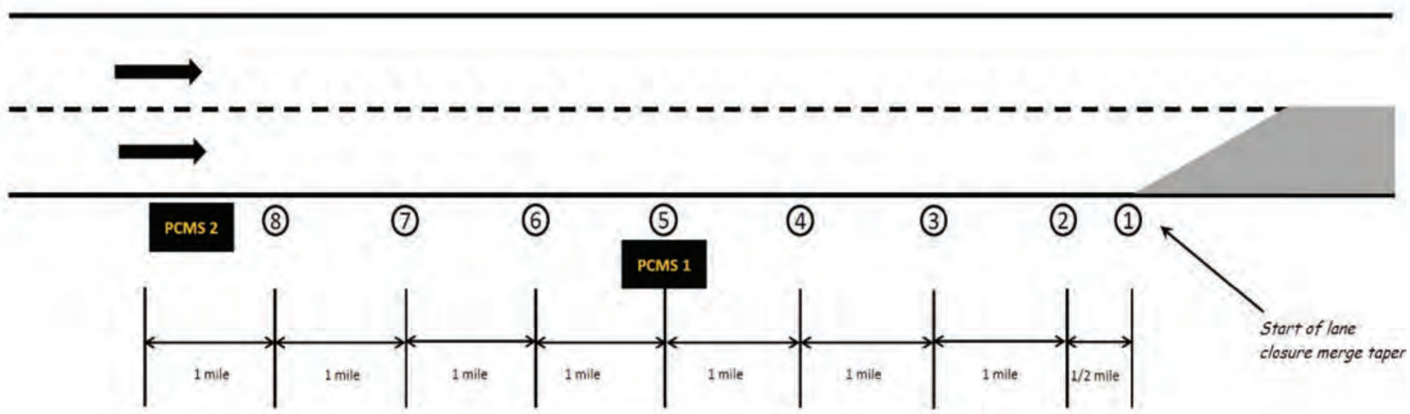
- An 18 percent to 45 percent reduction in crashes compared with an estimate of crashes if the system had not been deployed.
- Savings of between $1.4 million and $1.8 million in crash costs (savings of $6,600–$10,000 per night of deployment).

Figure 4.2 shows the QWS deployment plan used on the I-35 expansion project.

TxDOT also deployed a QWS on IH-610 and US-59 in Houston during the 2008 construction season and saw a 2 percent to 7 percent reduction in sudden braking and a 3 percent to 5 percent reduction in forced lane changes at these locations (Pesti et al. 2008).

The Illinois DOT (IDOT) deployed a QWS on two projects with the following results:

- I-70/I-57 interchange in Effingham—a 14 percent decrease in queuing crashes and an 11 percent reduction in injury crashes, despite a 52 percent increase in the number of days temporary lane closures were implemented during the evaluation.
- I-55 from I-70 to IL-140 in southern Illinois—13.8 percent reduction in rear-end crashes with QWS in place, even with 25.4 percent more traffic exposure.



PCMS 2 Message	PCMS 1 Message	Last 5-Minute Average Speed V (mph) ⑧	⑦	⑥	⑤	④	③	②	①
WATCH YOUR SPEED	ROAD WORK AHEAD	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0
WATCH YOUR SPEED	SLOW TRAFFIC 3 MILES	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	40 ≤ V < 55
WATCH YOUR SPEED	SLOW TRAFFIC 2 MILES	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	40≤ V< 55	V > 40 OR V = 0.0
WATCH YOUR SPEED	SLOW TRAFFIC 1 MILE	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	40≤ V< 55	V > 40 OR V = 0.0	V > 40 OR V = 0.0
WATCH YOUR SPEED	SLOW TRAFFIC AHEAD	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	V > 55 OR V = 0.0	40≤ V< 55	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0
WATCH YOUR SPEED	STOPPED TRAFFIC 3 MILES	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	0.0 ≤ V < 40
WATCH YOUR SPEED	STOPPED TRAFFIC 2 MILES	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	0.0 ≤ V < 40	Any value
WATCH YOUR SPEED	STOPPED TRAFFIC 1 MILE	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	0.0 ≤ V < 40	Any value	Any value
WATCH YOUR SPEED	STOPPED TRAFFIC AHEAD	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	V > 40 OR V = 0.0	0.0 ≤ V < 40	Any value	Any value	Any value

① *Non-Intrusive Traffic Speed Detector*

PCMS *Portable Changeable Message Sign*

Figure 4.2. Example QWS deployment plan (Credit: TxDOT).

4.1.5 Crash Modification Factor

Table 4.1 shows the CMF for a work zone QWS. Chapter 13 provides more information on developing WZCMFs.

4.1.6 Implementation Considerations

There are many different contracting options for including QWS in work zone projects. Some projects may include the QWS component as a bid item in an overall construction project and other projects may retain a QWS vendor with a stand-alone contract.

Table 4.1. CMFs for QWS.

Crash Type	Crash Severity	Facility Type	Volume Range (AADT)	CMF	Standard Error
Nighttime	All	Rural Interstate where queues **were expected**	55,000–110,000	0.559	0.255
Nighttime	All	Rural Interstate when queues **were actually** present	55,000–110,000	0.468	0.301
Nighttime	All	Rural Interstate when queues **were not actually** present	55,000–110,000	0.717 (not significant)	0.353

NOTE: The CMFs listed were developed through an empirical Bayes analysis using 234 control and 216 treatment nights of lane closures. The sample sizes were small in both expected and actual crashes because less than 1 year's worth of nighttime lane closures from each condition was available for analysis. AADT = annual average daily traffic; CMF = crash modification factor; QWS = queue warning system.

Several IDOT districts have on-call contracts to deploy QWS for shorter-duration work zones, lasting less than 2 weeks, that may have queues but do not have a project budget large enough to support the SWZ deployment.

MDOT notes the importance of calling out specific pay items (e.g., PCMS, sensors, cameras) when developing a contract so modifications to the system can be made throughout the project.

4.1.7 Design Features and Requirements

QWSs typically involve three basic components: (1) detection devices (video cameras, microwave or Doppler radar, infrared, etc.) placed upstream of the work zone to monitor and measure the speeds of approaching vehicles; (2) a server to receive and analyze the sensor data in real time and activate a message; and (3) PCMSs located upstream of the work zone to display a warning message.

When a PCMS detects slow or stopped traffic, it displays a predesigned warning message to alert the driver of the condition. Example messages posted on PCMSs for different scenarios are shown in Table 4.2. When the QWS detects no queue, the PCMS displays a more generic ROAD WORK AHEAD message.

Agencies have also placed portable rumble strips in the travel lanes upstream of the merging taper to provide tactile, audible, and visual alerts as drivers approach the lane closure.

At a minimum, the QWS must be able to

- Detect vehicle speed and volume over a user-defined interval (ranging from 30 seconds up to 10 minutes) and sense queuing of traffic in up to five lanes in one direction simultaneously.

Table 4.2. PCMS messages for QWS.

Scenario	Example Message	Speed Threshold
Free Flow	CAUTION/ ROAD WORK AHEAD	55 mph
Slow Traffic	SLOW TRAFFIC AHEAD/ PREPARE TO STOP	40–45 mph
Stopped Traffic	TRAFFIC STOPPED AHEAD/ PREPARE TO STOP	15–25 mph

NOTE: PCMS = portable changeable message sign; QWS = queue warning system.

- Automatically set the PCMS message sequences to reflect the current traffic-flow status to the nearest minute, update every 60 seconds, or update to a customized frequency defined by the engineer.
- Have default queue level thresholds (normal, slowing, stopped) based on any combination of vehicle speed, volume, or density based on conditions in the slowest or most congested lane.
- Use e-mail or text to alert contractor and agency personnel, including TMC or traffic operations center (TOC) staff, whenever the default queue level changes from normal to slowing or stopped.

Figure 4.2 provides an example QWS deployment plan and system logic used on the I-35 project in Texas. When preset detector thresholds are met at the first detector (closest to the work area), the first PCMS notifies travelers of slowed or stopped traffic and distance to the condition. Subsequent PCMSs (farther from the work area) also notify travelers of slowed or stopped traffic and approximate distance to the condition.

4.1.8 State of the Practice

QWS is one of the technology applications promoted by the FHWA's SWZ, during Round 3 of the FHWA EDC initiative. Many resources, including bid specifications, deployment plans, and case studies, are available on the National Work Zone Safety Information Clearinghouse (https://www.workzonesafety.org/swz/).

Colorado, Illinois, Iowa, Michigan, Minnesota, Ohio, Texas, and Wisconsin use QWSs as a standard practice; thus, these states have mature systems that generate accurate, dependable results.

As part of the FHWA Accelerated Innovation Deployment grant, WisDOT developed a QWS decision-support system to help designers and traffic engineers determine if a QWS is needed for a project. The intent of the system is to identify candidate work zones for QWS early on in the scoping and TMP phase of the project.

The decision-support system is integrated with the Wisconsin TMP (WisTMP) System. Maintained by the University of Wisconsin Traffic Operations and Safety Laboratory (UW-TOPS lab), the WisTMP system is an online program used to create, approve, monitor, and update TMPs.

The decision-support system integrates data from disparate WisDOT sources, such as the WisTMP, traffic volumes, crashes, and the photolog, to provide information on potential queues and delays, the presence of horizontal and vertical curves, and entrance and exit ramps within and in the vicinity of work zones. Figure 4.3 is an image of the decision-support system.

4.1.9 Cost

The cost to deploy a smart work zone such as the QWS depends on the project duration and the number of devices (e.g., message boards, traffic sensors, speed trailers, cameras) used. In general, the rental cost is the same for a PCMS or a traffic sensor or camera: approximately $1,000 per week. For longer-duration projects, the rental costs can be substantially lower.

Based on 2018 rental prices, MnDOT reported the cost estimate for a QWS project using 2 PCMSs and 6 sensors at $7,000 per week or $13,000 per month or $58,000 for 6 months.

The TxDOT *Smart Work Zone Guidelines* (2018) reported a cost of $104,160 for a QWS deployment in 2017 that used 1 PCMS and 4 sensors for 70 days (~0.7 percent of total construction costs).

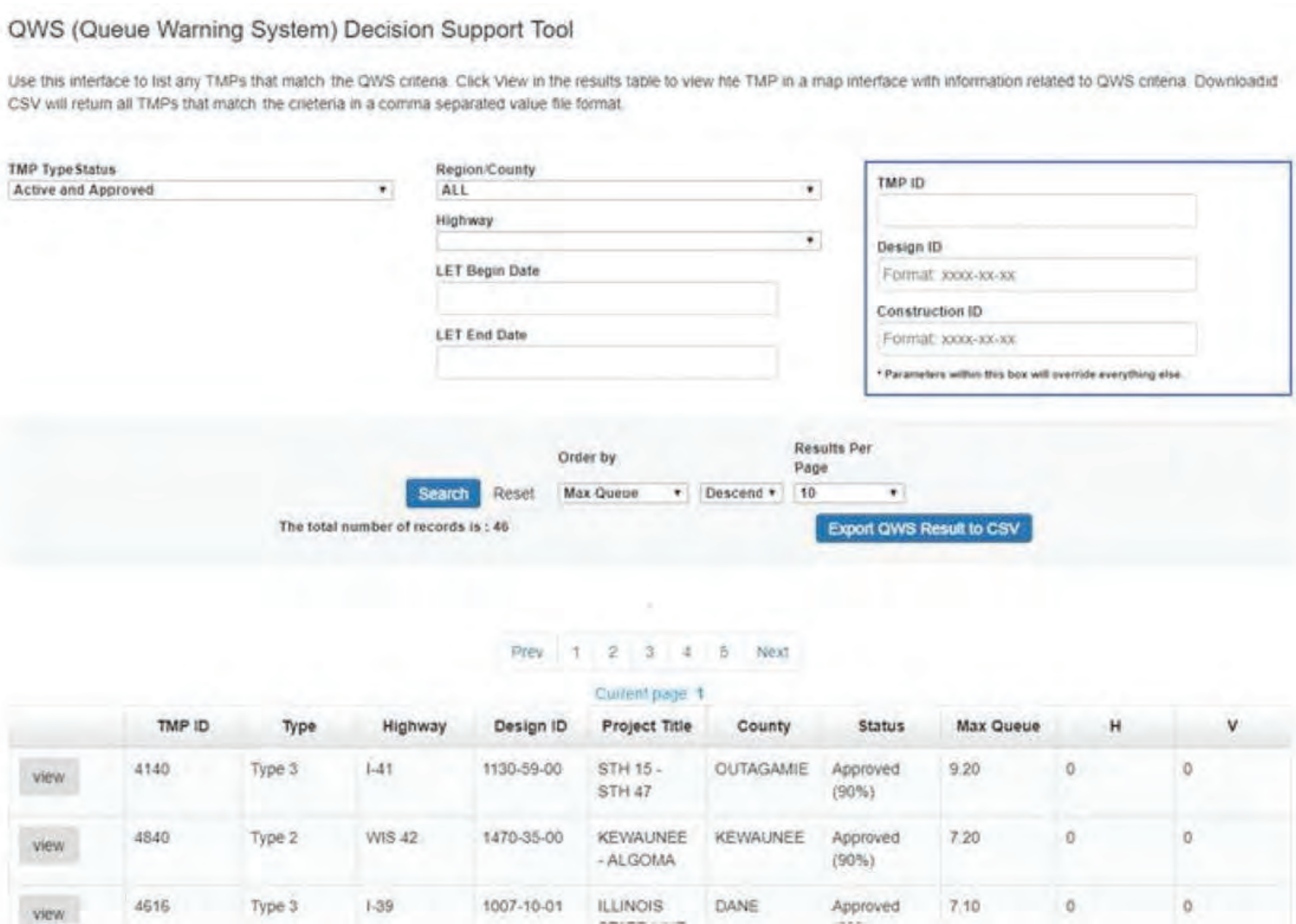


Figure 4.3. QWS decision-support tool (Credit: WisDOT).

Cost estimates for a QWS deployed by WisDOT in 2016 on two separate bridge construction projects were as follows:

- 6 PCMSs, 14 sensors for $826 per day (total for 77 days = $63,602).
- 16 PCMSs, 22 sensors for $725 per day (total for 202 days = $146,450).

4.1.10 Resources and References

FHWA Every Day Counts (EDC) Initiative: Smarter Work Zones, Technology Applications: Queue Warning web page. https://www.workzonesafety.org/swz/swztechnology-application/types-of-applications/queue-warning/.

McCoy, P. T., and G. Pesti. Effect of Condition-Responsive, Reduced-Speed-Ahead Messages on Speeds in Advance of Work Zones on Rural Interstate Highways. Presented at 80th Annual Meeting of the Transportation Research Board, Washington, D. C., 2001.

Morris, T., J. A. Schwach, and P. G. Michalopoulos. *Low-Cost Portable Video-Based Queue Detection for Work-Zone Safety*, Intelligent Transportation Systems Institute, Center for Transportation Studies, University of Minnesota, CTS Report No. 11-02, January 2011.

Pesti, G., P. Wiles, R. L. (K.) Cheu, P. Songchitruksa, J. Shelton, and S. Cooner. *Traffic Control Strategies for Congested Freeways and Work Zones*, FHWA/TX-08/0-5326-2, Texas Department of Transportation and FHWA, October 2008.

Queue Warning Systems in Work Zones: Summary of Uses and Benefits, ENTERPRISE Transportation Pooled Fund Study TPF-5 (231), June 2014.

TxDOT. *Smart Work Zone Guidelines: Design Guidelines for Deployment of Work Zone Intelligent Transportation Systems (ITS)*, Texas Department of Transportation, October 2018.

Ullman, G., and J. Schroeder. *Mitigating Work Zone Safety and Mobility Challenges through Intelligent Transportation Systems: Case Studies*, FHWA-HOP-14-007, FHWA, U.S. DOT, January 2014.

Ullman, G. L., V. Iragavarapu, and R. E. Brydia. Safety Effects of the Portable End-of-Queue Warning System Deployments at Texas Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2555, 2016, pp. 46–52.

Ullman, G., J. Schroeder, and D. Gopalakrishna. *Use of Technology and Data for Effective Work Zone Management: Work Zone ITS Implementation Guide*, FHWA-HOP-14-008, FHWA, U.S. DOT, January 2014.

Wiles, P. B., S. A. Cooner, Y. Rathod, and D. G. Wallace. *Advance Warning of Stopped Traffic on Freeways: Field Studies of Congestion Warning Signs*, FHWA/TX-05/0-4413-2, Texas Department of Transportation and FHWA, March 2005.

4.2 Work Zone Incident Management Plans

4.2.1 Description

A work zone Incident Management Plan (IMP) is one element of the traffic operations component of the TMP; "IMP" refers to strategies used to help the contractor and the agency respond appropriately to incidents during construction within a reasonable time frame and maintain safe traffic flow through the work zone.

4.2.2 When to Use

Long-term, complex reconstruction projects necessitate a comprehensive effort with procedures and processes to support the project. The complexity of the IMP depends on the complexity and duration of the project, as well as its effects in the corridor or network. DOTs require complete IMP documents for significant projects.

Short-term projects on lower-volume roads may simply require a meeting or ongoing coordination with the appropriate local or regional emergency response agencies.

4.2.3 Benefits

A work zone IMP provides the following benefits:

- Reduces the amount of time to detect, verify, and respond to an incident.
- Decreases time required for appropriate response personnel and equipment to respond to the scene.
- Facilitates management of the response apparatus and personnel on site to minimize the capacity loss associated with the incident and the response equipment.
- Provides travelers upstream of the incident with rapid notification, encourages a decrease in traffic demand entering the incident area, and reduces driver frustration.

4.2.4 Expected Effectiveness

Prompt detection and clearance of traffic incidents in work zones helps reduce secondary crashes and delay. Preparing a work zone traffic incident management plan and using strategies that improve detection, verification, and response, along with clearance of crashes, mechanical failures, and other incidents in work zones and on detour routes, can benefit safety and mobility.

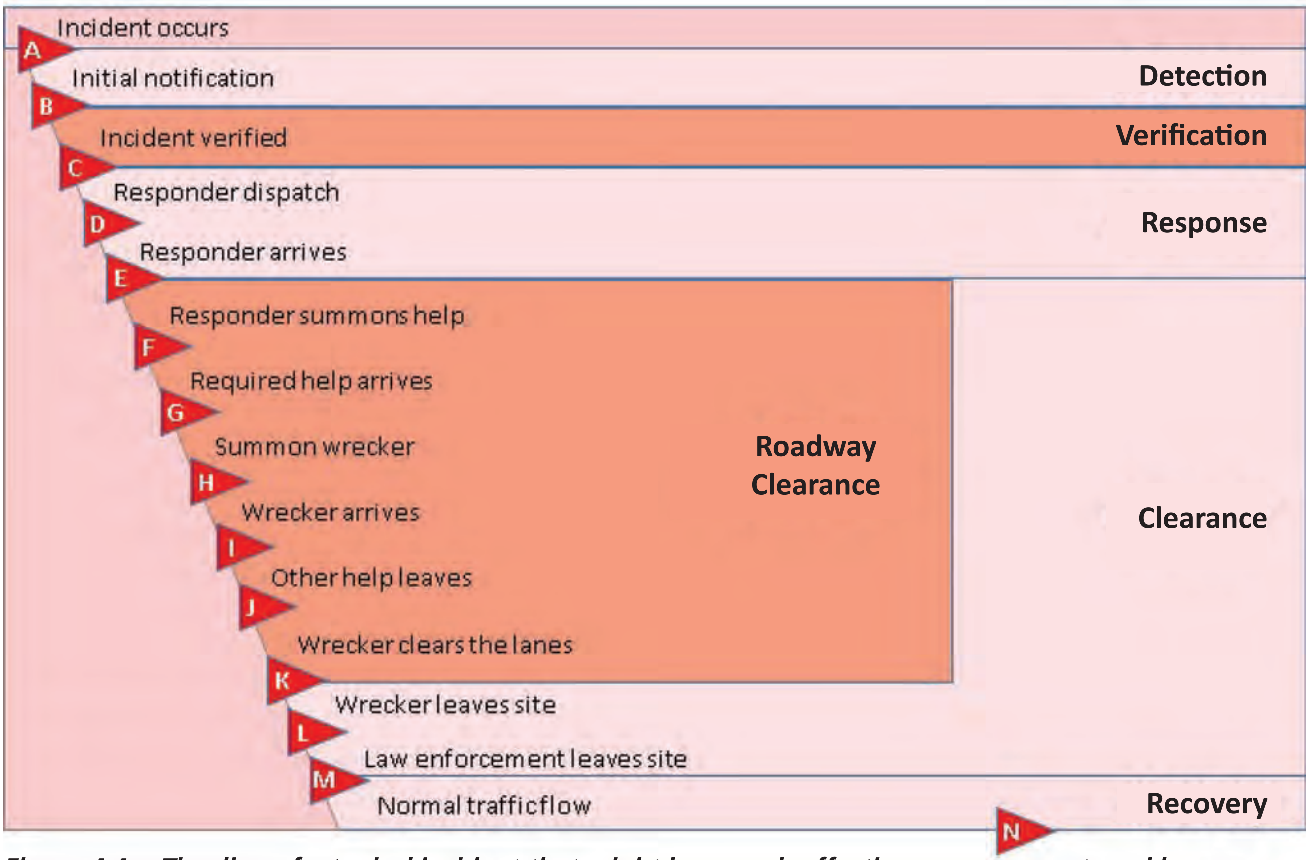


Figure 4.4. Timeline of a typical incident that might be a crash affecting one or more travel lanes.

Figure 4.4 illustrates the timeline of a typical incident that might be a crash affecting one or more travel lanes. The steps shown represent the typical sequence for most moderate-to-serious incidents.

4.2.5 Crash Modification Factor

No CMF is applicable for this strategy.

4.2.6 Implementation Considerations

As with any project, the minimum requirement is to identify whether a program exists and determine the role of the contractor in implementing that program. Project staff or the contractor should also contact appropriate response agencies in the corridor to discuss the proposed work zone, identify their concerns, and agree to procedures and strategies that will support traffic incident management. Communication and coordination are essential for any work zone. On more complex projects, this coordination will become more formalized and involve more stakeholders. It will also necessitate a greater commitment of time and resources on the part of the contractor.

For a project with multiple phases, it may be necessary to develop a plan for each project phase. The procedures and recommended strategies should be documented and distributed to all response agencies and construction personnel. Budget strategies that require implementation (e.g., signing, intelligent transportation system devices, traffic management center, service patrol) should be planned and implemented at the start of the project.

Regular training and follow-up sessions are necessary to ensure all agencies and construction personnel are familiar with plan procedures.

4.2.7 Design Features and Requirements

Agencies need to ensure that developing an IMP is a collaborative effort with the project owner and emergency response agencies; the IMP either can be a stand-alone document or incorporated into the TMP. The following is a standard format for an IMP table of contents:

- **Project description and map** (if an IMP is not incorporated in the TMP).
- **Emergency contact information.** Identifies contact information for contract personnel, project owners, and emergency response agencies responsible for responding to or designating response for incidents.
- **Existing protocols and agreements.** Each agency responding to an incident in the project area has specific priorities and responsibilities. Some of these roles may overlap, and the priorities of some agencies may affect the ability of other agencies to perform their duties. Discussing and documenting these roles and responsibilities during the planning phase of traffic incident management will minimize the probability of conflicts or confusion during an actual incident.
- **Procedures for communicating during an incident (communication flowchart).** In the event of an incident, it is essential that response agencies know how to contact one another to coordinate and confirm the most effective use of resources.
- **Incident-level definitions.** Incident levels are defined by the extent and duration of the anticipated effect on the roadway. Defining levels will help agencies identify appropriate actions and responses to the anticipated level of impact. The 2009 MUTCD (Section 6I.02, 6I.03, and 6I.04) divides incidents into three general classes based on duration: (1) major (>2 hours), (2) intermediate (30 minutes to 2 hours), and (2) minor (<30 minutes). Agencies can use these general criteria for classifying incident levels as a beginning point for determining appropriate levels of responses.
- **Incident-detection, response, and clearance strategies.** Once the appropriate level of response is determined for the work zone, the next step is to identify and evaluate candidate strategies for detecting, responding to, and clearing incidents from the roadway (e.g., temporary incident-detection systems, roving courtesy/service patrols, emergency turnaround access).
- **Identify alternative emergency routes.** Choose project-specific alternate routes and develop an alternative route map.
- **Disseminate traveler information.** Identify strategies (PCMSs, traffic alerts, websites, TMC, etc.) to facilitate timely information dissemination about work zone incidents.

4.2.8 State of the Practice

WisDOT has developed templates for IMPs, which are attached as appendices:

- Appendix E1 presents one example of a WisDOT IMP.
- Appendix E2 presents a second example of a WisDOT IMP.

4.2.9 Cost

Work zone IMP is part of the TMP and therefore has no separate cost associated with it.

4.2.10 Resources and References

Balke, K. *Traffic Incident Management in Construction and Maintenance Work Zones.* FHWA-HOP-08-056, FHWA, U.S. DOT, January 2009.

Bremer, W., D. A. Noyce, J. W. Shaw, M. V. Chitturi, and A. Bill. *Guidelines for Work Zone Designers—Positive Protection*. DTHF6114H00011, FHWA, U.S. DOT, May 2019.

Charles, P., and R. Higgins. *Successful Incident Management on a Major Reconstruction Project, Pacific Motorway Project, Queensland Australia,* University of Queensland, Australia, November 2001.

CDOT. *Guidelines for Developing Traffic Incident Management Plans for Work Zones,* Colorado Department of Transportation, 2008.

Dougald, L. E., N. J. Goodall, and R. Venkatanarayana. *Traffic Incident Management Quick Clearance Guidance and Implications,* FHWA/VTRC 16-R9, FHWA, Virginia Department of Transportation, February 2016.

Federal Emergency Management Agency. *U.S. Fire Administration Traffic Incident Management Systems*, FA-330, April 2008.

FHWA. *Intelligent Transportation Systems in Work Zones: A Case Study—Work Zone Traffic and Incident Management System, Keeping Traffic Moving During Reconstruction of the Big I, a Major Interstate-Interstate Interchange in Albuquerque,* FHWA-OP-04-072, U.S. DOT, January 2004.

Horowitz, A. J., and Xia J. *Guidebook on Incident Management Planning in Work Zones.* University of Wisconsin–Milwaukee. September 1, 2005.

I-95 Corridor Coalition. *Traffic Incident Management (TIM) Best Practices Report*, March 2010.

Marquess, A., P. Desai, G. Havinoviski, and C. Heise. *Safety Service Patrol Priorities and Best Practices,* FHWA-HOP-16-047, FHWA, U.S. DOT, April 2017.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Noyes, P. B. *Mainstreaming Incident Management in Design-Build: The T-REX Experience.* Colorado Department of Transportation, 2001.

Pennsylvania State Transportation Advisory Committee. *Traffic Incident Management Final Report*, Pennsylvania Department of Transportation, February 2014.

4.3 Temporary Incident-Detection and Surveillance Systems

4.3.1 Description

A temporary incident-detection and surveillance system uses sensors or video to detect crashes and other incident conditions within a work zone and then communicates that information to a local TMC or to emergency response agencies (Figure 4.5). The alerts are then confirmed remotely using live streaming video, photographs, or on-site personnel. Agencies can use this system to provide responders critical information to help them bring necessary equipment, identify how best to approach the incident, and take any additional precautions that might be needed to protect themselves and the public.

4.3.2 When to Use

Temporary incident-detection and surveillance systems should be considered for use under the following conditions:

- Long-term project duration in urban areas.
- Presence of a permanent intelligent transportation system (ITS) deployment, a TMC, or both.
- High public exposure or traffic delay.
- Projects with multiple construction stages or phasing.
- Frequent lane or ramp closures expected.
- Frequent crash history within the work zone corridor.
- Work-zone corridor at or near capacity.

4.3.3 Benefits

Temporary incident-detection and surveillance systems provide the following benefits:

- Improving the situational awareness of emergency responders will reduce the time to detect, respond to, and clear incidents.

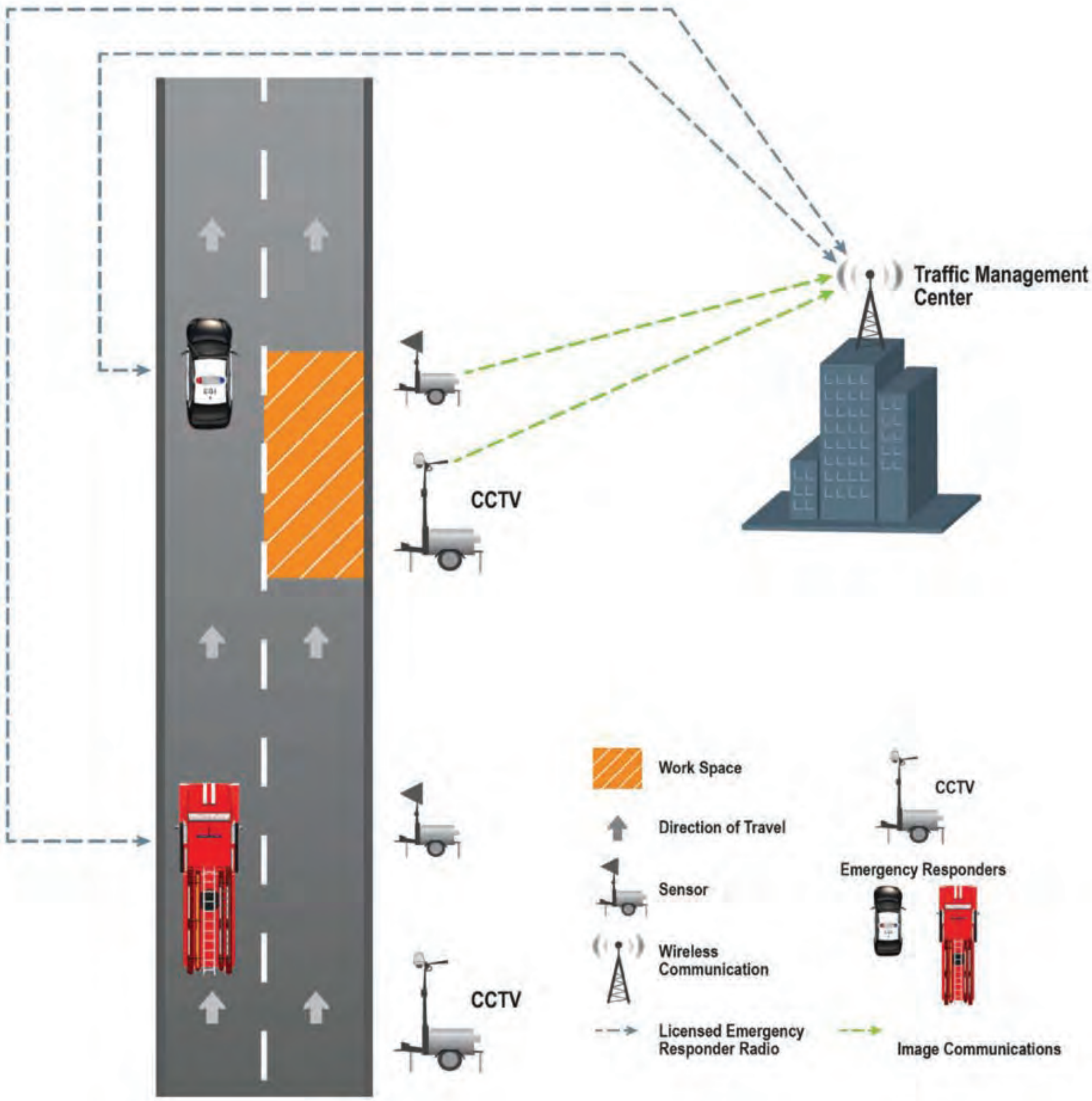


Figure 4.5. Temporary incident-detection and surveillance system layout (Credit: TxDOT).

- Provides details about each disabled vehicle or crash site (e.g., size of vehicle, orientation of vehicle, fuel or cargo spills) so the appropriate response vehicles and equipment can be deployed effectively.
- Reduces the probability of a secondary incident that may have severe consequences.

4.3.4 Expected Effectiveness

No recent studies were found that evaluated the effectiveness of temporary incident-detection and surveillance systems. However, a 2004 FHWA case study reported that using ITS in work zones helped reduce incident response time by 20 minutes.

4.3.5 Crash Modification Factor

No CMF is applicable for this strategy.

4.3.6 Implementation Considerations

The following aspects should be considered for deployment of temporary incident-detection and surveillance systems:

- Agencies need a reliable means of communication to transmit data, as geography or infrastructure may limit communication options.
- A TMC needs to be in place or established.
- An individual is required to monitor video surveillance cameras, usually at a traffic management center. As construction phasing progresses, agencies may need to relocate cameras and communications infrastructure.
- The system should be connected to a TMC that can contact the appropriate agencies to respond to incidents and notify the public.
- Personnel with special technical skills are required to keep cameras and communications systems operational.
- The system can be costly to install and maintain during the life of a construction project.

4.3.7 Design Features and Requirements

Incident-detection and surveillance systems typically include the following:

- Multiple closed circuit television (CCTV) cameras with pan, tilt, and zoom capabilities to ensure comprehensive coverage of the work zone and the approaches to it. CCTVs will typically be placed in areas of high risk, such as the approach to a taper or crossover. High-risk areas can also include locations where the designer anticipates motorists taking evasive or aggressive action.
- Format and frequency requirements for archive data transmission to a TMC.
- 24/7 system operation hours.
- Live alerts to various agencies or a TMC.
- Error detection and correction mechanisms.
- Automated continuous data-collection systems (if performance measures are needed or TMCs need situational awareness).

4.3.8 State of the Practice

Colorado, California, Massachusetts, Minnesota, Texas, and Virginia have used temporary incident-detection and surveillance systems on long-term construction projects.

4.3.8.1 Colorado

The Gap is an 18-mi stretch of I-25 in Colorado, running from south of Castle Rock to Monument. It is the only four-lane section of I-25, connecting Colorado's two largest cities—Denver and Colorado Springs. On average, nearly 80,000 vehicles travel the I-25 South Gap corridor daily with delays and crashes a common occurrence. To address safety concerns during construction, CDOT deployed an on-site TOC that uses cameras, signs, and vehicle-detection devices to help with incident management. Typically, construction projects feed into the larger TOCs across the state, but this project is the first ever in Colorado to have its own on-site TOC. The TOC is staffed 24/7 to monitor current roadway conditions and quickly respond, aiming to reduce congestion by suggesting drivers take alternate routes when incidents occur. Construction on the $350 million project, which is currently the longest construction zone in the state, began in Fall 2018; project completion is scheduled for 2022. The TOC is shown in Figure 4.6.

Figure 4.6. I-25 Gap project operation center (Credit: CDOT).

4.3.8.2 Work Zone Accident Reduction Deployment System

MnDOT led the launch of the Work Zone Accident Reduction Deployment (WZARD) system in January 2012 along eastbound I-94 between TH 15 in Saint Cloud to TH 101 in Rogers, totaling 34 mi. The system was designed so that when a snow plow or maintenance vehicle equipped with automatic vehicle location (AVL) came within a certain geofenced area, the central system received a signal to determine whether to disseminate a preprogrammed message. For example, if an AVL-equipped snow plow was active within a certain area, the system would post SNOW PLOW AHEAD USE CAUTION on the message signs within that area (Figure 4.7).

WZARD was designed in response to snow plow operators and maintenance personnel expressing concern for their safety and that of other road users when plowing or maintenance was under way. The primary purpose of WZARD was to improve safety for snow, ice, and other maintenance operations.

WZARD provided the following benefits:

- Automated geofenced AVL improved traffic safety during snow and ice operations and other work zone activities by informing vehicle operators of work vehicles ahead.

Figure 4.7. MnDOT WZARD system (Credit: MnDOT).

- Travelers along I-94 outside of the metro area received crucial traveler information, including advance warning of work zone activities and traffic incidents.
- Planned and currently installed roadside technologies were integrated with automated systems to streamline traveler information and reduce MnDOT and Minnesota State Patrol vehicle crashes or conflicts on the corridor.

4.3.9 Cost

The cost to deploy an SWZ, such as a temporary incident-detection system, will depend on project duration and the number of devices (e.g., message boards, traffic sensors, speed trailers, cameras) used. In general, the rental cost is the same for a PCMS or a traffic sensor or camera—approximately $1,000 per week. For longer-duration projects, the rental costs can be substantially lower.

TxDOT *Smart Work Zone Guidelines* (2018) reported the following costs for temporary incident-detection and surveillance systems:

- $2,395,816 (1 percent of total construction cost) for 8 PCMSs, 14 sensors, 8 cameras, and 8 trailers deployed for 76 months (~ $32,000/month).
- $1,574,058 (1 percent of total construction cost) for 9 PCMSs, 14 sensors, 9 cameras, and 9 trailers deployed for 46 months (~ $34,000/month).
- $306,616.75 (2 percent of total construction cost) for 3 trailers, 9 sensors, 3 cameras, and 3 PCMSs with modem deployed for 20 months (~ $15,000/month).

4.3.10 Resources and References

Balke, K. *Traffic Incident Management in Construction and Maintenance Work Zones,* FHWA-HOP-08-056, FHWA, U.S. DOT, January 2009.

CDOT *Guidelines for Developing Traffic Incident Management Plans for Work Zones,* Colorado Department of Transportation, 2008.

Charles, P, and R. Higgins. *Successful Incident Management on a Major Reconstruction Project, Pacific Motorway Project, Queensland Australia,* University of Queensland, Australia, November 2001.

Dougald, L. E., N. J. Goodall, and R. Venkatanarayana *Traffic Incident Management Quick Clearance Guidance and Implications,* FHWA/VTRC 16-R9, FHWA, Virginia Department of Transportation, February 2016.

FEMA. *U.S. Fire Administration Traffic Incident Management Systems,* FA-30, April 2008.

FHWA. *Intelligent Transportation Systems in Work Zones: A Case Study—Work Zone Traffic and Incident Management System, Keeping Traffic Moving During Reconstruction of the Big I, a Major Interstate-Interstate Interchange in Albuquerque,* FHWA-OP-04-072, U.S. DOT, January 2004.

Horowitz, A. J., and Xia J. *Guidebook on Incident Management Planning in Work Zones.* University of Wisconsin–Milwaukee. September 1, 2005.

I-95 Corridor Coalition. *Traffic Incident Management (TIM) Best Practices Report*, March 2010.

Noyes, P. B. *Mainstreaming Incident Management in Design-Build: The T-REX Experience.* Colorado Department of Transportation, 2001.

Pennsylvania State Transportation Advisory Committee. *Traffic Incident Management Final Report*, Pennsylvania Department of Transportation, February 2014.

TxDOT. *Smart Work Zone Guidelines: Design Guidelines for Deployment of Work Zone Intelligent Transportation Systems (ITS)*, Texas Department of Transportation, October 2018.

4.4 Freeway Service Patrols

4.4.1 Description

Freeway service patrols (FSPs) use specially equipped vehicles to provide emergency repairs and rapid clearance of stalled or disabled vehicles from the roadway. Vehicles can be positioned at either strategic locations or rove in the traffic stream.

4.4.2 When to Use

Tow/freeway service patrols are best suited for use in the following situations:

- Long project duration.
- High public exposure and traffic volume.
- Locations where incidents can create significant delays.
- Locations where shoulder-width reductions or closures are expected.
- Locations with a history of high crashes.

4.4.3 Benefits

The use of FSPs provides the following benefits:

- **Reduce roadway-clearance time.** Decreases the time between the first recordable awareness of the incident by a responsible agency and the first confirmation that all lanes are available for traffic flow.
- **Reduce incident-clearance time.** Lessens the time between the first recordable awareness of the incident by a responsible agency and the time that the last responder has left the scene.
- **Reduce the number of secondary incidents.** Decreases the number of crashes that occur after the primary crash, either within the original incident scene or within the queue in either direction, caused by the original incident.
- **Reduce nonrecurring traffic congestion and improve travel time reliability.** Removes debris, disabled vehicles, and minor crashes from the travel portion of the roadway quickly and safely.
- **Improve highway safety for responders and motorists.** Provides proper traffic control to support a safe incident work area for responders and victims.
- **Provide timely and accurate information to the TMC.** Allows staff to activate traveler information devices and warn motorists when they are approaching an incident or closure; to prompt systems such as 511, websites, and media; and to alert motorists of the current road conditions, lane or road closures, diversions, and any delays before their departure.

4.4.4 Expected Effectiveness

An evaluation of the arterial service patrol deployed in Missouri during the 2008 I-64 construction project demonstrated the following summary of findings (Ryan et al., 2010):

- A conservative benefit–cost ratio was 8.3:1.
- 183 secondary crashes were prevented per year.
- $1,034,000 in annual congestion cost was saved.

4.4.5 Crash Modification Factor

No CMF is applicable for this strategy.

4.4.6 Implementation Considerations

Clear communication between the TMC and the tow/freeway service patrollers is essential. In addition, both entities need to understand the other's job functions and needs. The patrollers are often the agency representative on the scene in the incident-command setting and relay the requests for agency resources from the incident commander to the TMC, as well as any information pertinent to the event. Relationships among different incident management stakeholders are vital to the success of FSPs as a traffic incident management tool. The most effective programs involve close relationships between law enforcement and FSP personnel, who trust and depend on each other.

When implementing contracts for towing services, a DOT needs to consider the level of service required of the contractor and the ensuing liability involved. The services permitted may differ from region to region, depending on laws and regulations in a given state. Some programs will not allow a private contractor to move vehicles from the roadway. Others, such as PennDOT, allow the contractor to remove disabled vehicles or minor incidents from travel lanes, but also require the contractor to carry additional liability insurance to cover any claims. Allowing the contractor some indemnification has proved beneficial in allowing contracted FSPs to clear incidents from travel lanes.

For example, the State of Florida allows the Florida Road Rangers some exceptions to liabilities, as the Rangers are private contractors acting as an agent of the state while moving incidents, disabled vehicles, or debris from travel lanes. Florida passed legislation, Statute 316.061(3), identifying the contracted FSP operator as an "authorized agent of the department." This allows patrollers to remove damaged or disabled vehicles from the roadway without being considered at fault for any additional damage that occurs to the disabled vehicle. With this additional protection in place, the contract service patrol providers are less hesitant to remove obstructions from the travel lanes, and they are able to operate as an agency-operated patrol would.

Training is paramount for the patrollers and may require National Incident Management training.

Other factors to consider when implementing tow/freeway service patrols include the following:

- Hours of operation.
- Patrol route selection based on historical incident statistics.
- Available personnel.
- Number of vehicles.
- Requirements for the types of vehicles to deploy.
- Equipment needed on the vehicles.
- Tools and equipment needed to perform the FSP support functions safely and effectively.

4.4.7 Design Features and Requirements

Towing patrols for work zones are mostly contracted services to remove disabled vehicles from the roadway and maintain operational safety. Contracted service patrols provide specific services, as identified in their contract scope of work, for a specific number of years and with requirements for route coverage. Their contracts may also include numbers of staff and vehicles. The contracted services option can be beneficial if implemented correctly and a clear, well-written contract and scope of services have been developed and executed (e.g., decreased maximum response time following reports of an incident, improved incident-clearance time requirements).

Depending on jurisdiction, tow/freeway service patrol activities range from providing basic support for stalled motorists to assisting in removing vehicles involved in major incidents to incident-coordination activities. The types of services offered include the following:

- Moving disabled vehicles from work zones.
- Providing fuel.
- Providing water to persons being assisted or for overheated vehicles.
- Changing flat tires.
- Providing mechanical assistance such as jump starts, minor mechanical repairs, and tire inflation.

- Assisting stranded motorists with cell phone service or providing a safe place they can wait if their vehicle is disabled.
- Arranging for towing by calling on behalf of the motorist.
- Acting as the agency's representative in the incident-command structure.
- Requesting emergency services.
- Providing information and updates to the TMC.
- Assisting other responding agencies such as law enforcement, fire and rescue, emergency medical services, and other response agencies, as needed.

4.4.8 State of the Practice

The following provides examples of FSP exclusively used on construction projects.

4.4.8.1 Oklahoma GO-DOT Program

At the time this guidebook was written, OKDOT is pilot testing a new program focused on keeping highway work zones clear of stranded or wrecked vehicles to prevent traffic delays. The pilot program, called GO-DOT, relied on the services of two specially equipped 2017 Ford F-450 4×4 crew cab medium-duty highway rescue trucks. This program is designed to quickly move stranded vehicles out of the busy work zone to the nearest safe location and was made possible by the FHWA as part of the nearly $88 million federally funded I-235 construction contract between I-44 and North 36th Street in Oklahoma City.

The two 2017 Ford F-450 trucks cost more than $400,000 to purchase and outfit. The vehicles are equipped with a wheel lift capable of lifting 3,500 lbs. and towing vehicles up to 7,800 lbs., such as recreation vehicles and travel trailers, as well as a wheel dolly for removing four-wheel-drive vehicles without damaging drivetrain components. The vehicle cabs can seat up to four additional passengers, which enables the crew to help quickly move motorists to a safer location. GO-DOT will also be equipped to provide basic auto maintenance such as jumping a dead battery, fixing a flat tire, or providing a few gallons of fuel for those who ran out of gasoline inside the work zone.

The trucks are operated by the prime contractor for the I-235 construction project. When the project is completed in 2019, OKDOT will take possession of the two vehicles and hire its own operators.

4.4.8.2 WisDOT Freeway Service Teams

WisDOT, state patrol, and county sheriffs implemented the Freeway Service Team (FST) program to expedite relocation of disabled and crashed vehicles by FST vehicles, which continuously patrol designated segments of Interstate and state highways during designated hours and through designated work zones. FSTs are frequently used as part of a project's work zone mitigation strategy to accomplish the following:

- Maintain capacity in work zones and high-volume freeway segments.
- Provide assistance free of charge to disabled motorists.
- Minimize work zone delay.
- Provide scene safety.
- Provide traffic control.
- Remove debris.

Project design staff work with regional traffic operations to identify and quantify the need for FSTs for work zone mitigation. The FST expense is paid from the project mitigation budget.

E-mail requests to the FST program manager for work zone FST are to be made by December 15 of the year before construction. All FST contracts are bid together in a statewide request for bids.

- December 15: FST requests due for next construction year.
- February: Request for bids issued.
- March: Bid selections made for construction season.

The FST is responsible for clearing the highway of automobiles, motorcycles, small trucks, (vehicles with a gross vehicle weight of 8,000 lbs. or less), and small nonhazardous debris. The FST relocates all cleared vehicles to the nearest drop-off location designated by the contract administrator. When responding to incident scenes, the FST provides assistance with traffic control as directed by law enforcement.

4.4.8.3 Missouri I-64 Traffic Response Program

The I-64 Traffic Response program operated while I-64 was closed for reconstruction between 2007 and 2009. The I-64 project involved reconstruction of 10 mi of roadway and 30 bridges along the corridor under a full road closure. An arterial service patrol was deployed to help reduce potential mobility effects along adjacent arterial corridors based on anticipated traffic diversions from the I-64 construction project. The I-64 Traffic Response Program included six pickup trucks available on weekdays from 5:00 a.m. to 9:30 p.m. and on weekends from 8:00 a.m. to 6:30 p.m.

Other examples of FSPs include

- Florida Department of Transportation (FDOT) Road Rangers Service Patrol (https://www.fdot.gov/traffic/roadrangers/about.htm)
- Georgia Department of Transportation (GDOT) Highway Emergency Response Operators (HEROs, http://www.dot.ga.gov/DS/Travel/HEROs)
- MDSHA Coordinated Highway Action Response Team (CHART, https://chart.maryland.gov/about/incident_management.asp)
- Houston TranStar Motorist Assistance Program (MAP, https://www.houstontranstar.org/about_transtar/callmap.aspx)

4.4.9 Cost

Costs depend on the number of trucks and operators available, hours of operation, roadway coverage area, and project duration. Cost estimates from available examples indicate a range between $250,000 to more than $500,000 for service on the main line only.

The cost for the I-64 Traffic Response Program that included the affected arterial routes was estimated at $730,000 per year (Ryan et al. 2010).

4.4.10 Resources and References

Balke, K. *Traffic Incident Management in Construction and Maintenance Work Zones,* FHWA-HOP-08-056, FHWA, U.S. DOT, January 2009.

CDOT. *Guidelines for Developing Traffic Incident Management Plans for Work Zones,* Colorado Department of Transportation, 2008.

FEMA. *U.S. Fire Administration Traffic Incident Management Systems*, FA-30, April 2008.

Marquess, A., P. Desai, G. Havinoviski, and C. Heise. *Safety Service Patrol Priorities and Best Practices,* FHWA-HOP-16-047, FHWA, U.S. DOT, April 2017.

Ryan, T., V. Chilukuri, M. Trueblood, and C. Sun. *Evaluation of Freeway Motorist Assist Program*, FHWA MO-2009-004, FHWA and Missouri Department of Transportation, February 2010.

4.5 Traffic Screens (a.k.a. Glare Screens, a.k.a. Gawk Screens)

4.5.1 Description

Traffic screens, also known as glare screens and gawk screens, are screens or paddles attached to the top or back of some types of barriers to reduce headlight glare from opposing traffic.

Traffic screens come in several forms and types of material. There are three general categories of screen types:

- Type I. Continuous screen that is essentially opaque to light from all angles.
- Type II. Continuous screen of an open material that is opaque where the angles are between 0 and 20 degrees from the driver's eye and increasingly transparent beyond 20 degrees.
- Type III. Individual elements positioned to block light at angles from 0 degrees to 20 degrees. Beyond 20 degrees visibility is clear between the elements.

Traffic screens are also used in work zones to block road users' view of construction activities that can be distracting. In this context, traffic screens are referred to as "gawk screens." This section deals with the use of temporary work zone gawk screens.

4.5.2 When to Use

The following discusses various agencies' warrants for using traffic screens.

The Arizona DOT (ADOT) *Standard Specifications for Road and Bridge Construction* (2008) states glare screens should be placed in urban construction zones where barriers are being used to separate opposing lanes of traffic, and when a barrier is separating traffic from areas of construction work longer than 1,500 ft.

The IDOT *Bureau of Design and Environment Manual* (2016) provides the following list of applications for glare screen use:

- Travel lane is within 2 ft of the barrier.
- High amount of peripheral ambient light exists.
- High volume of truck traffic exists.
- Vertical or horizontal alignment of the roadway may create a headlight glare problem.

IDOT encourages using glare screens if the following conditions are present:

- Design speed is greater than 50 mph on an undivided and unlighted highway with median widths less than 30 ft.
- Highway segment is on a divided highway that contains horizontal curves.
- Nighttime crashes are unusually frequent.
- Unusual transition points produce critical glare angles between traffic traveling in opposite directions.

Based on a synthesis of national practices, Johnson (2017) developed three conditions for glare screen use. Meeting one or more of the conditions should lead to an engineering review of the suspected glare issue, with the intent to determine if glare screens are the appropriate glare mitigation measure for the location. When more than one of the three conditions are met, this provides additional justification for the use of glare screens.

1. Headlight glare is known to be an issue on the segment of roadway to be reviewed, based on experience or data available to agency staff.
2. Crash history attributed to glare, or with headlight glare being a contributing factor in the crash reporting, is higher than average compared with similar highway segments.

3. Three or more of the following characteristics are met:
   – Median widths less than 20 ft.
   – ADT volumes exceed 20,000.
   – Larger-than-usual percentage of heavy vehicles present.
   – Absence of highway lighting.

4.5.3 Benefits

The use of traffic screens provides the following benefits:

- Reduces distractions to drivers caused by work activities in a work zone.
- Improves work zone safety by shielding drivers from oncoming headlight glare.
- May improve traffic flow by reducing the distraction of watching work zone activities.
- Protects vehicles from any flying debris from the work zone.

4.5.4 Expected Effectiveness

No studies were found that evaluated the safety or mobility effectiveness of traffic screens in work zones.

4.5.5 Crash Modification Factor

No CMF is applicable for this strategy.

4.5.6 Implementation Considerations

Factors to consider when determining whether to specify use of a screening system include the following:

- Night traffic volumes.
- Prevalence of night highway crashes.
- Highway geometry (lane/median width, vertical/horizontal curvature, etc.).
- Proximity of workers to live traffic.
- Extent of work area distractions.
- Direction and intensity of roadway lighting and ambient light from adjoining properties.

4.5.7 Design Features and Requirements

The design requirements for traffic screens are as follows:

- Minimum 24-in. height.
- Same length as the concrete barrier on which it will be mounted, without splicing, except accounting for longitudinal overhang between adjacent concrete barriers.
- Mounted with two poles, attached to the mounting plate with the mounting plate drilled into the top of the concrete barrier.
- Secured with a chain and pin, or other approved method, to the mounting pole.
- Capable of being securely connected to the adjacent screen section by polyethylene brackets, or similar approved fasteners made of nonmetallic materials.
- Capable of expanding without buckling.
- Capable of contracting without creating gaps in the screening and while remaining securely fastened to the adjacent screen.
- Faces on both sides of the screen are finished.
- Capable of remaining in place from traffic gusts, wind gusts, and other outdoor elements that may move or displace the screen.

Without Gawk Screens **With Gawk Screens**

Figure 4.8. Gawk screens (Credit: WisDOT).

4.5.8 State of the Practice

In March 2018, WisDOT piloted the use of gawk screens along a ½-mi stretch of the I-41 work zone in Winnebago County (Figure 4.8).

The Oregon DOT *Traffic Control Plans Design Manual* (2014) allows the use of work zone barrier screening systems and sets out specifications for the screens:

> 2.5-ft tall, opaque, and purposefully designed as a gawk screen. Designs may include chain link fencing material (or equivalent roll-type material) and steel vertical posts for support. Fencing material would either be opaque, or vinyl slats could be inserted into the chain link material to provide the desired visual screening benefit.

4.5.9 Cost

The cost for the I-41 project in Winnebago County, Wisconsin, was $12 per linear ft ($8 for material and $4 for installation).

4.5.10 Resources and References

ADOT. *Standard Specifications for Road and Bridge Construction*, Arizona Department of Transportation, 2008.

Bremer, W., D. A. Noyce, J W. Shaw, M. V. Chitturi, and A Bill. *Guidelines for Work Zone Designers—Positive Protection*, DTHF6114H00011, FHWA, U.S. DOT, May 2019.

IDOT. Work Zone Traffic Control, in *Bureau of Design and Environment Manual*, chapter 55, Illinois Department of Transportation, June 2016.

Johnson, D. *A Synthesis of US Glare Screen Warrants and Design Requirements with Model Warrants and Design Guide*. Master's Thesis, University of Illinois at Chicago, 2017.

Oregon DOT. *Traffic Control Plans Design Manual*, 9th edition, Oregon Department of Transportation, 2014.

4.6 Automated Speed Enforcement

4.6.1 Description

Automated speed enforcement (ASE) involves using roadside technologies, either fixed or portable, that combine radar and image-capturing capabilities to detect speeding vehicles and collect digital photographic evidence of the speeding incident. The system captures photos of the rear of the vehicle and the license plate, embedded with the date, time, location, and recorded speed. The agency or entity authorized to issue speeding citations then reviews the images and mails a citation to the vehicle's registered owner.

ASE systems in work zones function similarly to the permanent speed camera installations used in many jurisdictions to enforce speed limits or red-light violations through automatic citations.

4.6.2 When to Use

ASE systems should be considered in the following circumstances:

- There is an active work zone on an expressway or controlled-access highway (speed limit of 45 mph or higher).
- Workers are exposed or there are motorist hazards (lane shifts, lane splits, reduced lane widths, closed shoulders, rough pavement, etc.).
- Work zone will remain active over a long period of time.
- 24-hour speed enforcement is desired.
- Law enforcement availability is limited.

4.6.3 Benefits

The use of ASE systems in work zones provides the following benefits:

- Increases work zone speed limit compliance, thereby reducing the potential for crashes.
- Improves worker safety.
- Allows law enforcement officers to focus on other job duties (when an officer is not required to cite a speeding vehicle, as is allowed in Maryland and Pennsylvania).
- Eliminates officers' exposure to hazardous roadside traffic stops.

4.6.4 Expected Effectiveness

ASE systems have significantly reduced the number of drivers exceeding the PSL, the number of crashes in work zones, and the number of injuries and fatalities related to work zone crashes.

- The number of vehicles traveling 12 mph or more above the work zone speed limit has been shown to decrease by 85 percent (MDSHA 2019).
- Free-flow speed has been found to decrease by 6.8 mph (Avrenli, Benekohal, and Ramezani 2012).
- Automobile average speeds have been shown to decrease by 5.1–8.0 mph in the median lane and 4.3–7.7 mph in the shoulder lane (Benekohal et al. 2010).
- Truck average speeds have been found to decrease by 3.7–5.7 mph in the median lane and 3.9–6.4 mph in the shoulder lane (Benekohal et al. 2010).
- The number of vehicles exceeding mean speed has been shown to decrease by an average of 23.7 percent (Oregon DOT 2010).

4.6.5 Crash Modification Factor

Table 4.3 shows the CMF for ASE. Chapter 13 provides more information on developing WZCMFs.

4.6.6 Implementation Considerations

To begin using ASE in work zones, a state will first need to enact legislation that allows its implementation. States that already have legislation allowing automated enforcement of speeding

Table 4.3. CMFs for ASE.

Crash Type	Crash Severity	Facility Type	Volume Range (AADT)	CMF	Standard Error
All	Fatal, serious and minor injury	All	Not specified	0.83	0.01 (unadjusted)

NOTE: There were no studies available that specifically examined the safety effects of using ASE in work zones. The CMF was derived from past studies on nonwork zone roads. CMF = crash modification factor; ASE = automated speed enforcement; AADT= annual average daily traffic.

or red-light enforcement can provide a basis for a legislative request to allow ASE in work zones. Information on existing legislation permitting, limiting, or prohibiting the use of speed or red-light cameras at the state or local level can be found on the GHSA webpage.[10]

Agencies typically involved include the state DOT, state police or local police, the state department of motor vehicles, and courts. Whether workers need to be present in a work zone for drivers to receive a speeding ticket depends on state legislation. Advanced signs are necessary to alert drivers of the PSL and the use of ASE in the work zone.

Once agencies implement ASE for equipment and vehicles in designated work zones, officials normally operate the system during a well-publicized mandatory warning period of several weeks, during which violators receive warnings instead of citations. Currently, the Maryland SafeZones program issues warnings for 3 weeks at new long-term work zones. Citations are issued after the 3-week period. For short-term projects, such as paving projects, there is no warning period; rather, signs are posted to notify drivers that ASE will be in effect in the work zone.

In summary, agencies need to consider the following factors for ASE use in work zones:

- Legislation is required to authorize the use of ASE systems in work zones.
- Warning signs need to be placed well before drivers arrive at the work zone to inform them that an ASE system is in use.
- Systems usually need continuous staffing during deployment.
- The vehicle-mounted setup should be placed behind a protected area, preferably behind a barrier or guiderail, otherwise behind a TCD or on the shoulder.
- The grade of the roadway and any other features must not impair visibility of the setup.
- ASE systems are not intended to replace other work zone safety operations.
- Because each construction project is different, agencies can determine the selection, application, and location of ASEs on a project-by-project basis.

4.6.7 Design Features and Requirements

The following are the minimum requirements for ASE systems in work zones:

- **Field equipment for speed detection and image capture** can be mobile vehicle units (occupied or unoccupied) or temporary pole-mounted units. Each unit includes speed-measurement devices, violation-capturing systems, systems mounts, power supplies, site-deployment computers, cables, data-upload systems, and all other hardware required to operate the system as intended.

[10] https://www.ghsa.org/state-laws/issues/speed%20and%20red%20light%20cameras, accessed May 12, 2020.

- **Speed-detection equipment** includes radar, laser, or other proven technology that has International Association of Chiefs of Police approval for speed measurement. Approved speed-detection equipment needs to have an ongoing maintenance record to ensure it is calibrated and functioning properly. The speed-detection equipment should be able to immediately communicate error messages to the operator and record the date and time of system shutdown in the event of a malfunction or error.
- **Image-capture equipment** must be able to record front and rear images of a vehicle license plate upon a signal trigger from the speed-detection equipment. The image-capture equipment detection should include supporting hardware and software capable of simultaneously collecting readable license plate images in various lighting and environmental conditions. Images should be captured at sufficient resolution to display plate characters and data at clearly legible quality from both reflective and nonreflective plates.
- **A program database** stores all pertinent program information such as the notice of violation information, violation imagery, registered vehicle owner's number of offenses, notice of violation mailing date, date of and violator's response, appeal hearing dates for violators, hearing results, and collections received or outstanding.
- **Work zone signs** are placed well before the ASE operation, clearly indicate that ASE systems are in use, and specify the lowered speed limit, if any.
- **Systems for violation administration** manage payment processing and customer service.

4.6.8 State of the Practice

4.6.8.1 Pennsylvania

The Pennsylvania State Legislature amended Section 102 and Title 75 Pa C.S. §3369, granting permission for ASE to be used within active work zones in the commonwealth. This act, Senate Bill 172, was signed into law on October 19, 2018. Drivers exceeding the PSL by 11 mph or more in active work zones will get a warning in the mail for a first offense and will be ticketed $75 and $150 fines for second and third offenses. ASE violations are considered civil violations; therefore, no license points are assessed.

ASE began in fall 2019 with full deployment planned for 2020. Pennsylvania will pilot the ASE system for 5 years. PennDOT will start with two ASE units that will be moved between projects statewide. Eventually, the department will have 10 speed cameras for the initiative. Appendix F provides the operational process flowchart for ASE deployment.

4.6.8.2 Maryland

MDSHA, the Maryland Transportation Authority, and the Maryland State Police began the Maryland SafeZones in October 2009. The SafeZones pilot program ran from October 2009 through June 2010, with the long-term SafeZones program beginning on July 1, 2010 (Transportation Article § 21-810).

SafeZones deploys speed cameras aboard sport-utility vehicles called mobile ASE units. These units can be located within the limits of any work zone on expressways and controlled-access highways where the speed limit is 45 mph or greater. Images are only captured and used to issue a citation if a vehicle is exceeding the posted work zone speed limit by 12 mph or more (Figure 4.9). Citations may be issued regardless of whether workers are present in the work zone. Violators must pay a $40 fine and no license points are assessed.

Maryland has seven mobile ASE units that rotate through a series of predetermined work zones throughout the state. SafeZones program stakeholders use a variety of factors to determine camera deployment locations, including roadway and work zone characteristics (such as facility type), speed limit, TTC activities, and whether traditional in-person enforcement is

Figure 4.9. Automated speed enforcement signing (Credit: MDSHA, http://www.safezones.maryland.gov).

viable. Drivers can find out which work zones are using ASE by going online to the Maryland SafeZones website (http://www.safezones.maryland.gov).

Since 2010, SafeZones has been deployed at 78 enforcement locations in work zones on Interstates, national highways, and Maryland state routes. When the program began, approximately 7 out of every 100 drivers in SafeZones were exceeding the speed limit by 12 mph or more. As of April 2019, fewer than 1 driver of every 100 is receiving a citation, showing a more than 85 percent reduction in the number of vehicles traveling 12 mph or more above the work zone speed limit (Figure 4.10).

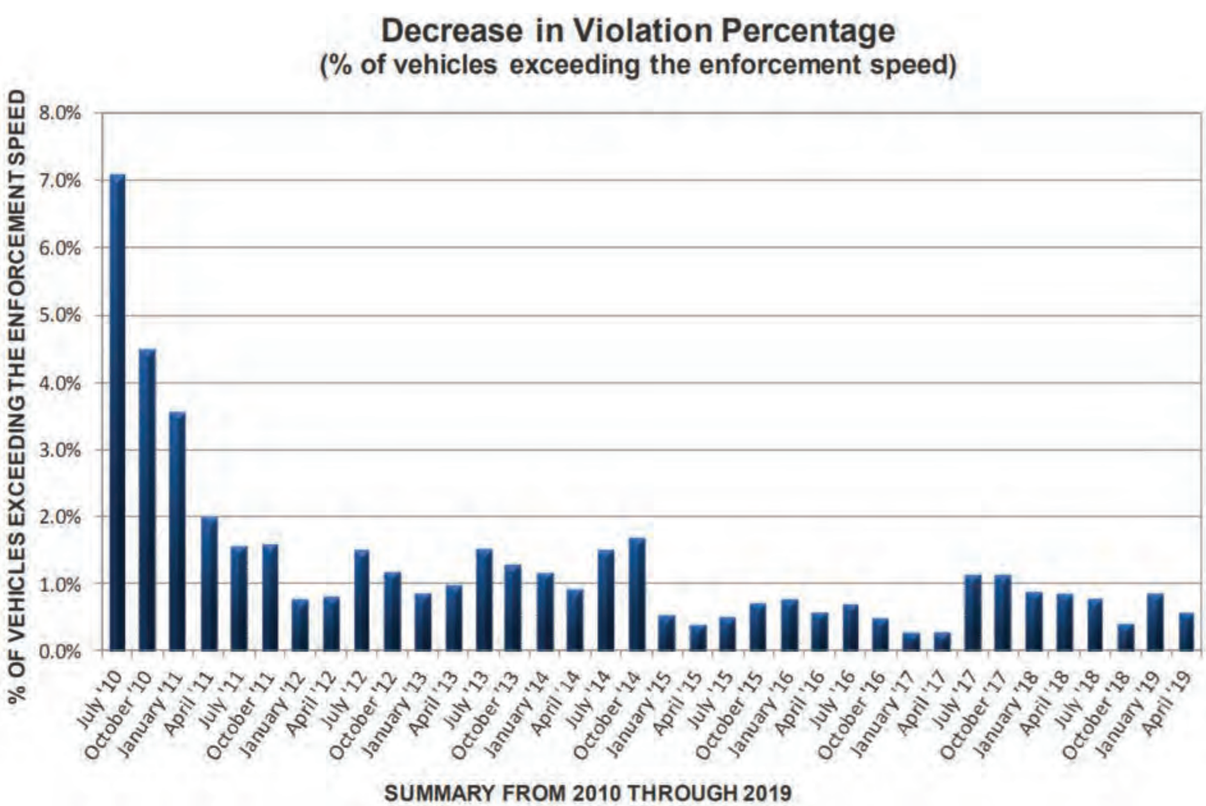


Figure 4.10. MDSHA ASE speeding quarterly report (Credit: MDSHA, http://www.safezones.maryland.gov).

Figure 4.11. Illinois ASE van with radar speed display sign (Credit: IDOT).

4.6.8.3 Illinois

In 2006, Illinois was the first U.S. state to implement ASE in work zones. The legislation requires that construction workers be present when ASE is in use. It allows ASE use day or night, even if the workers are behind temporary concrete barriers. The law also requires special signs to be posted to inform motorists of ASE in the work zones (Figure 4.11).

ASE began with a pilot program of two vans; as of this writing, five vans were in use during the construction season (usually April–October), with deployment limited to freeway work zones. The vans are staffed by specially trained Illinois State Police officers. Issuing a speeding citation is at the discretion of the officer and is generally limited to clear cases of excessive speed. The minimum fine was $375 for the first offense and $1,000 for the second offense; if the second offense is within 2 years of the first offense, the driver's license is suspended for 90 days.

4.6.8.4 Oregon

The 2007 Oregon legislative assembly passed House Bill 2466, allowing the Oregon DOT to use photo radar in work zones on non-Interstate state highways. To this effect, the Oregon DOT conducted a demonstration project to examine the effect of photo radar speed enforcement on traffic speed through an active highway work zone in 2010.

The 2013 Oregon Legislature passed House Bill 2465 (ORS 810.441).[11] This legislation replaced House Bill 2466, which expired on December 31, 2014.

ORS 810.441 allows the Oregon DOT to request the Oregon State Police or other law enforcement jurisdictions operate photo radar in highway work zones on state highways, including Interstates.

ORS 810.441 also identified criteria surrounding the use of photo radar, including the requirement to deploy photo radar within 100 yards of workers or within 100 yards of a configuration change. Signs announcing the use of photo radar must be posted, as well as the actual speed of

[11] https://www.oregonlegislature.gov/citizen_engagement/Reports/ODOTPhotoRadarWorkZonePilotReport2015.pdf, accessed May 12, 2020.

the vehicle, which must be displayed within 150 ft of the photo radar unit. A uniformed police officer in a marked vehicle must be present for a citation to be issued.

In 2018, the Oregon DOT requested the City of Medford Police Department to provide work zone photo radar on the I-5 Medford Viaduct and Barnett Road Overpass project. Medford Police Department deployed the work zone photo radar van for 15 days. Each deployment lasted for 4 hours. The legal speed through the work zone was 40 mph.

For this project, more than 1,058 work zone photo radar violations were captured and 686 speeding citations issued (an average of 11.4 per hour). Speeds recorded for the violations averaged 56 mph, with a high speed of 91 mph. As of this writing, Stage 2 of the I-5 project is currently under development. This project will use work zone photo radar and perform a formal speed-comparison study.

The Portland City Council, through City Ordinance #172517, directed the police bureau to deploy photo radar in highway work zones. The bureau used photo radar to enforce speed limits at two work zones during 2013 and 2014.

4.6.8.5 Washington

Washington, which authorized legislation in 2007, launched a pilot program in 2008, and although the legislature extended the pilot program to June 2013, WSDOT has not redeployed ASE beyond the 2008 pilot.

4.6.9 Cost

ASE costs are estimated at $150,000–$250,000, including system hardware and software costs.

4.6.10 Resources and References

Avrenli, K. A., R. F. Benekohal, and H. Ramezani. *Four-Regime Speed-Flow Relationships for Work Zones with Police Patrol and Automated Speed Enforcement*, University of Illinois, Urbana, 2012.

Benekohal, R. F., A. Hajbabaie, J. C. Medina, M.-H. Wang, and M. Chitturi. *Speed Photo-Radar Enforcement Evaluation in Illinois Work Zones*, FHWA-ICT-10-064, January 2010.

Boyer, R. *Highway Worker Safety: Automated Speed Enforcement*, Caltrans Division of Research and Innovation, August 3, 2011.

Cameras in Work Zones: Final Report, Pennsylvania State Transportation Advisory Committee, November 2012.

Chan, C.-Y., K. Li, and J.-H. Lee. *Assessing Automated Speed Enforcement in California*. California PATH Research Report UCB-ITS-PRR-2010-2, April 2010.

Chan, C.-Y. Field Evaluation of Work-Zone Automated Speed Enforcement Equipment and Traffic Monitoring Devices. Presented at 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.

Douma, F., L. Munnich, J. Loveland, and T. Garry. *Identifying Issues Related to Deployment of Automated Speed Enforcement*, CTS Project #2012045, Center for Transportation Studies, University of Minnesota, July 2012.

Franz, M. L., and G.-L. Chang. *Effects of Automated Speed Enforcement in Maryland Work Zones*, University of Maryland, 2010.

General Assembly of Pennsylvania, Senate Bill 172. 2017. (https://www.legis.state.pa.us/cfdocs/legis/PN/Public/btCheck.cfm?txtType=PDF&sessYr=2017&sessInd=0&billBody=S&billTyp=B&billNbr=0172&pn=2024, accessed on April 9, 2019).

Maryland State Highway Administration (MDSHA). Automated Speed Enforcement in Work Zones (http://www.safezones.maryland.gov, accessed April 9, 2019).

Oregon DOT. *Photo Radar Speed Enforcement in a State Highway Work Zone: Yeon Avenue Demonstration Project*, Oregon Department of Transportation, OR-RD-10-17, April 2010.

WSDOT. Automated Enforcement in Work Zone Pilot Project, Fall 2008/Spring 2009 Deployment. https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa1304/resources2/31%20-%20Automated%20Enforcement%20in%20Work%20Zone%20Pilot%20Project.pdf, accessed April 9, 2019.

4.7 Police Enforcement

4.7.1 Description

Police enforcement involves police patrols in the work zone under a contractual arrangement with the agency or contractor. Law enforcement activities can be in the form of stationary patrol vehicles, a police traffic controller (an officer does the flagging), circulating patrol vehicles, stationary patrol vehicles with their lights on, and stationary patrol vehicles with radar on.

4.7.2 When to Use

Federal regulations (23 CFR 630, Subpart K) list conditions for which work zone enforcement may be a valuable addition to the standard traffic controls. These include the following:

- Frequent worker presence adjacent to high-speed traffic without positive protection devices.
- Traffic control setup or removal that presents significant risks to workers and road users.
- Complex or very short term changes in traffic patterns with significant potential for road-user confusion or worker risk from traffic exposure.
- Night work operations that create substantial traffic safety risks for workers and road users.
- Existing traffic conditions and crash histories that indicate a potential for substantial safety and congestion effects related to the work zone activity, which may be mitigated by improved driver behavior and awareness of the work zone.
- Work zone operations that require brief stoppage of all traffic in one or both directions.
- High-speed roadways where unexpected or sudden traffic queuing is anticipated, especially if the queue forms a considerable distance in advance of the work zone or immediately adjacent to the work space.
- Other worksite conditions in which traffic presents a high risk for workers and road users, such that the risk may be reduced by improving road-user behavior and awareness.

4.7.3 Benefits

The use of police services in work zones provides the following benefits:

- **Speed control**. Extensive research has shown that the presence of a marked police vehicle is simply the most effective speed-control measure in work zones.
- **Enforcement**. Police enforcement increases motorists' compliance with work zone regulations and discourages aggressive or careless driving.
- **Traffic incident and accident management**. Work zone officers can immediately respond to any incident or accident, thus quickly restoring traffic flow and enhancing the safe operation of the work zone.
- **Traffic control**. A police officer commands respect and authority. Thus, the officer's presence facilitates the safe and efficient movement of traffic through the work zone (e.g., traffic merging during lane closure).
- **Increased visibility**. The presence of a marked police vehicle in the work zone is an effective measure to capture the attention of passing motorists, raising their alertness.

4.7.4 Expected Effectiveness

The use of police enforcement for work zone activities has been studied extensively with the following results:

- 16 percent to 24 percent reduction in speeding (Gan et al. 2018).
- 1.7–6.5 mph reduction in work zone mean speeds; 5.5 percent to 16 percent reduction in percentage of traffic exceeding work zone speed limit (Lee, Azaria, and Neely 2014).

- Speed reduction of 3.6 mph for automobiles and 2.7 mph for trucks (Chen and Tarko 2013).
- 6.3 mph reduction in free-flow speed (Avrenli, Benekohal, and Ramezani 2012).
- 4–12 mph reduction in average speeds for stationary patrol vehicles and 2–3 mph for circulating patrol vehicles (Carpenter, Hammond, and Lenzi 2012).
- 5–7 mph reduction in mean speeds (Benekohal et al. 2010; Hajbabaie et al. 2011).
- 1.4 mph reduction in average daytime speed, 1.1 mph reduction in average nighttime speed, and 17 percent reduction in percentage of vehicles exceeding PSL (Chen et al. 2007).
- 6 mph reduction in average vehicle speeds (Bowie 2003).
- 17 percent reductions in mean speeds; 15 percent reduction in 85th percentile speeds (Lindly, Noorjahan, and Hill 2002).
- 8–11 mph reduction in 85th percentile speeds (MnDOT 1999).

4.7.5 Crash Modification Factor

Table 4.4 shows the CMF for police enforcement. Chapter 13 provides more information on developing work zone CMFs.

4.7.6 Implementation Considerations

Obtaining sufficient police resources for work zone enforcement remains an ongoing concern in many states and is a limiting factor for many types of work zone enforcement. This issue has many dimensions, including budget and finance, human resources and labor relations, and organizational and jurisdictional factors. To a large extent, each agency's situation is a unique reflection of its state laws, collective bargaining agreements, and the established degree of cooperation or competition between state, county, and local law enforcement agencies.

4.7.7 Design Features and Requirements

Generally, using law enforcement officials on a continuing basis is warranted only on freeways or Interstate roadways where traffic volumes are in excess of 25,000–30,000 annual average daily traffic (AADT) and lanes are closed in peak periods. Where lane closures are limited to off-peak periods, a higher AADT (approximately 35,000) is typically considered a minimum threshold volume to justify law enforcement.

Also, to be effective, the construction work must allow space for law enforcement officials to stop violators at the point of infraction. If sufficient shoulder area does not exist, the city should consider constructing temporary pull-off areas. These guidelines are intended for long-term contractual law enforcement activities. They are not intended to limit the short-term use of law enforcement agencies for construction control for lane closures, traffic lane switching, and the like.

Table 4.4. CMFs for police enforcement.

Crash Type	Crash Severity	Facility Type	Volume Range (AADT)	CMF	Standard Error
All	All	Not specified	696 to 124,907	0.585	Not calculated

Note: The CMF was obtained using data from Indiana work zones and a random-effect negative binomial crash-frequency model, in which each observation represented 1 month of data. Detailed hourly data with enforcement efforts were not available at enough sites to be used in the model. CMF = crash modification factor; AADT = annual average daily traffic.

4.7.8 State of the Practice

Most states have policies regarding the use of uniformed off-duty police officers in highway construction work zones. Most frequently, the state DOT funds the program for the law enforcement agency. Police enforcement programs are often administered through an interagency agreement or memorandum of understanding between the state highway agency and the state police or state highway patrol.

Arrangements vary widely, however. In some cases, an unwritten policy of interagency cooperation allows the law enforcement agency to provide on-duty uniformed officers as needed. Some highway agencies work with local police agencies in addition to the state police.

4.7.9 Cost

Estimates of the cost of police enforcement range from \$150–\$250 per officer per hour.

4.7.10 Resources and References

Avrenli, K. A., R. F. Benekohal, and H. Ramezani. *Four-Regime Speed-Flow Relationships for Work Zones with Police Patrol and Automated Speed Enforcement*, University of Illinois, Urbana, 2012.

Arnold, E. D. *Use of Police in Work Zones on Highways in Virginia*, VTRC 04-R9 Virginia Transportation Research Council, Virginia Department of Transportation and the University of Virginia, Charlottesville, 2003.

Benekohal, R. F., P. T. V. Resende, and R. L. Orloski. *Effects of Police Presence on Speed in a Highway Work Zone: Circulating Marked Police Car Experiment*. Report FHWA-IL/UI-240. University of Illinois, Urbana, 1992.

Benekohal, R. F., A. Hajbabaie, J. C. Medina, M.-H. Wang, and M. Chitturi. *Speed Photo-Radar Enforcement Evaluation in Illinois Work Zones*. FHWA-ICT-10-064. January 2010.

Bowie, J. M. *Efficacy of Speed Monitoring Displays in Increasing Speed Limit Compliance in Highway Work Zones*. Brigham Young University. Theses and Dissertations. Paper 87, 2003.

Carpenter, J., P. Hammond, and J. C. Lenzi. *Law Enforcement in Work Zones: Survey Results, State's Approaches and Lessons Learned*. AASHTO Subcommittee on Construction Annual Meeting, San Francisco, CA, August 16, 2012.

Chen, E., and A. Tarko. *Best Practices for INDOT-Funded Work Zone Police Patrols*. Center for Road Safety, School of Civil Engineering, Purdue University, West Lafayette, IN, 2012.

Chen, E., and A. Tarko. *Programming Police Enforcement in Highway Work Zones,* Center for Road Safety, School of Civil Engineering, Purdue University, West Lafayette, IN., 2013.

Chen, Y., X. Qin, and D. A. Noyce. Evaluation of Strategies to Manage Speed in Highway Work Zones. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.

Gan, A., W. Wu, W. Orabi, and P. Alluri. *Effectiveness of Stationary Police Vehicles with Blue Lights in Freeway Work Zones*, Florida International University, Miami, May 2018.

Guidelines on Use of Law Enforcement in Work Zones, FHWA, U.S. DOT, Washington, D.C., 2011.

Hajbabaie, A., J. C. Medina, M. H. Wang, R. F. Benekohal, and M. Chitturi. Sustained and Halo Effects of Various Speed Reduction Treatments in Highway Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2265, 2011, pp. 118–128.

Lee, B. H. Y., D. Azaria, and S. Neely. *Work Zones and Travel Speeds: The Effects of Uniform Traffic Officers & Other Speed Management Measures*, UVM Transportation Research Center, University of Vermont–Burlington, 2014.

Lindly, J., S. Noorjahan, and S. Hill. *Identification of Potential Enhancements for Work Zone Safety*. Alabama Department of Transportation. April 2002. University Transportation Center for Alabama, University of Alabama, University of Alabama in Birmingham, and University of Alabama at Huntsville, 2002.

McCoy, P.T., and Bonneson, J.A. *Work Zone Safety Device Evaluation*. Report SD-92-10F. Center for Infrastructure Research, Lincoln, Neb., 1993.

MnDOT. *Effectiveness of Law Enforcement in Reducing Vehicle Speeds in Work Zones*, Office of Construction, Construction Programs Section, January 1999.

Ravani, B., C. Wang, W. A. White, and P. Fyhrie. *Evaluation of Methods to Reduce Speed in Work Zones*, AHMCT Research Center, University of California–Davis, 2012.

Richards, S. H., R. C. Wunderlich, and C. L. Dudek. Field Evaluation of Work Zone Speed Control Techniques. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1035, 1985, pp. 66–78.

Srinivasan, S. *Analyzing Effectiveness of Enhanced Penalty Zones and Police Enforcement as Freeway Speed-Control Measures*, Southeast Transportation Center, University of Tennessee, Knoxville, 2011.

Sulbaran, T., and D. Marchman. *Effectiveness of Increased Law Enforcement Surveillance on Work Zone Safety in Mississippi*, University of Southern Mississippi, Hattiesburg, 2007.

Ullman, G. L., and S. D. Schrock. *Feasibility and Design of Enforcement Pullout Areas for Work Zones*, Report No. FHWA/TX-02/2137-2, Texas A&M Transportation Institute, College Station, 2003.

Ullman, G. L., M. A. Brewer, J. E. Bryden, M. O. Corkran, C. W. Hubbs, A. K. Chandra, and K. L. Jeannotte. "NCHRP Project 3-80: Traffic Enforcement Strategies in Work Zones—Final Report." 2010.

Ullman, G. L., M. A. Brewer, J. E. Bryden, M. O. Corkran, C. W. Hubbs, A. K. Chandra, and K. Jeannotte. *NCHRP Report 746: Traffic Enforcement Strategies for Work Zones.* Transportation Research Board of the National Academies, Washington, D.C., 2013.

CHAPTER 5

Demand-Management Strategies

Demand-management strategies include techniques intended to reduce the volume of traffic traveling through the work zone. Demand management focuses on helping people use the infrastructure such as transit, ridesharing, and telework to encourage alternatives to driving. The following strategies are covered in this section:

- Strategies to shift mode of travel
- Strategies to shift time of travel

5.1 Strategies to Shift Mode of Travel

5.1.1 Description

The most common demand-management strategies for encouraging alternative mode choices are

- **Transit service improvements.** Modifies transit schedules or routes, increases in frequency, or establishes transit service in the corridor.
- **Transit/rail incentives.** Uses employer and traveler incentives such as subsidies and guaranteed ride home programs.
- **Shuttle services.** Reduces traffic through a work zone if sufficient users along the corridor can be anticipated to use the service.
- **Ridesharing and carpooling incentives.** Uses rideshare or carpool incentives to reduce the number of vehicles traveling through a work zone. Incentives may include setting aside preferential parking for carpools, adding main-line HOV lanes or bypass lanes on ramps, and providing vanpool vehicles.
- **Park-and-Ride promotion.** Creates, expands, or promotes (i.e., advertises) park-and-ride lots to encourage ridesharing or transit use.

5.1.2 When to Use

Work zones that may be appropriate for strategies to shift mode of travel include the following:

- Work zones in densely populated areas that support a variety of transportation choices.
- Projects in areas with an employment base large enough for agencies to affect travel demand by encouraging options such as teleworking, staggered work hours, flextime, and compressed work weeks.
- High-volume roadways that involve reducing major capacity or using detours.
- Work zones that will be in place for a significant time.
- Roadways that have high commuter traffic with similar origins and destinations.

5.1.3 Benefits

The use of demand-management strategies to shift mode of travel provides the following benefits:

- Reduces single occupancy–vehicle rates, which in turn reduces congestion, RUC, and emissions.
- Exposes less traffic to hazards related to driving through the work zone.
- Decreases workers' exposure to passing vehicles, thus lowering workers' risk of being struck.
- Reduces emergency vehicle response time to crashes.
- Shifts demand to other modes.

5.1.4 Expected Effectiveness

It is difficult to separate the effectiveness of individual strategies within a demand-management program, because these strategies are neither mutually exclusive nor cumulative. However, information from several work zones on which demand-management strategies were used suggests that traffic volumes decreased.

5.1.5 Crash Modification Factor

No CMF is applicable for this strategy.

5.1.6 Implementation Considerations

Several conditions must be in place for the traveling public to consider demand-management strategies advantageous within work zones:

- Alternative commuting options, such as transit, carpooling, vanpooling, bicycling, walking, and teleworking, must exist and be actively publicized.
- Travel times for the alternative commuting modes must be competitive with travel times for single occupancy vehicles.
- Travel alternatives must be convenient and comfortable for users.
- The destination must be walkable or otherwise easily accessible from the alternative mode site, as individuals will be without a vehicle.
- Incentives related to using alternative modes may be necessary, particularly those related to travel cost advantages, such as enticements and subsidies, value pricing, or parking management programs.

A detailed planning phase is crucial to implementing a successful demand-management plan for construction projects. Developing a plan requires selecting the most appropriate strategies and obtaining a commitment from all partners.

Additionally, partnerships with community organizations and businesses are important. Transit agencies can help determine how best to use transportation facilities and services during construction and what additional transit services may be needed. Employers near the work zone can provide traveler information and develop transportation alternatives, such as transit, vanpooling, flexible work hours, and telecommuting.

There are costs associated with specific demand-management strategies, such as costs for improving alternative routes or providing alternative transportation modes. Staff resources are needed to run and manage the program, and project-level staff involved with the construction project will need to provide project-specific information to the agency staff running the demand-management program. Ongoing costs should also include a public outreach campaign.

Public outreach costs can vary widely depending on the media distribution (e.g., television, radio, newspaper, website), the intended length of the campaign (or the project), and the frequency with which messages are disseminated.

5.1.7 Design Features and Requirements

One of the first steps is to identify people willing to try transportation alternatives, which is achieved through commuter surveys. This approach will ensure that resources are spent on individuals most likely to change and will verify that all elements of the demand-management program are captured in one implementation strategy.

Demand-management strategies succeed when combined with complementary strategies. The decision about which demand-management strategy to use for a specific project depends on the target audiences, messages to be communicated, available budget, agency resources and expertise with these strategies, multiple employer bases, and other factors.

Not every work zone requires implementing demand-management strategies before construction begins. Long-term construction projects in densely populated urban areas, which require lane closures for extended periods, are likely to have a more severe effect on traffic operation, and, thus, require more comprehensive demand-management strategies (e.g., temporary or permanent parking facilities; transit, rideshare, and carpool incentives) compared with maintenance projects on low-volume roadways or projects in rural areas.

5.1.8 State of the Practice

The following are examples of demand-management strategies used on construction projects.

5.1.8.1 I-395 Express Lanes Project, Virginia (2018–ongoing)

VDOT introduced a carpool incentive program designed to increase the number of carpools traveling I-395. Pool Rewards used a trip-tracking process through Commuter Connections, the D.C. regional network of transportation authorities, to estimate mileage: participating commuters provided data, namely trip origin, destination, mode use, and travel distance, in program applications and trip logs. New carpoolers received up to $130 over 90 days. To further incentivize carpooling in the I-395 corridor, from January to April 2018, the Pool Rewards program offered participants an additional $100 to join a new three-person carpool or add a third person to a two-person carpool.

5.1.8.2 I-40/I-440 (Fortify 40) Pavement Rehabilitation Project, Raleigh, North Carolina (2014–2016)

The I-40/I-440 Fortify 40 rebuild project was an 11-mi freeway pavement-replacement project in south Raleigh. This section of freeway served between 90,000 and 113,000 vpd and created recurring congestion in several sections within the project limits.

NCDOT allocated $12 million to the transit improvements that added five bus routes, operating only during peak hours (Monday–Friday, 6:00–9:00 a.m. and 3:30–6:30 p.m.). An evaluation of transit service during construction showed an increase of 433 trips per day during construction. Overall trip diversion was greater than 15 percent.

5.1.8.3 US-36 Express Lanes Project, Colorado (2012–2016)

The US-36 Express Lanes Project was a multimodal project led by CDOT and the Denver Regional Transportation District to reconstruct 16 mi of US-36 between Denver and Boulder. Project construction began in 2012 and was completed in 2016.

CDOT developed a construction mitigation plan to encourage travelers to choose sustainable travel modes during construction (36 Commuting Solutions, n.d.). Project components included adding an express high-occupancy toll lane in each direction, road widening, bus rapid transit accommodations, bus bypass ramps at several interchanges, bridge replacements, and a regional bike path. The following are program initiatives:

- **EcoPass Pilot Program.** EcoPass provided free annual transit passes for organizations located within 0.25 mi of three park-and-rides—McCaslin, Broomfield, and Westminster Center. Employers represented in the US-36 Master EcoPass Pilot Program included DoubleTree Hotel, Whole Foods, U.S. Bank, Home Depot, Famous Brands International, Panera Bread, Perkins Restaurant & Bakery, Panda Express, PetSmart, Return Path, and many smaller organizations. The EcoPass was valid for unlimited rides on all local, express, and regional transportation services; light rail; and Call-n-Ride service. In addition, EcoPass holders were eligible for the Guaranteed Ride Home (taxi) program in case of an emergency. The cost of a regional monthly pass outside of this program was $2,112 per year.

  In 2015, 919 employees who worked for 25 employers received EcoPasses. The EcoPasses were free in 2015, and employers received 70 percent off EcoPass contracts in 2016. The pilot program enabled employers to pass on the cost savings of a free transit pass, which also helped with employee retention. Another benefit was to free more parking spaces near employers.
- **Transit.** Solo drivers became eligible to receive a free 10-ride regional ticket book worth $45.
- **Carpool.** Drivers who joined a carpool or started their own were provided a one-time $75 incentive.
- **Vanpool.** Drivers were offered a one-time $75 incentive to subsidize the cost of joining a new vanpool. The savings were significant, especially for Boulder residents or employees who could combine multiple incentives from different organizations. For example, the University of Colorado Boulder offered employees a $15 incentive per month to join a vanpool. The City of Boulder and transportation advocacy organization GO Boulder also offered a $20 incentive per month to residents or employees who vanpooled.

Estimated results of these initiatives include reducing traffic congestion by almost 27,000 vehicle miles of travel per day.

5.1.8.4 826/836 Project, Florida (2009–2016)

FDOT District 6, in partnership with the Miami-Dade Expressway Authority, began a reconstruction project of the SR-826 (Palmetto Expressway) and SR-836 (Dolphin Expressway) Interchange. The project began construction in November 2009 and was completed in 2016. Construction affected 60 percent of all commuters in Miami-Dade County. To assist affected commuters using the 826/836 interchange, South Florida Commuter Services created an incentive program to motivate commuters to use the following alternative modes of transportation:[12]

- **Carpool Incentive Program.** Eligibility required carpooling 12 days or more per month. The monthly incentive was based on the number of individuals in a participating carpool: $50 each for two carpoolers, $100 each for three carpoolers, and $150 each for four or more carpoolers. The carpool incentive began in February 2012. Metrorail riders received a monthly $10 reward card and preferential parking (available on a first-come, first-served basis).
- **Vanpool Incentive Program.** Vanpools, made up of 5 to 15 people who commute together in a passenger van provided by South Florida Vanpools, also qualified for the incentive program. The Miami-Dade Metropolitan Planning Organization provided vanpool groups with a $400 subsidy toward the monthly lease. In addition, the SR 826/836 incentive program

[12] 826/836 Project. South Florida Commuter Services, https://www.commuterservices.com/fdot-unveils-826836-reconstruction-project-incentive-program/, accessed September 5, 2019.

provided qualified vanpool groups with 1 year of subsidies, not to exceed 50 percent of the monthly vanpool rider charge.

- **WeCar.** Registered commuters also received membership in WeCar, an auto-sharing program that allowed commuters to rent a vehicle on a short-term basis. The incentive program provided 10 hours of free WeCar use and waived the annual registration fee. Initially, three vehicles were located in Downtown Miami, Civic Center, and Brickell.
- **Emergency Ride Home Program.** Commuters registered in the incentive programs were also automatically enrolled in the Emergency Ride Home program. In the event of an unexpected emergency, the program provides free taxi service for registered commuters, 24 hours a day, 7 days a week.

From the time the incentive program began in 2012 until May 2013, 774 participants had enrolled in the program, which removed 486 automobiles from the daily commute and eliminated 151,146 trips (Udvardy 2013).

5.1.8.5 Alaskan Way Viaduct and Seawall Replacement Project, Washington (2012–2018)

To keep people and goods moving through King County during construction of the Alaskan Way Viaduct Program, WSDOT improved bus monitoring equipment, provided demand-management services, and enhanced transit and water taxi service:

- WSDOT funded the King County transit authority to continue 30 peak period trips, which helped increase combined peak period transit capacity on these routes by 18 percent.
- West Seattle Water Taxi provided peak-oriented shuttle service. The water taxi attracted nearly 400 riders and provided more than 4,000 additional seats each day between West Seattle and Downtown Seattle.

Transit ridership increased substantially during the project:

- The local public transport system was restructured in Fall 2012: the RapidRide C and D bus lines were introduced, while the free transportation in a section of downtown was phased out, significantly changing service operations in the Seattle area.
- Peak period ridership increased in all routes relative to the baseline by 43 percent, exceeding the system growth rate of 5 percent.
- Routes that received WSDOT funding carried on average 2,600 more people daily during the peak period than during the baseline. The largest change was in response to upgrading the peak and shoulder frequencies from every 15 minutes to every 7–10 minutes on Route 358 between Aurora Village and Downtown Seattle. This improvement, in combination with other factors, resulted in an estimated 1,130 additional weekday boardings during the peak period and 510 additional boardings during the shoulder periods.

The project exceeded five contract targets:

- Promotion of transit and ridesharing eliminated 10,776 trips, exceeding the reduction target of 1,380 trips.
- Incentives for transit and ridesharing eliminated 322 trips, exceeding the reduction target of 236 trips.
- Employer outreach eliminated 1,226 trips, exceeding the reduction target of 100 trips.
- The carpool program eliminated 641 trips, exceeding the reduction target of 370 trips.
- Residential outreach eliminated 451 trips, exceeding the reduction target of 390 trips.

5.1.8.6 Bridge Bucks, Washington, D.C. Metropolitan Area

Bridge Bucks was an incentive program that provided commuters $50 per month to encourage use of alternative means of transportation—bus, rail, carpool, or vanpool—instead of driving alone through the construction zone. Commuters could download the $50 fare media onto an eligible commuter's fare media account for use on whichever transportation alternative best suited their individual commuting needs. The following discusses the use of Bridge Bucks for three separate projects in the Washington, D.C., metropolitan area.

Woodrow Wilson Bridge Project (2004), Virginia. Several demand-management strategies were used to help drivers avoid construction congestion during replacement of the Woodrow Wilson Bridge, which carries I-495 over the Potomac River between Virginia and Maryland. Bridge Bucks provided $50 a month in transit passes for 1 year to commuters who switched from driving to taking buses, trains, or vanpools. Because everyone's commute is unique, Bridge Bucks was designed to be compatible with a variety of travel options, including Washington Metropolitan Area Transit Authority Rail, bus services (e.g., Metro Bus, Maryland Transit Authority, Fairfax County Connector), and organized vanpools. The pilot program was available on a first-come, first-served basis for 1,000 commuters (500 in Maryland, 500 in Virginia).

South Capitol Street Bridge Reconstruction (2007), Washington, D.C. In July and August 2007, the District of Columbia Department of Transportation (DDOT) conducted a major construction project that closed the South Capitol Street Bridge. DDOT partnered with the Washington Metropolitan Area Transit Authority to help ease the burden by encouraging motorists who used the bridge every day to take public transportation during the closure. DDOT started a Bridge Bucks program to compensate motorists affected by the closure. In addition, the transit authority reduced the regular bus fare on the affected route from $1.25 to $0.75, and the express bus fare from $3.00 to $1.25.

New York Avenue Bridge Reconstruction (2011), Washington, D.C. DDOT began construction on the New York Avenue NE Bridge (D.C. Bridge No. 534) in March 2011 and completed the project in October 2013. To mitigate traffic effects resulting from the construction, DDOT operated the New York Avenue Bridge Bucks Program between April 2011 and December 2012 to coincide with the number of lanes being reduced along the bridge. The program was available on a first-come, first-served basis for up to 2,000 eligible commuters per month.

New York Avenue Bridge Bucks averaged 617 applicants over the 19-month period. The highest monthly participation of 785 persons occurred in July 2011. This peak was attributed to D.C. Mayor Vincent Gray discussing during a weekly conference the program and its advantages and encouraging participation.

DDOT developed measures of effectiveness (MOEs) as part of a TMP assessment (Table 5.1). Of note, approximately 94 percent of applicants were approved. The majority of rejections involved commuters already using transit as their primary mode of commuting.

Table 5.1. Bridge Bucks MOEs, New York Avenue bridge reconstruction (2011), Washington, D.C.

MOEs	Number
Applicants	1,570
Approved Applications	1,478
Participants, Cumulative Monthly Basis	11,733
Participants, Monthly Average	617
Primary Mode Choice for Participants	Metrorail
Survey Renewals	1,478
SmarTrip Cards Issued	713
Fare Media Applied to SmarTrip Cards	$377,400
E-mail Inquiries through 3/30/2012	11,580

NOTE: MOE = measure of effectiveness.

On the surface, New York Avenue Bridge Bucks attracted the participation of a very low percentage of the commuters who traveled through the construction zone. However, it did provide commuters with a choice or incentive to use alternative modes to the single occupancy motor vehicle. This choice contributed to goodwill and a positive outlook toward DDOT and the District.

5.1.9 Cost

Costs depend on the type of demand-management strategy provided, the number of participants, and duration. Costs, based on available examples, range from $100,000 to $1 million.

A total of $12 million was allocated to transit improvements on the I-40/I-440 Fortify 40 rebuild project in North Carolina. WSDOT provided King County with $31.9 million to enhance transit and water taxi service, improve bus monitoring equipment, and provide demand-management services during construction of the Alaskan Way Viaduct Program projects.

5.1.10 Resources and References

36 Commuting Solutions, 2014 Annual Review, n.d., http://36commutingsolutions.org/36cs/wp-content/uploads/36-Commuting-Solutions-2014-Annual-Review.pdf.

CDOT. *Transportation Demand Management and Corridor Projects*, Colorado Department of Transportation, February 2002.

DDOT. *New York Avenue NE Bridge over Railroad Tracks Bridge Bucks Technical Memorandum,* District Department of Transportation, March 6, 2013.

Dowling, R., R. Margiotta, H. Cohen, and A. Skabardonis. *Guide for Highway Capacity and Operations Analysis of Active Transportation and Demand Management Strategies,* FHWA-HOP-13-042, FHWA, U.S. DOT, June 2013.

Lee, C., P. Winters, J. Pino, and D. Schultz. *Improving the Cost Effectiveness of Financial Incentives in Managing Travel Demand Management,* Florida Department of Transportation, October 2013.

MnDOT. *Mitigating Highway Construction Impacts with Transit,* Minnesota Department of Transportation, August 2012.

Taylor, K. W., and T. Gren. *Construction Traffic Mitigation Demand Management Evaluation I-405 South Bellevue and Renton Stage 1*, Washington State Department of Transportation, February 1, 2010.

Udvardy, J. 826–836 Incentive Program PowerPoint, South Florida Commuter Services, May 2, 2013. http://www.commuterservices.com/wp-content/uploads/2013/05/Jim-Udvardy-Paying-Commuters-to-Carpool-04.11.13.pdf, accessed September 5, 2019.

WSDOT. *Alaskan Way Viaduct and Seawall Replacement Project Moving Forward Projects Construction Traffic Mitigation—Enhanced Transit, Transit Travel Time and Demand Management Performance Report,* Washington State Department of Transportation, April 22, 2013.

5.2 Strategies to Shift Time of Travel

5.2.1 Description

Employer demand-management programs are employer-sponsored programs designed to reduce single occupancy–vehicle trips to and from the worksite.

The employment transportation market is largely responsible for peak period congestion conditions twice each weekday. As such, modal shifts for these trips can significantly reduce regional vehicle miles traveled (VMT) and carbon emissions, alleviate congestion during peak periods, and improve air quality, all while making better use of the transportation infrastructure throughout the day.

Strategies such as the following allow employees to reduce their number of weekly commute trips and shift work trips to nonpeak times of day.

- **Variable work hours.** This strategy involves allowing employees to offset work hours from the typical 9–5 standard, thus shifting commute travel to variable off-peak hours in order to reduce travel demand during peak periods.
- **Telecommuting.** Telecommuting entails working at home or at a telecommuting center near home, either full or part time. Motorists who normally travel through the work zone are encouraged to telecommute for the duration of the project to reduce the demand.
- **Compressed workweeks.** Employers may also reduce travel demand by enabling employees to compress regularly scheduled hours into fewer workdays per week.

5.2.2 When to Use

Work zones appropriate for strategies to shift time of travel include the following characteristics:

- Commuter traffic is significant.
- Employment and activity centers are located along the affected work zone route or within the vicinity of the work zone.

5.2.3 Benefits

The use of demand-management strategies to shift time of travel provides the following benefits:

- Distributes peak hour commuting over longer time period, thereby reducing travel demand during the peak periods.
- Reduces single occupancy–vehicle rates, which in turn reduces congestion, RUC, and emissions.
- Decreases workers' exposure to passing vehicles, thus lowering workers' risk of being struck.
- Reduces emergency vehicle response time to crashes.
- Shifts demand to other modes.

5.2.4 Expected Effectiveness

The effectiveness of employer demand-management programs varies based on the program elements included, the presence of financial incentives, and the transportation options available for accessing the worksite.

5.2.5 Crash Modification Factor

A CMF is not applicable for this strategy.

5.2.6 Implementation Considerations

Several conditions must be in place for the traveling public to consider demand-management strategies advantageous within work zones:

- Alternative commuting options, such as transit, carpooling, vanpooling, bicycling, walking, and teleworking, must exist and be actively publicized.
- Travel times for the alternative commuting modes must be competitive with travel times for single occupancy vehicles.
- Travel alternatives must be convenient and comfortable for users.
- The destination must be walkable or otherwise easily accessible from the alternative mode site, as individuals will be without a vehicle.

- Incentives related to using alternative modes may be necessary, particularly those related to travel cost advantages, such as enticements and subsidies, value pricing, or parking management programs.

A detailed planning phase is crucial to implementing a successful demand-management plan for construction projects. Developing a plan requires selecting the most appropriate strategies and obtaining a commitment from all partners.

Additionally, partnerships with community organizations and businesses are important. Transit agencies can help determine how best to use transportation facilities and services during construction and what additional transit services may be needed. Employers near the work zone can provide traveler information and develop transportation alternatives, such as transit, vanpooling, flexible work hours, and telecommuting.

There are costs associated with specific demand-management strategies, such as costs for improving alternative routes or providing alternative transportation modes. Staff resources are needed to run and manage the program, and project-level staff involved with the construction project will need to provide project-specific information to the agency staff running the demand-management program. Ongoing costs should also include a public outreach campaign. Public outreach costs can vary widely depending on the media distribution (e.g., television, radio, newspaper, website), the intended length of the campaign (or the project), and the frequency with which messages are disseminated.

5.2.7 Design Features and Requirements

One of the first steps is to identify people willing to try transportation alternatives, which is achieved through commuter surveys to determine who is interested in considering changing their transportation alternatives. This approach will ensure that resources are spent on individuals most likely to change and will make sure all elements of the demand management program are captured in one implementation strategy.

Demand-management strategies succeed when combined with complementary strategies. The decision about which demand-management strategy to use for a specific project depends on the target audiences, messages to be communicated, available budget, existing agency resources and expertise with these strategies, multiple employer bases, and other factors.

Not every work zone requires implementing demand-management strategies before construction begins. Long-term construction projects in densely populated urban areas, which require lane closures for extended periods, are likely to have a more severe effect on traffic operation, and thus require more comprehensive demand-management strategies (e.g., temporary or permanent parking facilities; transit, rideshare, and carpool incentives) compared with maintenance projects on low-volume roadways or projects in rural areas.

5.2.8 State of the Practice

5.2.8.1 826/836 Project, Florida (2009–2016)

FDOT District 6, in partnership with the Miami-Dade Expressway Authority, began a reconstruction project of the SR-826 (Palmetto Expressway) and SR-836 (Dolphin Expressway) Interchange. The project began construction in November 2009 and was completed in 2016. Construction affected 60 percent of all commuters in Miami-Dade County. To assist affected commuters using the 826/836 interchange—430,000 vehicles daily—the project encouraged companies to start a teleworking program by providing free consultant services from a South Florida Commuter Services telework expert. Services included site assessment, recommendations, implementation planning, webinars, and on-site meetings.

5.2.8.2 Washington Commute Trip Reduction Law

The Washington State Legislature passed the Commute Trip Reduction (CTR) Law in 1991 to address traffic congestion, air pollution, and petroleum fuel consumption. In 2006, legislators passed the CTR Efficiency Act, requiring local governments in urban areas with traffic congestion to develop programs that reduce single-driver trips and VMT per capita.

CTR targets workplaces with 100 or more full-time employees in the most congested areas of the state. Employers develop and manage their own programs based on locally adopted goals for reducing vehicle trips and miles traveled and overall congestion. The results of the CTR program include the following:

- Half a million employees at more than 1,000 CTR-affected worksites increased their carpool trip rate from 34.3 percent to 39.1 percent—43 percent higher than the state average and 66 percent higher than the national average. Commuters left about 22,400 automobiles at home every workday, either teleworking or traveling by other means such as bus, vanpool, train, walking, or biking, which reduced traffic.
- The average VMT per surveyed employee declined by 7.4 percent. Overall miles decreased by about 79 million annually. This resulted in a reduction of 3.7 million gallons of fuel, saving commuters almost $10 million in fuel expenditures. This reduced annual greenhouse gas emissions by 33,500 metric tons, the equivalent of 180 rail cars of coal or the same amount of carbon sequestered annually by about 31,500 acres of forest—enough trees to cover almost 60 percent of Seattle.

5.2.9 Cost

The cost of employer demand-management programs depends on the strategy provided, the number of participants, and duration. Costs, based on available examples, range from $100,000 to $1 million.

5.2.10 Resources and References

CDOT. *Transportation Demand Management and Corridor Projects*, Colorado Department of Transportation, February 2002.

DDOT. *New York Avenue NE Bridge over Railroad Tracks Bridge Bucks Technical Memorandum*, District Department of Transportation, March 6, 2013.

Dowling, R., R. Margiotta, H. Cohen, and A. Skabardonis. *Guide for Highway Capacity and Operations Analysis of Active Transportation and Demand Management Strategies,* FHWA-HOP-13-042, FHWA, U.S. DOT, June 2013.

Lee, C., P. Winters, J. Pino, and D. Schultz. *Improving the Cost Effectiveness of Financial Incentives in Managing Travel Demand Management*, Florida Department of Transportation, October 2013.

MnDOT. *Mitigating Highway Construction Impacts with Transit,* Minnesota Department of Transportation, August 2012.

Taylor, K. W., and T. Gren. *Construction Traffic Mitigation Demand Management Evaluation I-405 South Bellevue and Renton Stage 1*, Washington State Department of Transportation, February 1, 2010.

WSDOT. *Alaskan Way Viaduct and Seawall Replacement Project Moving Forward Projects Construction Traffic Mitigation—Enhanced Transit, Transit Travel Time and Demand Management Performance Report*, Washington State Department of Transportation, April 22, 2013.

CHAPTER 6

Control Strategies

"Control strategies" refers to the traffic control approaches employed to efficiently and safely accommodate road users within the work zone or the adjoining corridor, while providing adequate access to the roadway for the required construction, maintenance, or utility work to be performed. This section discusses the following control strategies:

- Full road closure
- Night work
- Two-way traffic on one side of a divided facility (i.e., crossover)

6.1 Full Road Closure

6.1.1 Description

Full road closure involves complete closure of the roadway for various time periods, providing the contractor full access to the roadway and rerouting traffic to nearby facilities.

Agencies commonly use full road closures over two time durations:

- **Full continuous road closure**. This approach involves rerouting all traffic and giving the contractor full access to the roadway with the expectation that construction time will be dramatically reduced. All operations can run continuously—24 hours a day, 7 days a week—which eliminates inefficiencies related to stopping and starting work. Full road closures can greatly reduce the duration of a project and reduce overall traffic exposure to work zones—causing greater disruption to normal travel patterns, though for shorter periods of time.
- **Exclusive weekend closures**. Agencies use weekend closures for only one mobilization and demobilization to occur each week, but for the 55 hours or so that lanes are closed the contractor will need to operate around the clock. Using full closures on weekends helps contractors avoid peak weekday traffic; however, weekend road closures can lead to a longer project duration than a continuous road closure.

6.1.2 When to Use

This strategy applies to many types of construction and maintenance activities and can be implemented on either a long-term or a short-term basis. Although some types of projects, such as complete bridge replacement, usually require long-term closure to traffic, the decision of whether and when to close a roadway is usually based on other factors, such as availability of alternative routes and the need to maintain access to abutting properties and businesses within the work zone. Full road closure may be employed in the following situations:

- Viable alternate routes exist and a full road closure will accelerate construction.
- The project requires reduced construction time.
- Agencies aim to minimize the effect on travelers.

CDOT has developed a full-closure strategic analysis tool to provide staff a uniform decision process to efficiently and effectively evaluate and approve full closures and ensure the agency can successfully implement them. The tool consists of three steps, each of which requires information from the applicant and a response from CDOT traffic staff. Figure 6.1 shows and describes these following steps, and Appendix G provides the Step 1 and Step 2 worksheets:

- **Step 1.** Applicant completes a worksheet describing the basic details of the closure scenario, including location, time, detour routes, and anticipated time savings associated with a full closure instead of phased construction with the highway remaining open. Upon receiving a completed worksheet, CDOT traffic staff uses the listed categories to evaluate the characteristics of the requested closure. Table 6.1 outlines the criteria to be considered, along with a description of how the performance of the closure scenario is to be rated in each category. The Step 1 worksheet provides CDOT staff the basis on whether the closure will be advanced to Step 2. Favorable ratings enhance the likelihood that the closure will be advanced, while

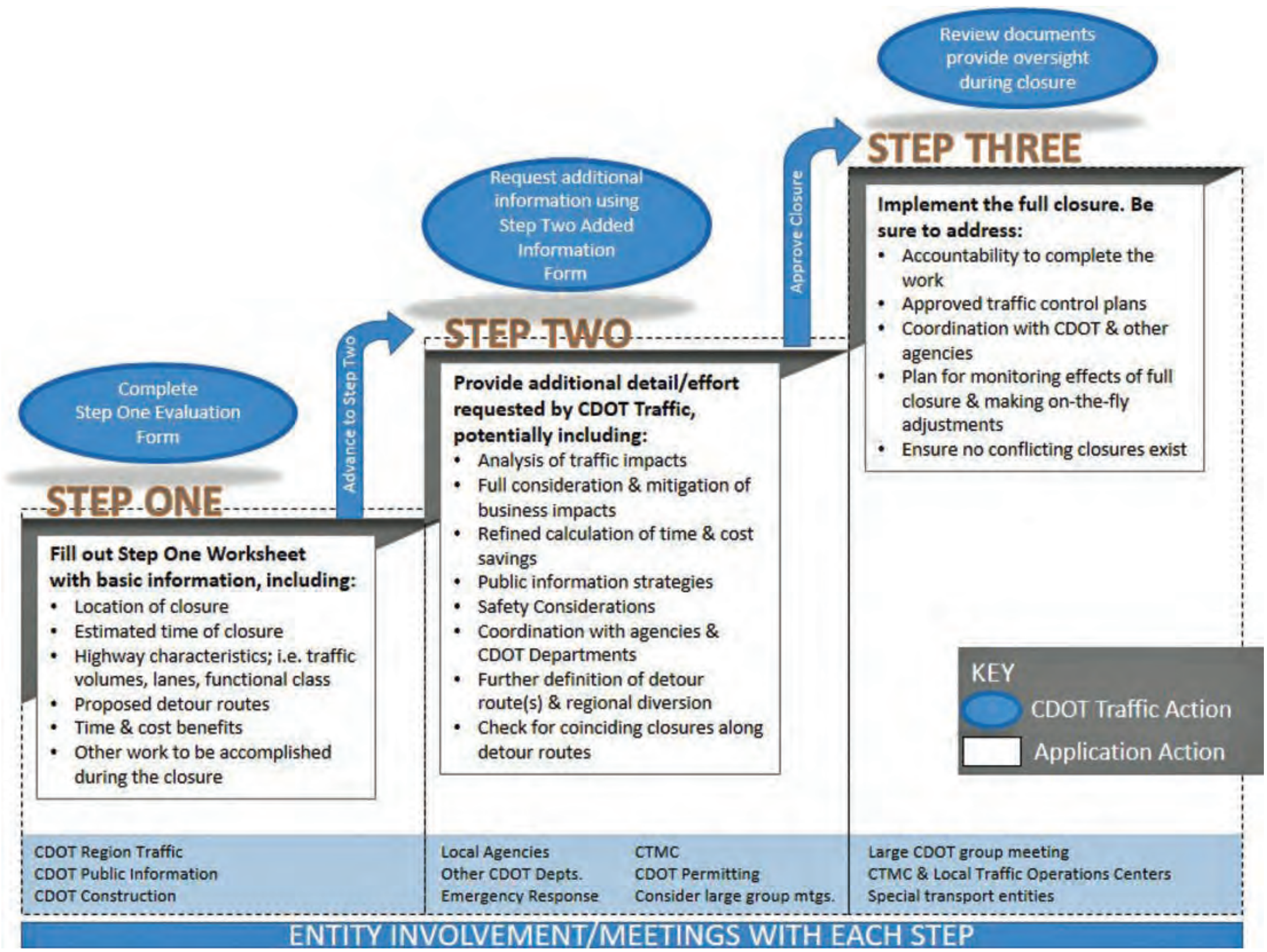


Figure 6.1. Steps involved in full-closure strategic analysis tool (Credit: CDOT).

Table 6.1. CDOT full-closure rating criteria, Step 1.

	Category	Favorable	Fair	Unfavorable
1	Impact to traffic (ADT x # of days, prorated)	<50,000	50,000–100,000	>100,000
2	Functional equivalence of detour roadways	Detour is the same or higher functional class as closed highway	Detour route is a different functional class, but will accommodate traffic in similar fashion to closed highway	Detour route is of functional class below the closed highway
3	Use of state highways as detour routes	Detour route uses all state highways	Detour route uses mixture of state and nonstate highways	Detour route uses all nonstate highways
4	Impacts to businesses and local access	There are no direct, exclusive local accesses to the closed highway segment	Local accesses to the closed highway can be accommodated by equivalent alternate means	One or more exclusive local accesses would be closed by the full closure
5	Travel distance added by detour	3x travel distance or less	3–5x travel distance	5x or more travel distance
6	Local agency coordination	No agency coordination required	1 agency to coordinate with	2 or more local agencies involved
7	Advance public notice	>2 weeks' notice	1–2 weeks' notice	<1 week's notice
8	Potential for diversion out of area	Well known regional travel options present	Limited regional travel options present	Very few good regional travel options present
9	Construction time savings	>30% reduction in construction time	0–30% reduction in construction time	No reduction in construction time
10	Ability to do concurrent work	Other activities can be done that would have required separate, additional full-closure time	Additional activities can be accomplished that would not have required separate, additional full-closure time	No additional activities can be accomplished

Note: ADT = average daily traffic.

unfavorable ratings can result in a request for more information, rejection of the proposed full closure, or significant modification to characteristics of the closure.

- **Step 2.** CDOT traffic staff use the Step 2 added information form to request the applicant provide additional information CDOT needs to better understand implementation of the closure. Additional information may be needed to evaluate project effects on traffic and businesses, describe traffic safety conditions, or define the detour routes or regional diversions. Upon receipt of the additional information, CDOT traffic staff will consider the closure scenario and determine whether the closure should advance to Step 3. It is possible that the closure will be denied based on Step 2 findings.
- **Step 3.** As Figure 6.1 shows, closures advanced by CDOT to Step 3 will be approved, even though several items may need to be addressed to ensure successful implementation. CDOT and the applicant will work together to ensure contractor accountability, monitoring of closure effects, and agency coordination.

6.1.3 Benefits

The use of full road closures provides the following benefits:

- Faster project delivery.
- Reduced inconvenience to motorists.
- Larger working area and increased productivity.
- Improved project quality from the reduction in the number of joints and seams potentially needing future maintenance.
- Reduced exposure for construction personnel and road users.

6.1.4 Expected Effectiveness

The FHWA study, *Full Road Closure for Work Zone Operations* (2003), examined six projects that used full road closures and reported a significant reduction in project duration (Figure 6.2). According to the study, the average duration reduction resulting from the use of full road closure was 76.5 percent, compared with part-width construction using traditional maintenance of traffic.

The reduced duration of full road closure projects translates into less traffic exposure, thereby eliminating crashes involving drivers and workers within the work zone. However, there may be an increase in crashes on the detour routes.

6.1.5 Crash Modification Factor

No CMF is applicable for this strategy.

6.1.6 Implementation Considerations

With full lane closures, agencies also need to consider other factors, such as the following:

- City/county agencies and personnel often need to be convinced of the feasibility of implementing full road closure and the potential benefits that can be realized, compared with traditional means of performing rehabilitation under traffic.
- Full-closure projects typically operate on an accelerated schedule. Before letting a project, the agency should consider the contractor's ability to provide adequate resources (e.g., materials, equipment, crew) to maintain an accelerated pace.
- The availability of detour routes to accommodate oversize, over-height, or overweight trucks is crucial and requires good communication and outreach to truck drivers and trucking associations to secure their buy-in.
- Effects on business or entertainment venues can be a factor. Many projects have planned closures around events and considered adverse effects to businesses during the planning process. Such planning helps to ensure a successful project.

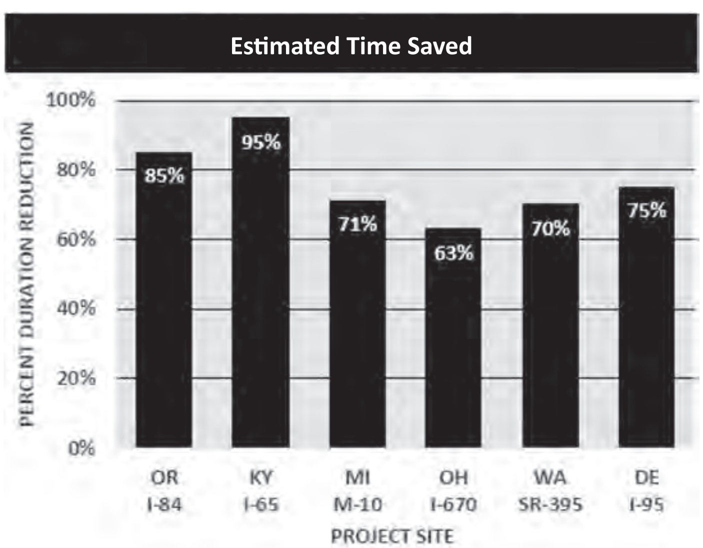


Figure 6.2. Estimated time saved: project days for full road closure versus estimated days with traditional maintenance of traffic (Credit: FHWA).

- Full-closure projects are often scheduled on a 24-hour work basis, so there is potential for adverse impacts to local residents, including noise and light pollution.
- Agencies and public information campaigns should encourage road users to consider public transportation alternatives on detour routes, where available. Arranging special provisions or incentives for the traveling public to use public transportation can have a marked effect on highway operations. In addition, demand-management techniques may be considered to ensure that alternative highway routes are not overloaded.

Potential drawbacks of full road and weekend closures include

- Significant short-term travel effects for the public.
- Increased traffic congestion on other routes.
- Need to construct a detour or runaround.
- Adverse effect on businesses relating to trip suppression (not enough traffic).
- Adverse effect on businesses on alternative routes (too much traffic).

(See Section 9.2, Lighting Devices, for other nighttime work zone considerations.)

6.1.7 Design Features and Requirements

The following requirements should be considered during the design of the full road closure:

- Detour routes are needed during a full road closure when the original road is closed.
- Detour routes should avoid creating unreasonable travel distances and delays.
- Full road closures are considered successful when the detour design results in acceptable delays (either through increased travel distances or congestion).
- Detour routes must have reserve capacity to be able to handle the increased traffic without creating significant delays. Agencies may need to consider improvements to the alternative route, such as temporarily removing curbside parking, adding lanes, improving traffic signals, and removing geometric bottle necks.
- Extensive public outreach campaigns are needed to publicize detours and distribute detour information through a variety of media.
- Special events such as holidays, sporting events, and concerts on planned road closures and alternate route options need to be considered.

6.1.8 State of the Practice

Currently, state transportation departments consider full-closure opportunities on a case-by-case basis and apply engineering judgment and various factors to weigh the decision. As described in the following examples, several DOTs have let and built projects using full road closures.

- **South Carolina (I-385 rehabilitation).** In January 2010, the South Carolina Department of Transportation (SCDOT) closed 15 mi of I-385 in Laurens County for rehabilitation. This was the first time SCDOT implemented full road closure for a nonemergency project. Doing so allowed SCDOT to complete the project in less than 8 months instead of 3 years if lanes were kept open and saved more than $34 million. The rehabilitated stretch of I-385 officially reopened on July 23, 2010—3 weeks ahead of the 8-month schedule—and under budget.
- **Michigan (M-10 Lodge Freeway, Fix Detroit 6 Program).** During the M-10 rehabilitation project, MDOT used a bidirectional full closure to ensure the project would be completed in one season. This project was part of the Fix Detroit 6 program that coordinated six high-profile

projects in the Detroit area during the 2002 and 2003 construction seasons. The traffic in the direction of the closure was detoured off the freeway.
  – Estimated duration without full closure: 6 months.
  – Actual duration with full closure: 53 days.
- **Delaware (I-95, Wilmington**). To expedite construction time, the Delaware DOT (DelDOT) chose a full closure for the 6.1-mi rehabilitation project because an alternate route, I-45, had sufficient capacity.
  – Estimated duration without full closure: 2 years.
  – Actual duration with full closure: 185 days.
- **Kansas** (**Route 458 rehabilitation project, Douglas County).** Route 458 between N 1050 Road and N 1116 Road was closed for 8 weeks for construction of two large culverts. A signed detour was in place during the full road closure.
- **California (Avenue 11 in Madera County).** The California High-Speed Rail Authority closed Avenue 11 in Madera County for 18 months as part of constructing an overcrossing to eliminate an at-grade crossing and allow vehicles to travel over the high-speed rail alignment and BNSF railroad tracks.
- **Oregon (I-84 Banfield Freeway, Portland).** The Oregon DOT used directional road closures over two consecutive weekends instead of using the traditional part-width night construction.
  – Estimated duration without full closure: 320 hours, or 32 nights for nighttime-only work.
  – Actual duration with full closure: 112 hours.
- **Georgia (I-285, between I-675 and I-20, Atlanta**). GDOT chose to use directional full weekend road closures on the 64-lane-mile project to reduce traffic impact. The project included a public information campaign that involved media campaigns, mass mailings, community meetings, and dynamic signing. The contractors paved an average of 8 mi each weekend. Because there were no vehicles on the directional road closure, trucks did not have to wait in traffic, which ensured a constant flow of material to the worksite.
  – Estimated duration without full closure: 2 years.
  – Actual duration with full closure: 12 weekends, 6 for each direction.

6.1.9 Cost

The cost to implement a full roadway closure depends on many factors, including any upgrades needed for the detoured route plus ongoing maintenance and traffic monitoring; supporting traffic control devices on both the main line and the detoured route; public outreach that takes into consideration the extent of the influence area; and RUC.

6.1.10 Resources and References

Babcock, M. W., and A. Alakshendra. Methodology to Measure the Benefits and Costs of Rural Road Closure: A Kansas Case Study, *Journal of the Transportation Research Forum*, Vol. 51, No. 1, Spring 2012, pp. 111–130.

Del Rosario, Z., E. Kaing, B. D. Taylor, and M. Wachs. *Why It Wasn't "Carmageddon": An Analysis of the Summer 2011 Closure of the Interstate 405 Freeway in Los Angeles,* Institute of Transportation Studies, University of California at Los Angeles, August 26, 2012.

DeVries, L., S. Hersey, A. Tesfaye, and D. Reeves. *Full Closure Strategic Analysis,* CDOT-2014-7, Colorado Department of Transportation, July 2014.

FHWA. *Full Road Closure for Work Zone Operations: A Cross-Cutting Study,* FHWA-OP-04-009, FHWA, U.S. DOT, August, 2003.

Hourdos, J., and F. Hong. *TH-36 Full Closure Construction: Evaluation of Traffic Operations Alternatives*, MN/RC 2010-04, Minnesota Department of Transportation, January 2010.

Lee, E-L., J. T. Harvey, and D. Thomas. Integrated Design/Construction/Operations Analysis for Fast-Track Urban Freeway Reconstruction, *Journal of Construction Engineering and Management*, ASCE, Vol. 131 (12), 2012, pp. 1283–1291.

McGowen, T. The Biggest Freeway Closure in the Car Capital of the World: A Brief Case Study, *Journal of the Transportation Research Forum*, Vol. 51, No. 1, Spring 2012, pp. 111–130.
Vergara, D. *Transportation Management Plan Empire/Burbank and Railroad Tracks Project,* State of California Department of Transportation, July 2013.

6.2 Night Work

6.2.1 Description

"Night work" refers to work performed at night (i.e., end of evening peak period to beginning or morning peak period) to minimize work zone impacts on traffic and adjacent businesses. Night work must be undertaken using the appropriate lighting devices. Refer to Section 9.2 for information on work zone lighting devices.

6.2.2 When to Use

The decision of whether to perform work at night should involve a comprehensive cost-effectiveness evaluation that considers the implications of each alternative (including active night work) with respect to three key impact factors:

1. On the community and traffic (business operations, pedestrians and bicyclists, emissions, public transit, emergency services, noise effects, lighting and glare effects, traffic diversion impacts, etc.).
2. On safety (worker and motorist safety).
3. On constructability (worker efficiency, lighting plan quality, and materials and equipment availability).

Night work will increase the amount of mobilization and demobilization, as it will recur every day.

Night work is appropriate at project sites that have lower traffic volumes at night than during the day, when work may be easier or safer. The primary objectives of work zone traffic control are ensuring an acceptable level of safety for workers and road users, minimizing adverse effects on traffic flow and the community, and allowing the project to be completed on schedule and at an acceptable level of quality. If these objectives cannot be met during daytime construction, nighttime work may be appropriate (Antonucci et al. 2005).

EVALUNITE is a simple software package, developed in 2004 for IDOT, to evaluate the suitability of nighttime work for highway projects.

The software was developed using Microsoft Excel and Visual Basic for Applications. The software has a user-friendly interface that leads the user through the process of data input and running the model in a simple and clear manner. The input data are case sensitive and may differ greatly from one project to another. Therefore, most input variables are user-specified. However, default values were set for these variables in case the required information is not available to the user. This feature is useful, as it is quite likely that users will not have all the input data, especially at the planning stage of the project. In determining these default values, developers attempted to identify realistic estimates for many parameters based on previous studies and the results of state DOT questionnaire surveys.

Using the priorities and objectives set by the agency, the model comes up with a recommendation concerning the use of night shifts in highway projects. The model consists mainly of two main modules—the cost module and the effectiveness module.

The cost module consists of three different cost models—a traffic delay model (Figure 6.3), an accident cost model (Figure 6.4), and a construction cost model (Figure 6.5). The cost modules assess all the variables that can be quantified using dollar values.

The effectiveness module considers three main qualitative aspects: (1) environmental and social factors, (2) safety factors, and (3) construction-related factors. A number of factors were identified in relation to each aspect. The environmental aspects include factors such as noise disturbance, economic impacts on surrounding business, light glare to motorists, and air pollution. The safety aspects relate to workers' safety only, as the motorists' safety is considered in the accident cost model. The construction-related factors are materials and equipment availability, freedom to plan lane closures, work quality, and temperature (Figure 6.6).

By comparing the total expected cost, which includes the delay, accident, and construction costs, to the effectiveness of each alternative, agencies can use the tool to make the decision of nighttime versus daytime construction. Therefore, it is important to determine a total score for the effectiveness of each alternative (daytime and nighttime) and use that score in conjunction

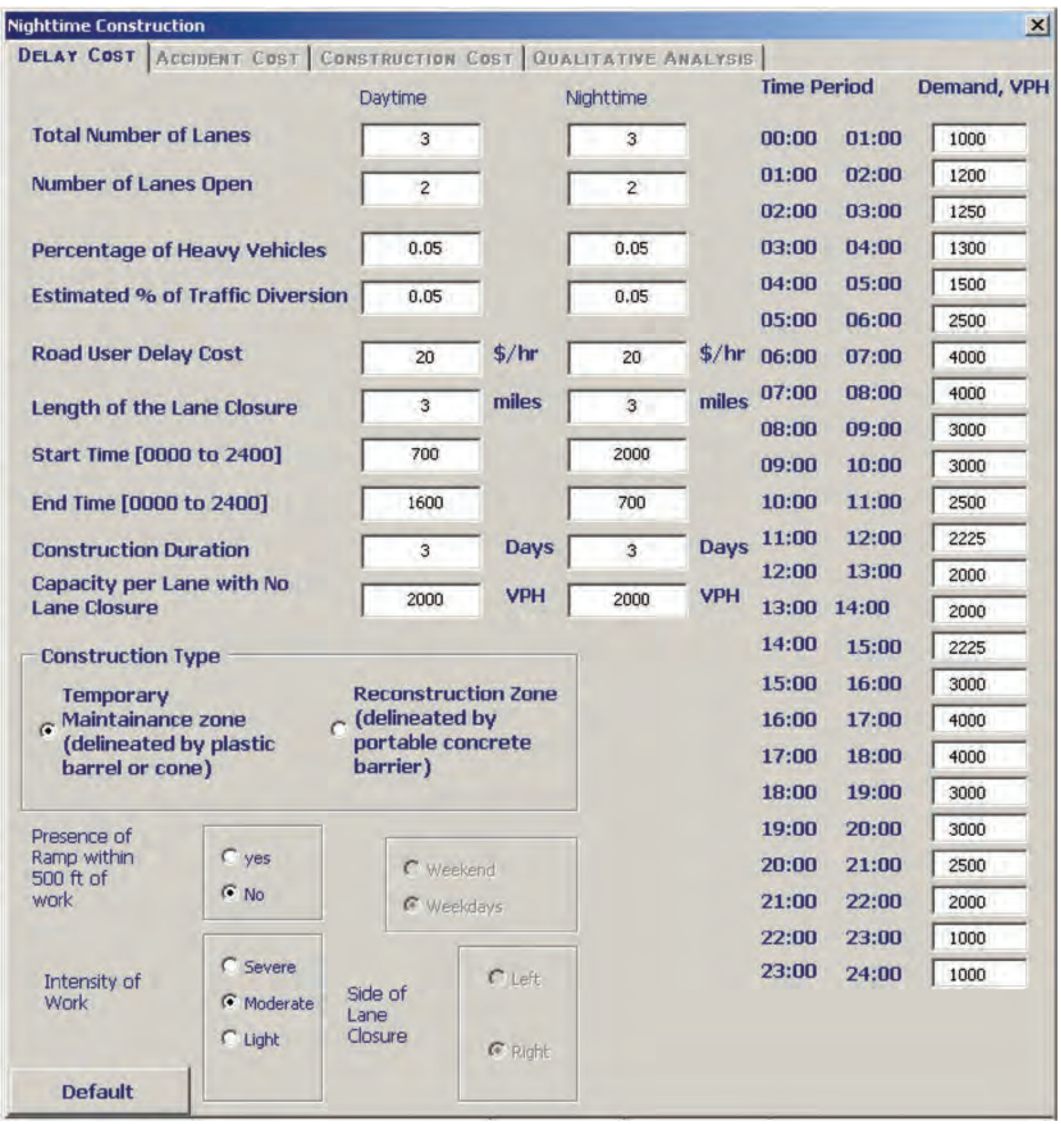


Figure 6.3. Traffic delay model user interface (Credit: IDOT).

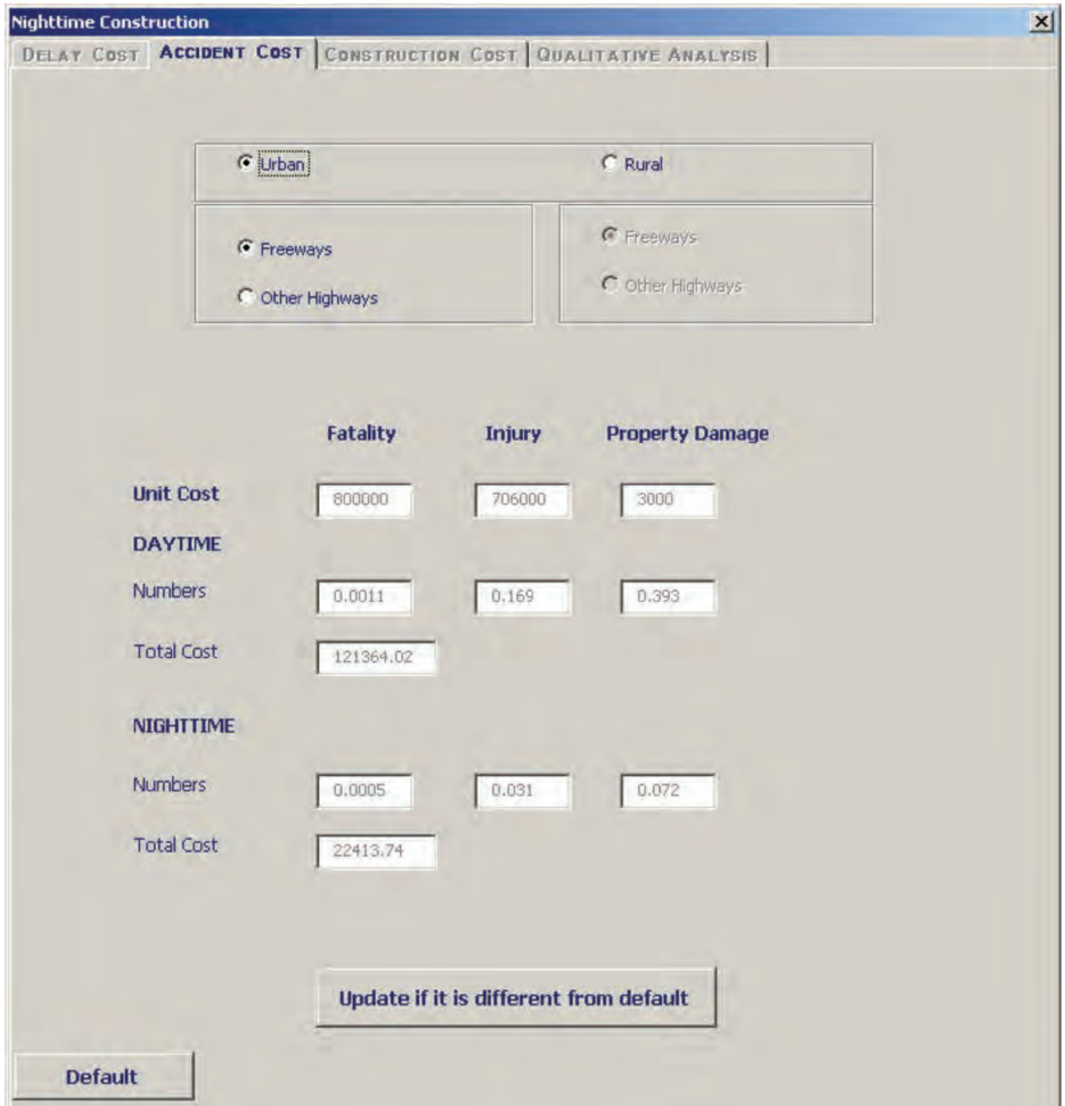


Figure 6.4. Accident cost user interface (Credit: IDOT).

with the total cost to make the decision. Agencies can use different methods, depending on the decision-maker's preference and the particular situation, to combine the score of each factor and its relative importance weight to find the combined score.

6.2.3 Benefits

The use of night work provides the following benefits:

- The effects of roadwork on traffic congestion and motorist delays can be significantly reduced or avoided.
- The work zone is more flexible because traffic interference is reduced.
- Quality can be achieved when sufficient lighting is provided. Cooler temperatures can enhance the quality of the concrete set at night.
- Less traffic interference and longer work shifts can positively affect productivity and efficiency.
- More lanes can be temporarily closed to accommodate work activities.
- Lanes can be closed for a longer duration, improving efficiency and reducing completion time.

Figure 6.5. Construction cost user interface (Credit: IDOT).

6.2.4 Expected Effectiveness

NCHRP Report 627: Traffic Safety Evaluation of Nighttime and Daytime Work Zones (Ullman et al. 2008) examined crash risk and type related to nighttime and daytime roadwork. The report's findings indicated that night work does not result in a significantly greater crash risk for an individual motorist traveling through the work zone than does day work. The increases in crash risk for work operations requiring the temporary closure of travel lanes were essentially identical when performed at night or during the day. In addition, traffic crashes that occur in nighttime work zones were not necessarily more severe than those that occur in similar daytime work zones—again when compared across similar work operations. The implications of these findings are that work activities that require temporary lane closures have substantially lower total safety effects on the motoring public when the work is done at night. The lower traffic volumes at night result in a much lower number of crashes occurring over a work operation of a given duration.

Although the increased risk of a crash is similar, *NCHRP Report 627* also reported that differences do exist in the types of crashes that occur at nighttime and daytime work zones. For example, based on the NYSDOT work zone traffic-crash and worker-accident database,

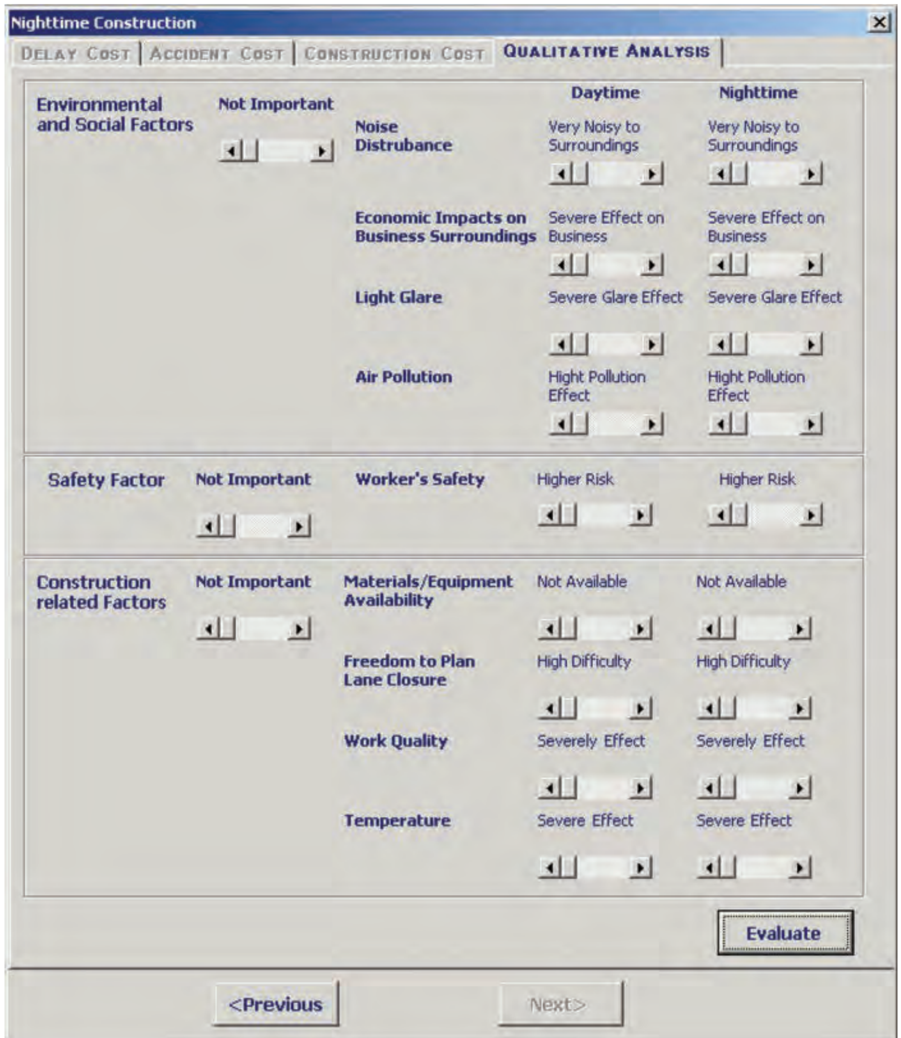


Figure 6.6. Qualitative analysis user interface (Credit: IDOT).

traffic crashes involving workers, construction vehicles or equipment, and construction materials and debris (both intrusion and non-intrusion crashes) comprise a greater percentage of crashes at night than during the day. Although the relative percentage of these crashes was higher at night, they were only a small proportion of the total work zone crashes in either time period.

6.2.5 Crash Modification Factor

Table 6.2 shows CMFs for night work. Chapter 13 provides more information on developing work zone CMFs.

6.2.6 Implementation Considerations

Scheduling construction activities during nighttime, when traffic demand is typically at its lowest, is viewed by many transportation agencies as an effective strategy to alleviate the negative effects of work zones on the traveling public. However, this argument addresses only one aspect of road construction related to traffic congestion and delay. Nighttime operations also affect other aspects that need to be considered. Some of these aspects are construction related, such as work productivity, work quality, worker safety, and construction costs; others relate to traffic

Table 6.2. CMFs for night work.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error
Work zone with one or more lanes closed (workers present)					
Nighttime	All	Freeways and expressways	All	1.61	0.06
Nighttime	Injury	Freeways and expressways	All	1.42	0.09
Work zone with no lanes closed (workers present)					
Nighttime	All	Freeways and expressways	All	1.58	0.15
Nighttime	Injury	Freeways and expressways	All	1.41	0.23

Note: Nighttime crashes were defined as those occurring from 7:00 p.m. to 6:00 a.m. The CMF calculation did not examine the difference in safety effects between the closure of a single lane and the closure of multiple lanes. Also, the CMF calculation did not consider initial lane configuration of the roadway. Because the CMFs were calculated for periods when workers were present, they may overestimate crashes if applied to all periods when the work zone is in place. It is possible that the presence of workers may induce rubbernecking and additional distractions that would increase crashes relative to times when the work zone is in place, but no construction or maintenance activities are under way. CMF = crash modification factor.

and worker safety, impacts on neighboring communities and businesses, air quality, and energy conservation. Therefore, agencies need to consider all these important aspects for a specific situation before they can make an informed decision on nighttime construction.

6.2.7 Design Features and Requirements

Nighttime construction requires a detailed illumination plan, careful work planning and sequencing, traffic control, and nuisance-mitigation planning.

Workers need to be aware of additional risks associated with night work; therefore, additional safety training may be needed before starting night work.

Agencies should review the TCDs at night to ensure they are in proper condition and are visible under night conditions.

Construction work zone lighting and glare specifications should identify appropriate levels of lighting based on work tasks. In addition, the agency will need practical methods for inspecting nighttime work zone lighting arrangements.

6.2.8 State of the Practice

Transportation agencies routinely use nighttime construction to conduct highway maintenance and reconstruction projects. However, a literature search showed that no uniform guidelines or procedures currently exist at the national level to assist agencies in making decisions on when to employ nighttime operations.

Decisions to conduct maintenance operations at night vary from state to state and transportation agencies consider nighttime opportunities on a case-by-case basis, applying engineering judgment and various factors to weigh the decision.

6.2.9 Cost

Night work is more expensive than equivalent daytime activities; however, the potential for greater productivity is high.

6.2.10 Resources and References

Antonucci, N. D., K. K. Hardy, J. E. Bryden, T. R. Neuman, R. Pfefer, and K. Slack. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 17: A Guide for Reducing Work Zone Collisions.* Transportation Research Board of the National Academies, Washington, D.C., 2005.

Bhagavathula, R., R. Gibbons, A. Medina, and T. Terry. *Examination of the Current Practice of Lighting in Virginia: Nighttime Work Zones and Improving Safety Through the Development of Nighttime Lighting Specifications: Summary Report,* FHWA/VTRC 18-R4, Virginia Department of Transportation, September 2017.

Bryden, J. E., and D. J. Mace. *NCHRP Report 475: A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance.* TRB, National Research Council, Washington, D.C., 2002.

Ellis, R. D., Jr., S. Amos, and A. Kumar. *NCHRP Report 498: Illumination Guidelines for Nighttime Highway Work.* Transportation Research Board of the National Academies, Washington, D.C., 2003.

Elrahman, O. A. *Night-Time Road Construction Operations Synthesis of Practice.* New York State Department of Transportation, May 2008.

Finley, M. D., G. L. Ullman, J. D. Miles, and M. P. Pratt. *Studies to Assess the Impact of Nighttime Work Zone Lighting on Motorists,* FHWA/TX-13/0-6641-1, Texas A&M Transportation Institute, May 2013.

Freyssinier, J. P., J. D. Bullough, and M. S. Rea. *Documentation of Semi-Permanent High-Mast Lighting for Construction*, C-05-06. New York State Department of Transportation, September 2006.

Gates, T. J., P. T. Savolainen, T. K. Datta, and P. Nannapaneni. Differences in Nighttime Luminance of Work Zone Drums with and without Steady-Burn Warning Lights. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2258, 2011, pp. 16–24.

Khaled, E-R., L. Y. Liu, L. Soibelman, and K. Hyari. *Nighttime Construction: Evaluation of Lighting for Highway Construction Operations in Illinois,* Report No. ITRC FR 00/01-2, Illinois Transportation Research Center, Illinois Department of Transportation, August 2003.

McAvoy, D. S., K. L. Schattler, and T. K. Datta. Driving Simulator Validation for Nighttime Construction Work Zone Devices. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2015, 2007, pp. 53-63.

Nighttime Lighting Guidelines for Work Zones: A Guide for Developing a Lighting Plan for Nighttime Work Zones, American Traffic Safety Services Association, April 2013.

Pesti, G., P. Wiles, R. L. (K.) Cheu, P. Songchitruksa, J. Shelton, and S. Cooner. *Traffic Control Strategies for Congested Freeways and Work Zones,* FHWA/TX-08/0-5326-2. Transportation Institute, Texas A&M Transportation Institute, November 2007.

Rebholz, F. E., A. Al-Kaisy, K. Nassar, L. Liu, L. Soibelman, and K. El-Rayes. *Developing a Decision Support Tool for Nighttime Construction in Highway Projects*, ITRC FR 00/01-5, Illinois Transportation Research Center, May 2004.

Shane, J. S., A. Kandil, and C. J. Schexnayder. *NCHRP Report 726: A Guidebook for Nighttime Construction—Impacts on Safety, Quality, and Productivity.* Transportation Research Board of the National Academies, Washington, D.C., 2012.

Ullman, G. L., M. D. Finley, J. E. Bryden, R. Srinivasan, and F. M. Council. *NCHRP Report 627: Traffic Safety Evaluation of Nighttime and Daytime Work Zones.* Transportation Research Board of the National Academies, Washington, D.C., 2008.

Ullman, G. L., M. D. Finley, and B. R. Ullman. *Assessing the Safety Impacts of Active Night Work Zones in Texas*, FHWA/TX-05/0-4747-1, Texas A&M Transportation Institute, October 2004.

Ullman, G. L., B. R. Ullman, and M. D. Finley. *Evaluating the Safety Risk of Active Night Work Zones*, FHWA/TX-05/0-4747-2, Texas Transportation Institute, Texas A&M University Transportation Institute, April 2005.

Vecellio, R. L., and J. R. McCarthy. *Lighting Specifications for Nighttime Construction Work Zones on Active Highways*, Alabama Department of Transportation, December 2006.

6.3 Two-Way Traffic on One Side of a Divided Facility (i.e., Crossover)

6.3.1 Description

This strategy involves closing one side of a divided multilane highway and moving all traffic to the other side as a two-way operation (often with a median barrier separating opposing traffic flows to prevent head-on collisions). This strategy allows work activities to occur on the closed side, separated from traffic by a significant distance. In some instances, crossovers will need to make full use of all pavement on the other side, including shoulders, to maximize traffic capacity provided.

6.3.2 When to Use

The use of crossover should be considered under the following situations:

- The project has a long duration.
- Opposing traffic lanes do not carry peak hour traffic.
- Projects have multiple construction stages or phasing.
- Worker safety is at risk.
- Detour routes and adequate median or shoulder width are not available.

6.3.3 Benefits

The use of median closures provides the following benefits:

- A median crossover maintains traffic flow within the agency's ROW, reducing the effects on nearby alternative routes.
- A median crossover removes all traffic from the work area and allows the contractor better control of the work operation. Better-quality work may extend pavement and bridge deck service lives and reduce the frequency and extent of future maintenance and reconstruction operations.
- Wider temporary lane widths resulting from median crossovers may better accommodate wide loads and could mean the difference between allowing them on site as opposed to detouring them off site.
- Agencies may realize cost savings if some crossovers on freeway projects are left in place after the project is completed. Because these crossovers are designed to carry Interstate traffic, they are constructed with a high-type pavement that adds to the cost. If crossovers are left in place, this cost may be partially recovered as a cost savings to future construction.
- Crossovers also leave options open for emergency construction and remain available for future operations plans, including incident management. Crossovers that remain in place after construction require traffic control to alert drivers that the crossover is not open and that using the crossover is not allowed.

6.3.4 Expected Effectiveness

No studies were found that evaluated the effectiveness of median crossovers in work zones.

6.3.5 Crash Modification Factor

No CMF is applicable for this strategy.

6.3.6 Implementation Considerations

A median crossover requires special consideration in the planning, design, and work phases because unique operational problems (e.g., an increase in the risk of head-on crashes) can arise. The following are some considerations for designers when assessing the use of median crossovers:

- Will the crossover result in restricting traffic in a reduced lane configuration longer than would a conventionally staged operation?
- Can temporary lanes be constructed in the median?
- Will selecting a crossover result in a shorter contract time?
- Can the work be accomplished without crossover? If considering another option, will it cause an additional safety risk to TTC zone personnel?

- Will a restricted section create difficulties for emergency vehicles when passing through or responding to accidents in, or downstream of, a crossover segment? Pullouts at 1-mi intervals are suggested for disabled vehicles, incident management staging, and law enforcement vehicles. Agencies should also consider using courtesy patrols for disabled vehicles and incident management.
- Will a crossover add capacity? It is important to first verify that a median crossover strategy can provide adequate traffic capacity.
- Will using crossovers significantly increase the project cost? Agencies will need to construct temporary pavement in the median of the roadway at both ends of the project, which adds to the overall project cost.

The primary consideration when selecting crossover locations is traffic needs. A tangent section on flat terrain is the most desirable location for constructing a crossover.

DOTs also need to ensure that newly created roadside hazards are adequately protected, and that work area access points near and in the crossovers are adequately designed and delineated.

One disadvantage of crossover construction is that temporary pavement will be necessary at each exchange to provide entrance and exit ramp access in the direction of travel of the shifted traffic. Crossover construction is most beneficial on projects where ramp access is not mandatory.

6.3.7 Design Features and Requirements

The guidance for permanent design for alignment, barriers, delineation, and illumination applies to the design for elements of temporary crossovers. The 2009 MUTCD (Section 6G.16) provides the following guidance for the design of crossovers, as well as a general crossover diagram (Figure 6H-39):

- Separate tapers from lane drops from the crossovers.
- Design crossovers for speeds no lower than 10 mph below the posted speed, the off-peak 85th percentile speed before the work started, or the anticipated operating speed of the roadway, unless unusual site conditions require a lower design speed.
- Use a good array of channelizing devices, delineators, and full-length, properly placed pavement markings to provide drivers with a clearly defined travel path.
- Design the crossover to accommodate all vehicular traffic, including trucks and buses.

Transportation agencies may also consider the following additional design elements for installing a crossover:

- Many times, the median becomes a location where waste material or other debris is deposited. There is no way to know the soil characteristics without a subsurface exploration/investigation in the crossover area, which may include power or hand borings.
- The typical temporary crossover roadway has a 4:1 side slope.
- A sag curve needs to be provided in the crossover between the main-line roadways. This can become more challenging when the main-line roadways are at different elevations and the median width is narrow. Drainage must flow away from each main-line roadway to prevent water or ice from accumulating.
- Profile elevations are shown in each direction and on each side of the proposed roadway, typically where the pavement marking edgeline would be installed. Typically, elevations are provided at least every 50 ft along curved sections and every 100 ft along tangent sections.
- As the crossover is a large impermeable area and it is generally difficult to remove surface water from the pavement quickly, agencies need to prevent concentrated flow drainage patterns.

- Temporary barriers are used to separate the two directions of traffic. Both directions of traffic need appropriate deflection distance; if this is not possible, barriers need to be pinned as per state standards.
- Temporary illumination may be considered, to improve visibility at the crossover locations.
- Requirements might also address advisory speed (or speed reduction) on approach to crossover, lane width through the crossover point, temporary pavement markings, removal of conflicting markings, and construction signs.
- A systematic evaluation is needed to evaluate whether contraflow traffic using the crossover will have an adverse effect on the existing roadway safety hardware (guardrail, crash cushions, etc.).

6.3.8 State of the Practice

The standards and specifications for Iowa, Washington, Montana, Connecticut, Ohio, Wisconsin, and New York include specific guidance for the design of work zone crossovers. However, only NYSDOT has a specific policy to consider median crossovers as an alternative method of work zone traffic control.

6.3.9 Cost

The cost of installing a crossover depends on many factors, including soil characteristics, drainage requirements, elevation difference, and condition of the crossover lane or the need to widen lanes to adequately accommodate crossover traffic.

6.3.10 Resources and References

Highway Design Manual Revision No. 85, Chapter 16—Maintenance and Protection of Traffic in Highway Work Zones (Limited Revision), *Engineering Bulletin (EB 16-017)*, New York State Department of Transportation, April 2016.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Schurr, K. S., B. R. Gardner, and S. Rijal. *Optimal Design of Work Zone Median Crossovers*, NDOR Research Project Number SPR-P1(06) P581, September 2010.

WisDOT. *Facilities Development Manual (FDM) 11-50-5 Transportation Management Plan Process*, Wisconsin Department of Transportation, May 15, 2019.

CHAPTER 7

Project Coordination

7.1 Description

"Project coordination" (PC) refers to the various strategies and actions undertaken to coordinate with other projects, utilities, and ROWs.

Although they reduce the delays in starting a project or eliminate conflict between agencies, utilities coordination and ROW coordination fall outside the realm of work zone safety and mobility. These activities focus on the effects of a single project, rather than on reducing the combined effect of two or more projects, which more typically defines what is meant by PC.

7.2 When to Use

"PC," as discussed in this section, strictly refers to the coordination within a single project or among multiple projects within a corridor, a region, and possibly across agency jurisdictions, to minimize work zone impacts and produce time and cost savings. PC can occur during project planning and design as well as during the construction stage.

In the planning stage, PC typically focuses on scheduling and sequencing projects to minimize project effects to drivers, stakeholders, and the community. During the construction stage, PC activities emphasize identifying and monitoring the day-to-day work activities that adversely affect the transportation network and finding ways to mitigate the combined effects of those activities across multiple projects.

FHWA (Theiss, Ullman, and Moinet 2016) developed a matrix that identifies examples of PC activities by project phase (Table 7.1).

7.3 Benefits

According to the FHWA *Guide to Project Coordination for Minimizing Work Zone Mobility Impacts* (Theiss, Ullman, and Moinet 2016), PC provides significant cost savings, ability to identify projects earlier, opportunity to reduce and manage traffic disruptions across projects, and ability to improve road-surface quality. Specific benefits include the following:

- Sequencing the order in which multiple projects are completed to incrementally build additional capacity into the travel corridor or network, so that each completed project provides the greatest benefit to travelers during each successive project.
- Combining projects or project tasks along a travel route segment, so the effect on traffic occurs for the collective tasks at one time instead of individual effects for each activity.
- Scheduling projects or project tasks to avoid significantly restricting capacity on a single travel route or on multiple roadways that serve as convenient alternatives for travelers when they encounter work zone congestion and delays.

Table 7.1. Examples of PC activities by project phase.

Agencies Involved	Project Planning and Design	Project Delivery
Single	• Compile a database of agency planned projects over the next 3–5 years. • Develop a map showing project locations in the region, possibly color-coded to illustrate current, near-term, and long-term schedules. • Determine and execute the sequence of the projects that will minimize total delays and disruptions to the traveling public in the corridor or region.	• Develop and implement a regional plan that encompasses the various ongoing agency projects in a corridor or region. • Conduct regular coordination meetings between staff of various projects going on simultaneously in a corridor or region to identify and eliminate potential lane closure conflicts, combine compatible lane closures into a single coordinated lane closure where possible, etc. • When possible, establish business processes to coordinate agency maintenance activities with nearby construction project efforts. • Link an agency's lane closure permitting approvals with agency construction- and maintenance-coordination efforts.
Multiple	• Expand project database and mapping tools to include other agencies in region, utility companies, and private sector developer projects that will affect the roadway system. • Establish a web-based approach to sharing and providing appropriate access to the database and map.	• Develop and implement a regional plan that considers and addresses projects being performed by all agencies and other stakeholders in the region. • Conduct regular regional coordination meetings between stakeholders to resolve lane closure conflicts as they arise.

NOTE: PC = project coordination.
SOURCE: Theiss, Ullman, and Moinet (2016).

7.4 Expected Effectiveness

While it is not feasible to measure the safety or mobility effectiveness of PC, this strategy is expected to have a beneficial effect on safety related to all types of work zones by potentially reducing traffic congestion, reducing exposure of highway users to work zones and workers to traffic, and improving emergency response and enforcement of work zone traffic laws. Transportation agencies that focus on improving coordination, planning, and scheduling of work activities have had positive experiences.

Agencies should also measure the effect of improving coordination on the changes in processes and the estimated change in the degree of cooperation attained.

7.5 Crash Modification Factor

No CMF is applicable for this strategy.

7.6 Implementation Considerations

Agencies use different methods and scopes to accomplish PC. Coordination methods include establishing a formal organization that spearheads coordination across a geographic area, using software or mapping to organize project data entered by various agencies so schedules can be coordinated, convening coordination meetings to discuss project activities (e.g., lane closures), or jointly establishing performance goals for a corridor and collaborating to monitor and meet them.

Coordination with emergency responders is vital when planning and scheduling work zones. It is important for police, fire, and emergency medical service agencies to be aware of alternative routes around work zones and possible congestion points. These agencies should also have their own plans for how best to respond to incidents in work zones.

7.7 Design Features and Requirements

According to the FHWA *Guide to Project Coordination for Minimizing Work Zone Mobility Impacts* (Theiss, Ullman, and Moinet 2016), establishing a formal PC process typically consists of five major steps, with a feedback loop between the last two steps (Figure 7.1):

- **Step 1. Establish the vision.** The vision needs to begin with, or at least be supported by, agency upper management, as coordination efforts can sometimes require changing contract

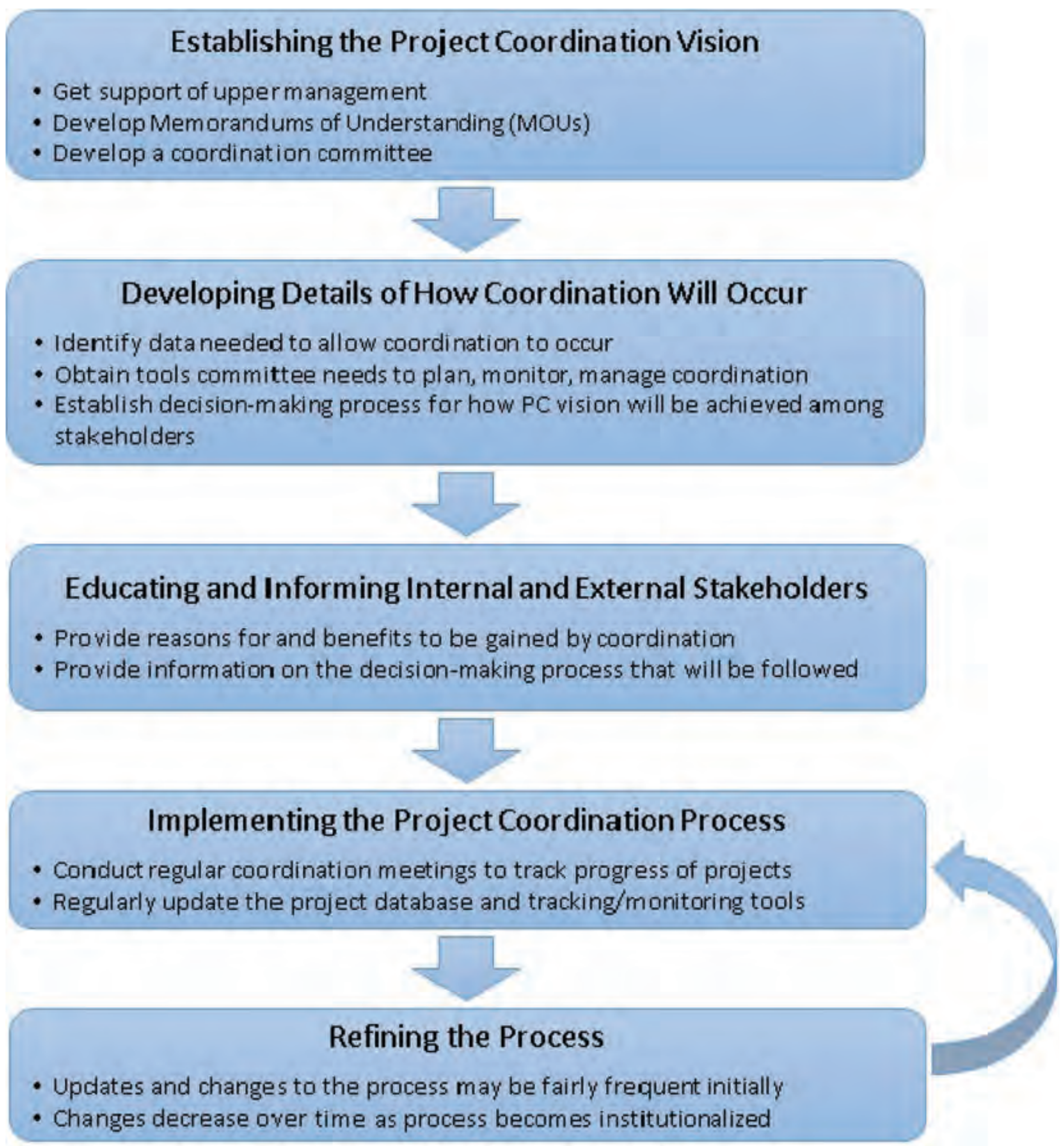


Figure 7.1. Process flow for steps to establish a regional PC process.

language, reallocating staff resources, and forging a cooperative relationship with other regional agencies and stakeholders. Toward this end, it may be necessary to develop formal memorandums of understanding between stakeholders to obtain their commitment to the PC efforts. A coordination committee that includes decision makers with authority to speak on behalf of their agencies or entities is also needed. These individuals may come from several areas of the organization, such as construction, maintenance, design, operations, traffic engineering, contract administration, and public information.

- **Step 2. Develop coordination details**. Data on expected roadway and traffic conditions, such as travel times, traffic volumes and capacities, and the vehicle and load sizes that can be accommodated, are usually needed. The coordination committee will need to identify tools that allow the committee to plan, monitor, and manage the projects effectively. These may include analytical tools to estimate expected traffic problems, databases to log key information about each project or activity along a corridor or within a region, and visualization tools such as geographic information system programs that can map the projects in the database and make that map available to the various stakeholders in the region and at regular committee meetings.
- **Step 3. Educate and inform internal and external stakeholders**. It is important that project staff understand the significance of coordination efforts that will occur and why they are being implemented. It is also helpful to explain the decision-making process (and its underlying data and analyses).
- **Step 4. Implement the project-coordination process**. At the corridor/regional level, it will be necessary to schedule regular coordination meetings with all affected stakeholders. For state agencies, this may involve multiple divisions and offices (i.e., planning, construction, maintenance, operations, permitting, and public information). The meetings will assess the various projects in the corridor or region as the coordination committee moves through the project-development process:
  - ***Long-range assessment***. Stakeholders can compare expected general traffic impacts and anticipated schedules.
  - ***Medium-range assessment.*** Stakeholders discuss and examine the traffic impacts, expected project staging and sequencing, and anticipated letting dates in greater detail.
  - ***Short-term or current project assessment.*** Stakeholders examine and coordinate upcoming day-to-day scheduling of lane closures and other bottlenecks created, to minimize travel impacts as best possible.

  These scheduled meetings are also an opportunity for the agency to update the tracking databases and tools to ensure information is current.
- **Step 5. Refine the process**. The final step is to refine the PC process as the stakeholders become more comfortable with the efforts, understand what is working well, and identify what needs to be revised. Early on, this refinement may be fairly extensive and involve changes to committee and subcommittee structure and staff involvement. Over time, the refinements may become less frequent and less substantial.

7.8 State of the Practice

PC is an innovation promoted by the FHWA's SWZ, a part of Round 3 of the EDC initiative (EDC-3). Work completed under TRB's second Strategic Highway Research Program has yielded an optimization tool to help in the sequencing effort. As of this writing, the Work Zone Impact and Strategy Estimator (WISE) software is currently undergoing demonstration testing and is available to those interested in applying it to their situation. Many resources, including training and outreach materials, peer exchanges, WISE software, and workshops are available on the Smarter Work Zones page at the National Work Zone Safety Information Clearinghouse (https://www.workzonesafety.org/swz/).

The FHWA Office of Operations, Work Zone Management Program website lists examples of how cities and regions have successfully coordinated projects and their associated benefits (http://ops.fhwa.dot.gov/wz/construction/crp/index.htm).

7.8.1 DDOT Improving I-295/DC-295 Projects

Figure 7.2 shows the five active projects DDOT has as of this writing between South Capitol Street SE and East Capitol Street SE along I-295/DC-295.

All of these projects have site-specific TTC plans, which may differ in relation to the main line (I-295/DC-295) by type and time of day. In addition, I-295 varies from two lanes at the southern end to three lanes north of Malcolm X Avenue SE. Thus, daily ongoing roadway restrictions (lane closures, barriers, etc.) and other work zone operations across the entire I-295/DC-295 Corridor present increased risks to roadway users. All of these unexpected conditions, combined with other driver distractions (not related to the work zone) present challenges for the driver to navigate the 5 mi of I-295/DC-295 that will be in a constant state of construction between 2019 and 2021.

To improve mobility and safety, DDOT developed a one-stop web site with information on closures and changes affecting motorists, bicyclists, and pedestrians (https://www.improving295dc.com/). DDOT also assigned a project coordinator to conduct weekly PC meetings with all project maintenance of traffic leads and public outreach liaisons to discuss upcoming work activities, lane closures, conflicts, and other project-related issues and concerns. All individual project teams expressed concern about vehicle speeds through their project limits during these meetings; consequently, DDOT lowered the speed limit on the corridor.

7.8.2 Work Zone Impact and Strategy Estimator

Through Round 3 of EDC, FHWA encourages adoption of road PC to minimize the effects of work zones.

WISE was created to support planning and scheduling of work zones at the regional program (mesoscopic) level along multiple highway routes within a corridor or network. WISE offers a proactive alternative that relies on traffic data in the form of transportation-planning dynamic traffic assignment models—specifically through the simulation-based dynamic traffic assignment DynusT software. WISE is designed to consider projects that create traffic impacts for at least a few weeks; it is not generally intended to consider very short term construction or maintenance projects lasting less than a week.

In practice, WISE is a decision-support system for use by planners and engineers to help them evaluate the traffic effects of work zones and better schedule or sequence a set or program of projects and determine other strategies to reduce adverse effects. WISE has the capability to evaluate the regional effect of various strategies, such as day/night operations, accelerated construction techniques, and traveler/community information campaigns. WISE evaluates renewal projects at both the planning and the operations levels. When used as a planning tool, WISE develops an optimized renewal programming schedule that minimizes the total cost of delays to the public and agency construction costs. When used at the operational level, it evaluates the effect of individual strategies at the project level and provides results that can then be used as part of an iterative procedure with the planning analysis.

7.8.3 Michigan DOT One Corridor Focus

Through its One Corridor Focus initiative, MDOT manages work zones along key corridors as a single unit rather than discrete projects, which enables the DOT to better mitigate travel time

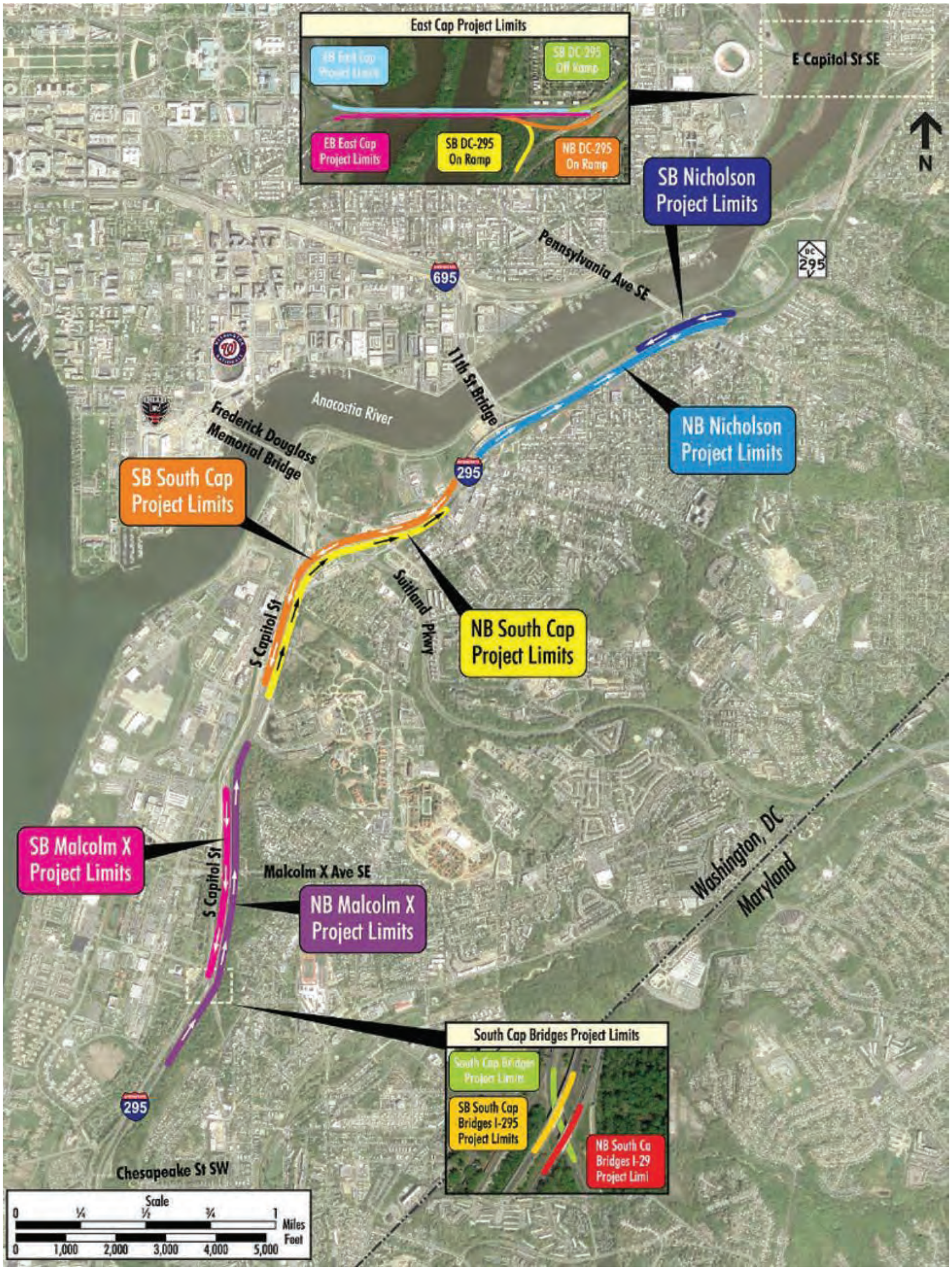


Figure 7.2. I-295 project map (Credit: DDOT).

delay during construction and maintenance activities. The One Corridor Focus began as a result of lengthy travel delays resulting from 19 concurrent reconstruction projects on Interstate 94 in 2010, a corridor that stretches 250 mi through three MDOT regions. MDOT uses several methods to manage and coordinate road projects along key corridors, including establishing goals and measuring performance during construction, applying consistent work zone standards, and coordinating with stakeholders throughout planning and construction.

7.9 Cost

The main cost is generally the time involved for the DOT-assigned project coordinator, which can vary from $50,000 to $200,000 per year. Costs tend to be higher when a DOT has five or more complex projects within a short segment of roadway, which may require a full-time coordinator.

7.10 Resources and References

Boudreau H., and B. Schroeder. *Commonwealth Avenue Analysis and Public Outreach,* Massachusetts Department of Transportation, Work Zone Safety Conference, September 12, 2018.

Brookes, C., M. Kapitanov, and J. Paracha. *Michigan Department of Transportation Project Coordination on the I-94 Corridor*, Smarter Work Zones Project Coordination Case Study, FHWA, 2010.

DDOT. *Improving 295 DC, I-295 / DC-295 Corridor Project Limit*, District Department of Transportation, 2018.

FHWA Every Day Counts (EDC) Initiative: Smarter Work Zones, Project Coordination web page. https://www.workzonesafety.org/swz/swzproject-coordination/.

Kapitanov, M., and J. Paracha. *Importance of Diverse Stakeholder Engagement to Project Coordination Efforts*, Smarter Work Zones Project Coordination, FHWA, Year 2011.

Luttrell, T. B., and K. A. Duffy. *Highway Construction Coordination to Minimize Traffic Impacts*. AASHTO, August 2006.

Owen, H., D. Morena, and T. Scriba. Work Zone Corridor Management in Michigan, *Optimizing Performance Mobility and Safety Making Work Zones Work Better*, FHWA-HOP-13-052, FHWA, U.S. DOT, Summer 2013.

Theiss, L., G. Ullman, and A. Moinet. *Guide to Project Coordination for Minimizing Work Zone Mobility Impacts,* FHWA-HOP-16-013, FHWA, U.S. DOT, April 2016.

CHAPTER 8

Alternative Contracting and Construction Strategies

Contracting strategies refer to the contractual agreements used to accelerate construction completion of transportation projects. A contracting strategy is the combination of the delivery method, the procurement procedure, and the payment provision.

The traditional strategy, and in most cases the ideal choice, to contract a project is the design–bid–build (DBB) delivery method, a low-bid procurement procedure, and a unit-price payment provision. However, this traditional approach may not provide the best value for all project types, especially for traffic-critical projects that require a quick changeover from the design into the construction stages. In such instances, state DOTs have started implementing alternative contracting methods (ACMs) to yield time savings during the procurement or construction phases (or both). This section discusses the following ACMs:

- Design–build
- Construction manager/general contractor
- Cost-plus-time (A+B) bidding selection method
- Incentive/disincentive clauses
- No-excuse incentives
- Lane rental
- Value engineering
- Accelerated bridge construction

Accelerated construction is the use of special materials and techniques to reduce the time it takes to rehabilitate or reconstruct a roadway. Examples of accelerated construction strategies include the following:

- Precast modular concrete road panels and bridge elements (e.g., culverts, bridge deck slabs, pavement slabs).
- High early-strength concrete.
- Self-propelled modular transports (SPMTs) to quickly replace an existing bridge with one fabricated completely off site.
- Hot in-place asphalt recycling.

Accelerated bridge construction (ABC) is presently the most common form of project-level accelerated construction and is also discussed in this section.

8.1 Design–Build Contracting Method

8.1.1 Description

Design–build (D-B) is a delivery method in which one entity (the design–builder) is awarded a single contract for design and construction services. In this method of project delivery, the design is often broken into packages or segments, allowing construction to begin on portions of the project while other elements are still being designed.

8.1.2 When to Use

The D-B method is not suited for every project. This method works best for

- Projects that need to be "fast-tracked" or expedited;
- Projects that allow for innovation in design and construction;
- Projects with funding deadlines that traditional DBB delivery may not be able to meet;
- Emergency projects;
- Projects with a clearly defined scope, design basis, and performance requirements;
- Projects with low possibility for significant change during all phases of work;
- Projects with low risk of unforeseen conditions;
- Projects with a complete National Environmental Policy Act process;
- Projects that require minimal or no ROW acquisition and limited utility relocation; and
- Projects that can use best-value procurement or other methods tailored to benefit the specific needs of a project.

CDOT and WSDOT have developed formal guidance on how to select a project-delivery method from the three common delivery methods of DBB, D-B, and CM/GC.

CDOT and the University of Colorado developed the Project Delivery Selection Matrix (PDSM) to provide a risk-based and objective selection approach to comparing and choosing the most suitable project-delivery method. Use of the PDSM is expanding throughout the transportation industry, as it is increasingly being used by other state DOTs. More information on the PDSM can be found in Section 12.4 of this guidebook. The PDSM, a list of CDOT projects that used the PDSM, and the project comparison results are provided on the CDOT PDSM web page (https://www.codot.gov/business/designsupport/adp-db-cmgc/pdsm).

Using CDOT's PDSM as a foundation, WSDOT developed the Project Delivery Method Selection Guidance (PDMSG). The PDMSG is available at https://www.wsdot.wa.gov/construction-planning/project-delivery/method-selection-guidance. More information on the PDMSG can be found in Section 12.6.

8.1.3 Benefits

The main benefit of D-B is that it allows the design and construction phases to overlap, thereby reducing project completion time. Other advantages of the D-B method include the following:

- Allows for greater innovation in selecting design, materials, and construction methods.
- Reduces claims resulting from design errors.
- Allows for a single contract that addresses quality, costs, and schedule from design through construction.
- Offers price certainty, as construction cost is known and fixed during design.
- Allows for a shortened project-delivery time that can reduce user costs.
- Requires less DOT expertise and fewer resources.

8.1.4 Expected Effectiveness

Multiple studies have evaluated the effectiveness of D-B as a delivery method. However, because of variations in project scope and difficulty in identifying comparable DBB projects for use as baselines, these studies produced highly variable results.

The results of an internal FDOT study conducted in March 2014 indicated that using the D-B approach to deliver a $55 million and 814-day project resulted in a cost savings of $6,457,345 and total time savings of 656 days compared with using DBB (https://www.fdot.gov/construction/DesignBuild/DBGeneral/GeneralInfoMain.shtm).

A 2006 FHWA study on D-B projects, completed under Special Experimental Project No. 14, Alternative Contracting (SEP-14), reported the following:

- Average 14 percent time savings for D-B projects when compared with DBB schedule estimates and a 3 percent reduction in total cost (based on survey respondent estimates).
- Average reduction of 1 percent between planned and actual construction duration based on actual data for the surveyed D-B projects. In contrast, comparable DBB projects showed an average increase of more than 11 percent in actual construction duration.

In 2007, FDOT conducted a comprehensive evaluation of its ACMs (Ellis et al. 2007). FDOT obtained performance data for all its constructed projects completed between January 1998 and March 2006. The project database included 3,130 projects, of which 1,160 used ACMs. The evaluation compared the performance of each ACM to the traditional DBB contracting performance. Project performance evaluation focused on four key areas: (1) cost, (2) time, (3) contractor performance, and (4) value contribution. The following are the most significant findings of this evaluation:

- **Cost**. Average cost growth for projects using ACMs was 8.04 percent compared with 9.36 percent for traditional DBB projects (excluding incentive costs). D-B projects had a cost growth of 4.45 percent.
- **Time**. Average time growth for projects using ACMs was 4.13 percent compared with 16.47 percent for traditional DBB projects.

8.1.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.1.6 Implementation Considerations

D-B projects can utilize either a one-step or two-step selection process. In a one-step process, a request for proposal (RFP) is issued to a number of participants, and any and all parties can respond to this RFP with a proposal.

In the two-step D-B process, a request for qualifications (RFQ) is first issued to a number of participants. Those participants then respond with a statement of qualifications explaining their experience and their capability to perform the work. From the statements of qualifications, a short list of the three to five most qualified respondents is determined. The RFP is then issued only to the short-listed firms, which then develop a full proposal including cost, schedule, and technical responses to the RFP.

The proposal most advantageous to the project owner from both cost and technical aspects is then awarded, using either a “low-bid” or a “best-value” selection process. For a low-bid selection, the D-B contract is awarded to the lowest responsive and competent bidder. Best-value selection permits the consideration of additional factors, such as experience, qualifications, innovation, technical approach, quality-control methods, and project management.

A D-B project requires extensive work to develop an RFQ and RFP. Typically, state DOTs have hired consultants to assist in this effort.

8.1.7 Design Features and Requirements

Sufficient preliminary engineering (30 percent) needs to be performed before an agency can execute a D-B contract. Project scope needs to be clearly defined. ROW limits and acquisition processes are required to be well under way to minimize delays to the contract. Another standard practice is to require the agency to complete environmental processes, such as those mandated under the National Environmental Policy Act, before moving into the RFP stage of procurement.

8.1.8 State of the Practice

According to the Design–Build Institute of America, as of January 2019, D-B is a limited option in only seven states—Alabama, Iowa, New Jersey, New York, North Dakota, Pennsylvania, and Wisconsin. D-B is widely permitted in the rest of the states and the District of Columbia.

D-B is institutionalized and extensively used by state DOTs of Colorado, California, Florida, Michigan, Minnesota, Ohio, Utah, and Washington. Examples of D-B projects are widely available on the state DOT websites and are not repeated here to avoid duplication. Instead, readers are requested to refer to the following state web pages for more information on D-B case studies.

- The CDOT Alternative Delivery Program web page (https://www.codot.gov/business/designsupport/adp-db-cmgc) includes summaries of active and completed projects that were delivered using D-B or CM/GC. The web page also includes lessons learned from D-B and CM/GC projects.
- The Caltrans D-B Program web page (https://dot.ca.gov/programs/design/design-build-program) provides example summaries of two projects that were delivered using D-B. The reasons for selecting the D-B approach are also listed as part of the project summaries.
- The FDOT Construction web page (https://www.fdot.gov/construction/DesignBuild/AllSites/DesignBuildSites.shtm) provides information on current and planned D-B projects. Also included is a summary of D-B projects, which is updated quarterly.
- The MDOT Innovative Contracting web page (https://www.michigan.gov/mdot/0,4616,7-151-9625_21539_53226---,00.html) lists future, active, and completed projects that will be delivered using either D-B or CM/GC.
- The MnDOT D-B web page (https://www.dot.state.mn.us/designbuild/index.html) provides information on completed, active, and future projects delivered using the D-B approach.
- The ODOT Alternative Project-Delivery web page (http://www.dot.state.oh.us/Divisions/ConstructionMgt/design-build/Pages/Design_Build.aspx) provides information on upcoming D-B projects, as well as examples of past D-B projects that were awarded using both least cost and best value.
- The UDOT Innovative Contracting web page (https://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,4552) provides information on completed and future D-B and CM/GC projects. Additional information such as laws, rules, policies, guidelines, and RFP templates can also be found on this web page.

In addition, the FHWA ACMs Library web page (https://www.fhwa.dot.gov/construction/contracts/acm/) provides several D-B resources including state DOT legislation, state DOT D-B project website links, manuals of instruction, and proposal templates. Case studies of D-B projects can be found on the FHWA SEP-14 Active Project List (https://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm) and on the FHWA Center for Innovative Finance Support D-B web page (https://www.fhwa.dot.gov/ipd/alternative_project_delivery/defined/new_build_facilities/design_build.aspx).

8.1.9 Cost

D-B is a planning strategy and there is no separate cost for its implementation. The costs associated relate to in-house or consultant-staffing resources to develop and manage a project.

8.1.10 Resources and References

Caltrans. *Alternative Procurement Guide*, California Department of Transportation, April 2008.

Ellis, R., J.-H. Pyeon, Z. Herbsman, E. Minchin, and K. Molenaar. *Evaluation of Alternative Contracting Techniques on FDOT Construction Projects,* Final Report, Florida Department of Transportation, July 2007.

FDOT. *Design–Build and Design–Bid–Build: Comparison of Overall Cost and Time*, Internal FDOT Study, March 2014.

FHWA. *Design-Build Effectiveness Study*, As Required by TEA-21 Section 1307(f), January 2006.

MDOT. *Innovative Construction Contracting Guide*, Michigan Department of Transportation, September 5, 2014.

Minchin, E., L. Ptschelinzew, G. C. Migliaccio, U. Gatti, K. Atkins, T. Warn, G. Hostetler, and S. Asiamah. *NCHRP Report 787: Guide for Design Management on Design-Build and Construction Manager/General Contractor Projects.* Transportation Research Board of the National Academies, Washington, D.C., 2014.

Turner-Fairbank Highway Research Center. *Alternative Contracting Method Performance in U.S. Highway Construction*, FHWA-HRT-17-100, FHWA, U.S. DOT, April 2018.

UDOT. *Alternative Contracting Process*, SEP-14 Construction Manager General Contractor, Annual Report 2011, Utah Department of Transportation, February 2012.

UDOT. *Best Value Design-Build Selection Manual of Instruction*, Utah Department of Transportation, October 2017.

8.2 Construction Manager/General Contractor

8.2.1 Description

The construction manager/general contractor (CM/GC) project-delivery method allows an owner to engage a construction manager (CM) during the design process to provide constructability input. The design firm and the CM are contractually required to work together during the design phase to create a project that is potentially less expensive and is quicker and easier to construct. Some state laws refer to the CM/GC delivery method as the construction-manager-at-risk method.

8.2.2 When to Use

Projects best suited for the CM/GC process include complex components that require innovation, or “thinking out of the box,” and are typically located in urban areas. Other projects that are a good fit for the CM/GC process are projects that have public involvement or include ROW or utility issues that affect the overall schedule.

The CM/GC is less suitable for straightforward projects, projects with an easily defined scope and low risk, and projects that lack schedule sensitivity.

CDOT and WSDOT have developed formal guidance on how to select a project-delivery method from the three common delivery methods of DBB, D-B, and CM/GC.

CDOT and the University of Colorado developed the PDSM to provide a risk-based and objective selection approach to comparing and choosing the most suitable project-delivery method. Use of the PDSM is expanding throughout the transportation industry, as it is increasingly being used by other state DOTs. More information on the PDSM can be found in Section 12.4 of this guidebook. The PDSM, a list of CDOT projects that used the PDSM, and the project comparison results are provided on the CDOT PDSM web page (https://www.codot.gov/business/designsupport/adp-db-cmgc/pdsm).

Using CDOT's PDSM as a foundation, WSDOT developed the PDMSG. The PDMSG is available at https://www.wsdot.wa.gov/construction-planning/project-delivery/method-selection-guidance. More information on the PDMSG can be found in Section 12.6.

8.2.3 Benefits

The CM/GC method is based on team building and cooperation between the project owner, the design firm, and the CM from the beginning of the project's conceptual design through final construction. CMs can reduce occurrences of change orders, project construction delays, and increased project costs by preventing these obstacles in the design phase instead of dealing with them in the construction phase. The CM will thus need the ability to input constructability reviews, construction phasing, material availability, and cost estimating throughout the design process.

Use of the CM/GC delivery method provides the following benefits:

- Allows fast-tracking of design and construction activities, resulting in time savings.
- Allows for innovation and constructability recommendations during design, but the agency retains significant control over the design.
- Enables the CM/GC to invest more in cost engineering and constructability reviews once guaranteed maximum price (GMP) is established, thus minimizing risks.
- Fixes project costs and completion responsibility.
- Reduces design costs by reducing the amount of detail required and by focusing the pre-construction early design effort on constructible solutions.

8.2.4 Expected Effectiveness

Caltrans has reported $80 million in cost avoidance by using CM/GC for five projects in FY 2017–18 (Table 8.1).

Table 8.1. Caltrans CM/GC projects for FY 2017–18.

Project Name	Work Description	Construction Capital Cost at Contract Award	Project Savings
Highway Facility Rehabilitation, Reconstruction, or Replacement Projects Implemented by Caltrans			
SBD 58 Kramer Junction *Innovation: Earthwork and landscape changes*	Highway Realignment	$165,245,000	$41,266,000
SBD 215 Barton Rd IC *Innovation: Project staging, temporary facility changes, and elimination of items*	Interchange Reconstruction	$47,401,000	$3,203,000
Subtotal for projects implemented by Caltrans		$212,646,000	$44,469,000
Nonrehabilitation, Reconstruction, or Replacement Projects Implemented by Others			
ALA 80 Bay Bridge *Innovation: Revised pile and concrete requirements*	Foundation Removal	$44,079,000	$4,388,000
SD 5 North Coast Corridor, package 2 *Innovation: Earthwork, use of on-site material plants and material recycling plants*	HOV Lanes	$93,821,000	$31,050,000
SD 5 North Coast Corridor, package 3 *Innovation: Changed aesthetic treatment and fencing*	HOV Lanes	$5,330,000	$818,000
Subtotal for projects implemented by others		$143,230,000	$36,256,000
Totals for all Transportation Projects		**$355,876,000**	**$80,725,000**

NOTE: CM/GC = construction manager/general contractor.

8.2.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.2.6 Implementation Considerations

The selection of the design firm is the initial step during the early stages of the project. The design firm is typically contracted through project completion, which includes site investigations, alternative analyses, cost estimates, detailed design, construction bid documents, and department-related construction-management services.

The CM is selected on the basis of qualifications, past experience, or best value. The owner advertises an RFP when the scope and schedule are known, typically before the preliminary design (i.e., 30 percent) is complete. The CM submits a response to the department's RFP. The CM is contracted for the design phase to provide input regarding construction phasing, constructability reviews, cost estimating, scheduling, and other feedback.

At substantial design completion (≥60 percent), the owner and the CM negotiate a GMP to construct the project based on the defined scope and schedule. If this price is acceptable to both parties, they execute a contract for construction services, and the CM becomes the general contractor.

Major risks and disadvantages of a CM/GC delivery method include the following:

- The project price is negotiated with a CM and not competitively bid.
- A designer may not include CM/GC.
- Use of GMP may lead to a large contingency to cover uncertainties and incomplete design elements.
- Use of GMP can lead to disputes over the completeness of the design and contract changes.
- CM/GC design input does not necessarily translate into better design quality.

8.2.7 Design Features and Requirements

Under the CM/GC delivery method, the project owner selects a CM/GC firm to perform preconstruction and construction-management services. During the design phase, the CM/GC firm acts in an advisory or management role. The firm provides constructability reviews, value engineering suggestions, construction estimates, and other construction-related recommendations. At some point on or before design reaches 100 percent completion, the agency and the CM/GC firm negotiate a GMP, which is primarily based on the partially completed design and includes the CM/GC cost estimate for the remaining design elements.

Once the GMP is established, the CM/GC firm starts the construction phase, thus allowing the design and construction phases to overlap. During construction, the CM/GC firm acts as a general contractor and performs contractually obligated work. The contractor holds the construction contract and risk for any construction costs that exceed the GMP.

8.2.8 State of the Practice

CM/GC is frequently used by the state DOTs of Colorado, California, Michigan, Minnesota, and Utah. Examples of CM/GC projects are widely available on the state DOT websites and are not repeated here to avoid duplication. Instead, readers are requested to refer the following state web pages for more information on CM/GC case studies:

- The CDOT Alternative Delivery Program web page (https://www.codot.gov/business/design support/adp-db-cmgc) includes summaries of active and completed projects that were delivered using D-B or CM/GC. The web page also includes lessons learned from D-B and CM/GC projects. CDOT began using CM/GC in 2009 and has, as of this writing, used CM/GC to deliver more than 15 projects.
- The Caltrans CM/GC Program web page (https://dot.ca.gov/programs/design/contract-manager-general-contractor) provides example summaries of projects delivered using a CM/GC approach. The reasons for selecting CM/GC are also listed as part of the project summaries.
- The MDOT Innovative Contracting web page (https://www.michigan.gov/mdot/0,4616,7-151-9625_21539_53226---,00.html) lists future, active, and completed projects that will be delivered using either D-B or CM/GC.
- The MnDOT CM/GC web page (http://www.dot.state.mn.us/const/tools/const-manager-general-contractor.html) provides information on completed, active, and future projects delivered using the CM/GC approach.
- The UDOT Innovative Contracting web page (https://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,4552) provides information on completed and future D-B and CM/GC projects. Additional information such as laws, rules, policies, guidelines, and RFP templates can also be found on this web page.

In addition, the FHWA ACMs Library web page (https://www.fhwa.dot.gov/construction/contracts/acm/) provides CM/GC resources, including state DOT legislation, state manuals of instruction, and proposal templates.

Case studies of CM/GC projects can be found on the FHWA SEP-14 Active Project web page (https://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm).

8.2.9 Cost

CM/GC is a planning strategy and there is no separate cost for its implementation. The costs associated relate to in-house or consultant-staffing resources to develop and manage a project.

8.2.10 Resources and References

ADOT. *Construction Manager at Risk (CMAR).* Intermodal Transportation Division, Arizona Department of Transportation, September 2010.

AASHTO. *Primer on Contracting for the Twenty-First Century,* 5th ed., AASHTO Subcommittee on Construction, Washington, D.C., 2006.

Anderson, S. D., and I. Damnjanovic. *NCHRP Synthesis 379: Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion*. Transportation Research Board of the National Academies, Washington, D.C., 2008.

Caltrans. *Alternative Procurement Guide,* California Department of Transportation, 2008.

Harper, C. M., D. Tran, T. McGuire, and K. Molenaar. Selecting a Procurement Procedure for Highway Construction Projects. Presented at 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.

MDOT. *Innovative Construction Contracting*, Michigan Department of Transportation, April 2013.

Minchin, E., L. Ptschelinzew, G. C. Migliaccio, U. Gatti, K. Atkins, T. Warn, G. Hostetler, and S. Asiamah. *NCHRP Report 787: Guide for Design Management on Design-Build and Construction Manager/General Contractor Projects.* Transportation Research Board of the National Academies, Washington, D.C., 2014.

MnDOT. *Innovative Contracting Guidelines*, Office of Construction and Innovative Contracting, Minnesota Department of Transportation, Saint Paul, December 2008.

UDOT. *Alternative Contracting Process: SEP-14 Construction Manager General Contractor*. Utah Department of Transportation Annual Report 2011, February 2012.
UDOT. *Benefits of Contract Manager/General Contractor (CM/GC)*, Utah Department of Transportation, February 2009.
UDOT. *Construction Manager General Contractor Selection: Manual of Instruction*, Utah Department of Transportation, June 2015.

8.3 Cost-Plus-Time (A+B) Bidding Selection Method

8.3.1 Description

Cost-plus-time, or A+B, bidding uses a cost parameter (A) and a time parameter (B) to determine a bid value. The cost component (A) is the traditional bid for the contract items and is the dollar amount for work performed under the contract. The time component (B) is the total number of calendar days required to complete the project, as estimated by the bidder, multiplied by an agency-determined daily RUC to translate time into dollars.

The bid for award consideration is based on a combination of the bid for the contract items and the associated cost of the time according to the following formula:

$$A + (B \times RUC/Day) = Total\ Bid$$

This formula is only used to determine the lowest responsible bidder for award and is not used to determine payment to the contractor.

8.3.2 When to Use

A+B procurement is best suited for highway projects in urban settings with high volumes of road users. Also, it is suitable for projects that severely affect local businesses during the construction and for projects with a tightly constrained end date. Many state agencies use A+B bidding with incentive/disincentive (I/D) provisions as an additional motivation for contractors to save time.

Examples of projects that could be considered for A+B bidding include the following:

- Widening projects for which permanent traffic control is to be set up for an extended period of time.
- Projects that have multiple activities occurring, which don't necessarily have to be done sequentially.
- Projects for which the contractor's presence or activities will affect traffic, regardless of whether traffic control is set up.
- Projects that allow alternate solutions, when one solution may take significantly less time to construct but designers are hesitant to specify a proprietary solution.
- Projects in which innovative solutions by the contractor are sought (i.e., specialty work), which may be beyond the designer's expertise.

CDOT and the University of Colorado have jointly developed a Procurement Procedures Selection Matrix (PPSM) to provide a risk-based and objective selection approach to choosing a procurement procedure from the three common procurement criteria of low bid, best value, and best qualified. The PPSM is available on the CDOT website at https://www.colorado.edu/tcm/procurement-procedure-selection-matrix. More information on the PPSM can be found in Section 12.5.

8.3.3 Benefits

The use of A+B contracting provides the following benefits:

- Reduces construction-induced congestion and delays.
- Encourages bidders to develop more detailed and well thought out plans.
- Encourages contractors to develop innovative means of reducing overall construction time at the lowest cost.
- Encourages contractors to schedule construction operations in a manner that maximizes the efficiencies of crews and equipment.
- Encourages the contractor to find ways to make up for days lost to weather.
- Reduces complaints related to congestion from road users and local communities.
- Lessens environmental impacts and reduces pollution related to construction.

8.3.4 Expected Effectiveness

Kent (2008) summarized the performance results of 120 NYSDOT A+B bidding projects worth almost $2 billion:

- On average, contractors bid 32 percent less than the agency's estimated time and completed ahead of schedule.
- NYSDOT awarded 90 of the 120 contracts to the low A portion bidder (i.e., the bidder with lowest A+B total also had the lowest A portion contract amount). The agency awarded the other 30 contracts to a bidder with a higher A cost and a shorter B duration. The added A cost of these 30 contracts was less than 1 percent.
- 103 contractors earned incentives and shared total incentive payments of $49,069,174. Total incentives paid were approximately 2.5 percent of original contract value for these 103 contracts.
- The agency fined 8 contractors for not completing projects on time (i.e., disincentive). The total cost of fines was $592,000.
- 59 contractors asked for and received adjustments to the B portion of the contract because of circumstances outside of their control.
- Cost saving was estimated to be $246 million.
- Construction time saved was estimated to be 20,000 days.

The Iowa DOT used A+B bidding—in combination with other strategies—to reduce construction time from 2 years to 1 year on the 24th Street-I-29/80 Interchange Bridge replacement project in Council Bluffs in 2009. A+B was selected to reduce the project-delivery time and open all lanes on the new bridge within one construction season (April–October).

8.3.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.3.6 Implementation Considerations

An issue to consider with A+B bidding is the potential for project costs to increase. State agencies will need to consider that shortening the duration of a project will cost a premium related to acceleration, aggressive management of subcontractors, the use of specialty equipment, or a combination of any of the three. For example, a bidding firm may see an opportunity to reduce the total effects on a project with a shorter duration solution that increases the primary cost items, but in return would reduce the impact on overall traffic control cost. However, a bidding firm would not likely bid the shorter duration, as savings associated with traffic control are not shared with the firm. To avoid this situation, state DOTs may implement incentive/disincentive clauses.

8.3.7 Design Features and Requirements

According to Caltrans (2002), other than a few specific exceptions, projects that agencies should consider for A+B bidding are those having an estimated cost of $5 million or more and a daily RUC of $5,000 or more. Once the agency establishes these parameters, the project engineers establish a maximum number of construction days for bids to be considered responsive. Any bids that exceed this amount are considered unresponsive and are discarded. Next, the project engineers determine the daily RUC for the time portion of the bids.

To evaluate the proposals, the agency will multiply the estimated duration of construction by the RUC to create the time portion of the bid. This B value is added to the project cost (the A portion) to generate the total bid. Caltrans will award the contract to the firm with the lowest total A+B.

8.3.8 State of the Practice

Under SEP-14, 29 States (Arkansas, California, Colorado, Delaware, Georgia, Idaho, Indiana, Iowa, Kentucky, Maine, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Nevada, New York, North Carolina, North Dakota, Oklahoma, Pennsylvania, South Carolina, Texas, Utah, Vermont, Virginia, Washington, and Wisconsin) and the District of Columbia have used the A+B method.

The FHWA Highways for Life Demonstration Program web page (https://www.fhwa.dot.gov/hfl/projects/) provides a list of projects that used the A+B approach.

8.3.9 Cost

A+B is a planning strategy and there is no separate cost for its implementation. The costs associated relate to in-house staffing resources to develop or manage a project, or both.

8.3.10 Resources and References

Anderson, S. D., and J. S. Russell. *NCHRP Report 451: Guidelines for Warranty, Multi Parameter, and Best Value Contracting*. TRB, National Research Council, Washington, D.C., 2001.

Caltrans. *Guidelines for Use of A+B Bidding Provision*, California Department of Transportation, September 2002.

Kent, D. *Innovative Contracting Techniques That Consider Driver Impact, Use of A+B Bidding*, New York State Department of Transportation, 2008.

Mallela, J., and S. Sadasivam. *Work Zone Road User Costs: Concepts and Applications*, FHWA-HOP-12-005, FHWA, U.S. DOT, 2011.

WSDOT. *A+B Bidding*, Washington Department of Transportation, 2014.

8.4 Incentive/Disincentive Clauses

8.4.1 Description

An incentive is a contracting provision that compensates the contractor a specific amount of money for each day that critical work is completed ahead of schedule or for achieving set goals. A disincentive assesses a fee for each day identified that the contractor overruns the specified time or for failing to achieve set goals. Contracts may pair these two provisions in an incentive/disincentive (I/D) clause.

8.4.2 When to Use

Preferred candidate projects for I/D use are the following:

- Projects on high traffic-volume facilities, generally in urban areas.
- Major reconstruction or rehabilitation that will severely disrupt traffic on a facility.
- Projects with lengthy detours.
- Projects with critical completion dates.
- Projects that involve nighttime construction.
- Projects with significant road-user delay costs or community or local business impacts.

I/D use is not suitable for

- Projects with open-to-traffic constraints, such as weekends to accommodate seasonal peak volumes or extended periods for special events, which significantly limit the number of work hours or days per week.
- Projects with third-party coordination concerns, such as utility relocations.

Pyeon and Lee (2012) developed a systematic procedure to determine appropriate I/D dollar amounts using the Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) scheduling tool. The procedure is shown in Figure 8.1 and briefly summarized in the following steps:

- Step 1. Set up a schedule baseline based on CA4PRS schedule analysis.
- Step 2. Evaluate the impact of the work zone on the traveling public, especially RUC based on CA4PRS traffic analysis.
- Step 3. Estimate the contractor's cost for additional resources for I/D acceleration and the contractor's savings from schedule compression. Also, estimate the contractor's savings in field-operation cost by using project duration reduction results from the schedule acceleration.
- Step 4. Estimate the agency's cost savings from schedule compression.
- Step 5. Use sensitivity analysis to determine the reasonable value of discount factors to split I/D benefits and costs between the contractor and the agency.
- Step 6. Make a decision on the I/D implementation based on the comparison of savings for the contractor (i.e., additional acceleration cost savings and field-operation cost savings) and benefits to road users and the agency from schedule compression.
- Step 7. Set up a daily incentive amount and a maximum incentive amount based on Steps 1–6, as well as project budget constraints.
- Step 8. Set up a daily disincentive amount and a maximum disincentive amount based on the previously described procedure and parameters.

8.4.3 Benefits

The use of I/D clauses provides the following benefits:

- Earlier project completion or open-to-traffic date.
- Minimizes impacts to motorists and the community.
- Improves worker safety.
- Reduces road-user delay costs.
- Encourages contractor efficiency and productivity.
- Provides disincentives for failing to meet contract completion or open-to-traffic date.

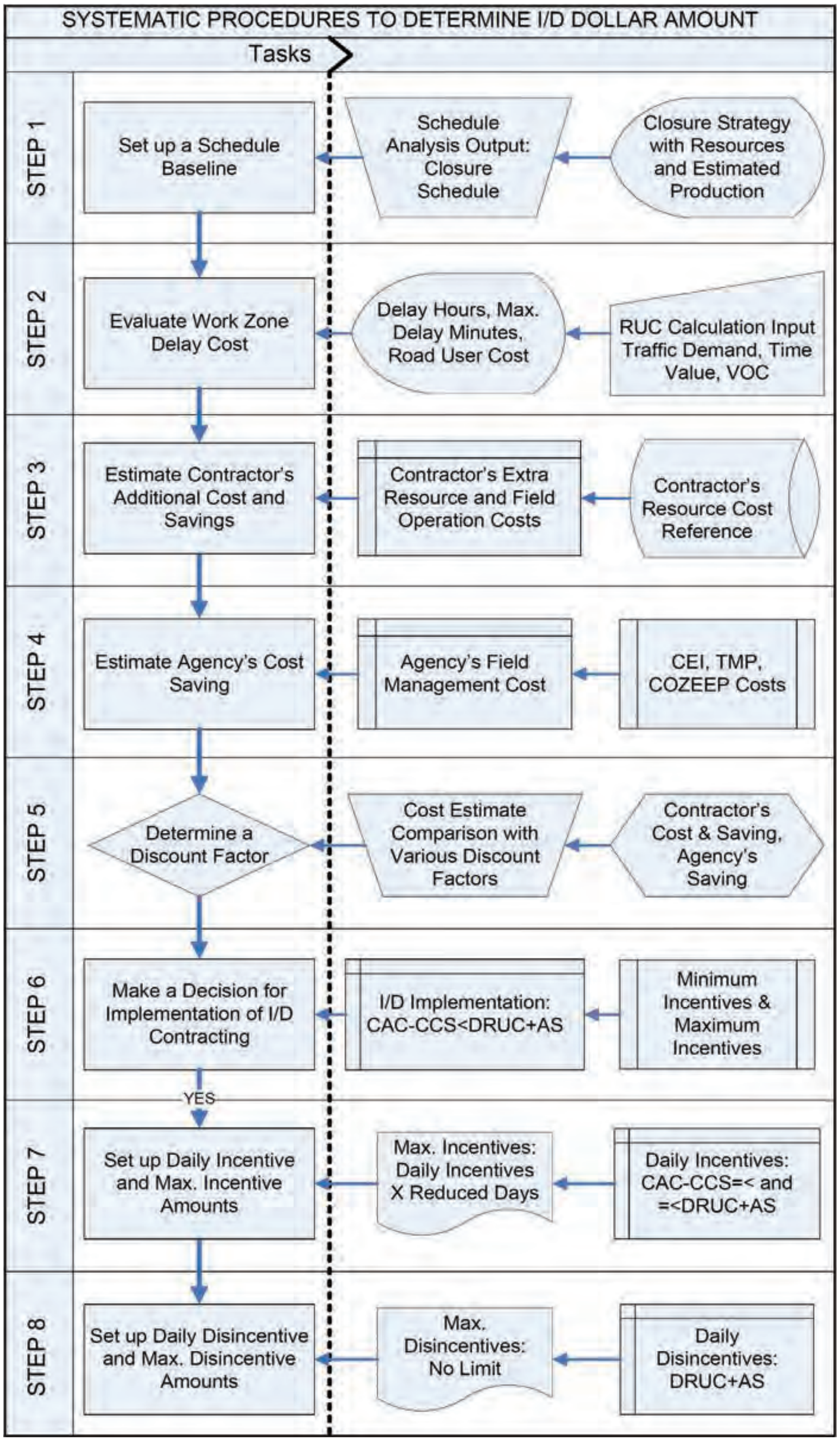


Figure 8.1. Flowchart of systematic procedures for determination of I/D dollar amount.

8.4.4 Expected Effectiveness

Sun, Edara, and Mackley (2012) examined the effectiveness of 20 MoDOT I/D contracts from 2008 to 2011 and evaluated the extent to which they mitigated work zone traffic effects. In considering an average project, the percentage of RUC savings was around 13 percent of the total contract amount, or $444,389 of $3,464,620. The net RUC savings were about $7.2 million after subtracting the approximately $1.7 million paid in incentives. In other words, every dollar paid in incentives resulted in approximately $5.30 of RUC savings.

Ellis et al. (2007) performed a comprehensive quantitative evaluation on FDOT construction projects. A total of 144 I/D projects were evaluated and compared with traditional DBB, non-I/D contracting projects. The quantitative project cost and time evaluation results indicated that I/D projects showed average time savings of 16.5 percent but average cost overruns of 3.3 percent.

Arditi, Khisty, and Yasamis (1997) studied several projects for IDOT and found that 93.3 percent of projects that used I/D provisions finished on time or ahead of schedule compared with 41.4 percent that did not use I/D provisions.

8.4.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.4.6 Implementation Considerations

All I/D provisions are used in conjunction with liquidated damages. In other words, the disincentive portion of an I/D provision consists of more than just the minimum agreed-to daily engineering construction costs that will be recovered if a milestone or project is completed late.

RUC is the most common item included in both the incentive and disincentive rates for a highway project. The total incentive amount available needs to be included in both the project estimate and the programming, and the amount should be less than or equal to the associated RUC (or a maximum of 5% of the estimated construction costs). The I/D assessment must be large enough to motivate the contractor to work an accelerated schedule.

Agency costs can be higher for I/Ds because staffing hours will be increased to monitor contract time and impacts associated with excusable delays. Critical path–method scheduling should be considered to facilitate tracking of time adjustments.

Time adjustments from change orders or delays can become a major source of dispute on projects with I/D provisions. Calendar days should be used to avoid any potential for controversy, with exceptions for weather and legal holidays.

8.4.7 Design Features and Requirements

As I/D is a contract provision, design features and requirements are not applicable to this strategy.

8.4.8 State of the Practice

NCHRP Report 652: Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts (Fick et al. 2010) states that at least 46 states have had experience with contracts involving some variation of I/D provisions.

8.4.9 Cost

I/D is a planning strategy and there is no separate cost for its implementation. The costs associated relate to in-house or consultant-staffing resources to develop and manage a project. However, agency costs for projects with I/D provisions can be higher because staffing hours will be increased to monitor contract time and impacts associated with excusable delays.

8.4.10 Resources and References

Arditi, D., J. Khisty, and F. Yasamis. Incentive/Disincentive Provisions in Highway Contracts, *Journal of Construction Engineering and Management*, 123, 1997, pp. 302–307.

Ellis, R., J. Pyeon, Z. Herbsman, E. Minchin, and K. Molenaar. *Evaluation of Alternative Contracting Techniques on FDOT Construction Projects*, Final Report, Florida Department of Transportation, July 2007.

Fick, G., E. T. Cackler, S. Trost, and L. Vanzler. *NCHRP Report 652: Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts.* Transportation Research Board of the National Academies, Washington, D.C., 2010.

Pyeon, J.-H., and E. B. Lee. *Systematic Procedures to Determine Incentive/Disincentive Dollar Amounts for Highway Transportation Construction Projects*, California Department of Transportation, CA-MTI-12-2908, June 2012.

Sillars, S. N. *Establishing Guidelines for Incentive/Disincentive Contracting at Oregon DOT*, FHWA-OR-RD-07-07, Oregon Department of Transportation, 2007.

Sun, C., P. Edara, and A. Mackley. *Use of Incentive/Disincentive Contracting to Mitigate Work Zone Traffic Impacts*, Midwest Smart Work Zone Deployment Initiative, InTrans Project 06-277, November 2012.

8.5 No-Excuse Incentives

8.5.1 Description

A no-excuse incentive (NEI) is a monetary incentive for early completion, for which the contractor receives the bonus by completing the work on or before a drop-dead date that cannot be adjusted for any reason. The contractor receives the full incentive payment for work completed on or in advance of this date. There are no excuses for adjusting this date, including utilities, permitting, change orders, weather, site conditions, or any other cause short of a natural catastrophe. Conversely, the contractor is not assessed disincentives, aside from normal liquidated damages, for not meeting the completion date. The incentive amount is based on RUC and other costs that reflect the value to the agency and the public for finishing the project by a certain date. NEI is also known as a locked incentive date or a no-excuse bonus.

8.5.2 When to Use

An NEI should be considered for use under the following situations:

- Projects for which finishing early would provide some benefit but finishing late would cause severe damages (e.g., projects with an arrangement of multiple construction contracts for which finishing late would cause collateral effects to subsequent contractors, a road opening to accommodate major traffic events).
- Projects with critical completion dates, such as a major sporting event.
- Projects with high RUC, impacts to the local and business communities, or both.

8.5.3 Benefits

The use of an NEI provides the following benefits:

- Enables an earlier project completion or open-to-traffic date.
- Minimizes impacts to motorists or the community.

- Improves worker safety.
- Reduces road-user delay costs.
- Encourages contractor efficiency and productivity.

8.5.4 Expected Effectiveness

In 2010, MnDOT successfully used the NEI specification on six projects to deliver them within the anticipated project schedule. MnDOT reported that NEIs motivated contractors to complete the work instead of asking for time extensions, eliminated claims, and improved the working relationship with MnDOT. Affected stakeholders were satisfied that MnDOT was able to meet construction commitment dates and reduce construction impacts.

8.5.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.5.6 Implementation Considerations

An NEI provision remains as a nontraditional contracting technique under SEP-14 and requires FHWA approval before being used.

The total incentive amount available needs to be included within both the project estimate and the programming, and it should be less than or equal to the associated RUC (or a maximum of 5 percent of the estimated construction costs). The bonus can be tied to milestones, a final completion date, or both.

An effective NEI provision will clearly state the incentive amount, all the relevant work items, a substantial completion definition, the unit of time used, and the no-excuse completion date. The owner and the contractor need well-defined time limits for submittals, reviews, and any other administrative issues within the contract and the project schedule. Ambiguities will complicate contract administration.

Utility schedules are crucial, requiring the utility companies to also increase staffing or work overtime. Contractors may commit to sharing bonuses with utility companies, subs, and others to get these companies or groups to commit to working toward a bonus. Alternatively, the owner may establish contingency funds to cover the increased workload.

8.5.7 Design Features and Requirements

As NEIs are a contract provision, design features and requirements are not applicable to this strategy.

8.5.8 State of the Practice

About 13 state DOTs (Alabama, Florida, Georgia, Iowa, Massachusetts, Minnesota, Missouri, North Carolina, Pennsylvania, South Carolina, Virginia, Wisconsin, and Wyoming) use NEI provisions. Florida and Minnesota have used this provision to a greater extent than other states.

Case studies of NEI projects can be found on the FHWA SEP-14 Active Project web page (https://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm).

8.5.9 Cost

This strategy is an innovative contracting strategy and there is no additional cost to implement this strategy.

8.5.10 Resources and References

AASHTO. *No Excuse Incentive Provisions Survey,* AASHTO Subcommittee on Construction, Contract Administration Section, Washington, D.C., May 2010.

MnDOT. *Locked Incentive Date (LID) Evaluation Report*, Minnesota Department of Transportation, December 2010.

8.6 Lane Rental

8.6.1 Description

Lane rental is a payment provision used by agencies to minimize the effects of a project on the traveling public. It is a method of transferring roadway user costs to the contractor. The contractor must rent a lane to close it. This creates a monetary incentive for the contractor to be innovative and minimize the duration of lane closures.

The contractor makes decisions that consider the roadway user costs, both during the bid and as the contract progresses. The contractor's bid consists of a combination of the cost to perform the work (component A) with the cost of the impact to the public (component B) to provide the lowest cost to the public. By providing a more aggressive scheduling package, a contractor may be able to gain a competitive advantage by decreasing the overall effect to the traveling public and thereby reducing the amount for bid consideration.

8.6.2 When to Use

Lane-rental provisions are adequate in projects with long, unavailable, or impractical detours, and when peak hour traffic is adversely affected. Agencies should use lane-rental provisions in projects that include multiple roads and high traffic volumes, as well as some flexibility for intermittent or temporary lane closures, significant RUC, and high community and local business impacts.

According to the MnDOT *Innovative Contracting Guidelines* (2008) and *NCHRP Report 652*, good candidates for the use of these provisions include projects that involve the following features:

- Bituminous mill and overlay,
- Grading,
- Full-depth patching,
- Diamond grinding,
- Full-depth reclamation,
- Cold recycle,
- Guardrail projects (replacement and installation),
- Sign upgrades,
- Pavement marking,
- Crack sealing, and
- Signal systems.

8.6.3 Benefits

The use of lane rental provides the following benefits:

- Helpful for contractors scheduling work to minimize traffic restrictions in duration and lane closures.
- Ideal for projects that significantly affect the traveling public (i.e., reduces RUC).
- Useful in major urban area projects and rural projects with flagging operations.

8.6.4 Expected Effectiveness

According to the MDOT *Innovative Construction Contracting Guide* (2015), lane-rental provisions encourage contractors to set work schedules that keep lane closures to a minimum. FHWA report *Work Zone Road User Costs: Concepts and Applications* (Mallela and Sadasivam 2011) recognizes that lane rental can accomplish the following:

- Reduce work zone RUC.
- Positively affect work zone safety.
- Encourage contract efficiency and productivity.
- Better accommodate local traffic flow.

8.6.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.6.6 Implementation Considerations

FHWA report *Work Zone Road User Costs—Concepts and Applications* identifies the following disadvantages of lane-rental provisions:

- Contractors are likely to plan work at night, which may reduce worker safety.
- Project completion time does not necessarily decrease.
- Additional agency resources are required.
- Contract change negotiations become more difficult.
- Additional documentation and coordination are required.

The following factors are important when selecting lane rental for a project:

- Traffic restrictions or lane closures with no (or limited) alternate routes result in a high user cost.
- The project is free of third-party conflicts outside the control of the contract (e.g., right-of-way, utility, environmental).
- There is a high degree of confidence that design uncertainties have been addressed in the plans.
- A reasonable contractor can accurately schedule (and bid) the necessary lane closures to complete the work as described.
- "Closures" can be well defined.
- Opportunities exist to reduce closure times.
- User fees are substantial enough to offset the cost of the effort to reduce the closure time.

Safety needs to be addressed with every lane-rental project. Plans and specifications should identify cases when lane closures will be required, decreasing the chance that contractors will take safety risks to reduce lane-rental charges.

8.6.7 Design Features and Requirements

Lane-rental fee rates depend on the number and type of lanes closed and can vary for different hours of the day. For example, the peak hour periods of 6:00 to 9:00 a.m. and 3:00 to 6:00 p.m. could have an hourly rental fee of $2,000 for closing one lane, while a lane closed at any other time could have a rental fee of $500 per hour.

The incentive for lane rental is limited to a maximum of 5 percent of the estimated construction cost. The maximum incentive is determined and listed in the special provision for lane rental as "Lane Rental, Incentive." The incentive payment will be determined by subtracting from the contract lane-rental lump sum bid by the contractor the total lane-rental assessments, which cannot exceed the maximum. For example, if a contractor bids $1 million (lump sum) for lane rental and the total of the lane-rental assessments is $900,000 based on 900 hours at $1,000 per hour, then the lane-rental incentive equals $100,000, provided it does not exceed the maximum incentive listed in the special provision.

8.6.8 State of the Practice

Arizona, Colorado, Indiana, Maine, New York, North Carolina, Oklahoma, and Washington have experimented with or implemented the use of lane-rental provisions.

8.6.9 Cost

Lane rental can increase construction cost. On a standard project, a contractor may see an opportunity to reduce total impacts. A shorter-duration solution may increase the primary item cost but reduce lane rental and overall traffic control costs. The contractor will try to determine the most advantageous bid while balancing the potential overrun in lane-rental costs.

8.6.10 Resources and References

FDOT. *Contract Duration and Alternative Contracting Techniques*, Florida Department of Transportation, Tallahassee, March 2012.

Fick, G., E. Cackler, S. Trost, and L. Vanzler. *NCHRP Report 652: Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts*. Transportation Research Board of the National Academies, Washington, D.C., 2010.

Mallela, J., and S. Sadasivam. *Work Zone Road User Costs: Concepts and Applications,* FHWA, U.S. DOT, Washington, D.C., 2011.

MDOT. *Innovative Construction Contracting Guide,* Michigan Department of Transportation, 2015.

MnDOT. *Innovative Contracting Guidelines*, Office of Construction and Innovative Contracting, Minnesota Department of Transportation, December 2008.

UDOT. *Lane Rental Guidelines*, Utah Department of Transportation, April 2010.

WSDOT. *Lane Rental*, Washington State Department of Transportation, 2013.

8.7 Value Engineering

8.7.1 Description

Value engineering (VE) is defined as a systematic process of review and analysis of a project, during the concept and design phases, conducted by a multidisciplinary team of persons not involved in the project.

8.7.2 When to Use

VE studies can occur at one or more stages of project development.

- VEs can be conducted at the scoping (conceptual) stage before commencing design activity.
- VEs can occur at the preliminary field inspection stage, or when approximately 30 percent of the design is complete. At this point, the project design is at a stage when the team can make recommendations on its alignment and overall design without concern that changes will affect the project schedule.
- VE study is also appropriate when approximately 60 percent of the design is completed. At this stage, the VE team has access to more complete project information, including most of the specific items to be included in the completed roadway. Cost estimates are more likely to be complete at this stage.

On federal-aid highway projects, the FHWA can withhold federal-aid highway funds from any eligible project that did not receive a VE study.

8.7.3 Benefits

A VE program provides a definitive tool to improve value in any project, product, or process. Cost savings, reduced risk, improved schedule, enhanced design, and quality have been common outcomes of VE studies. Additional benefits include review of design and construction standards to improve quality and reduce project completion time.

8.7.4 Expected Effectiveness

FHWA and state DOTs have recognized tens of millions of dollars in project cost savings from completed VE studies. These savings represent a return on investment of over 100:1 when considering the cost of conducting the VE studies.

FHWA annually collects information on VE accomplishments achieved within the Federal-Aid Highway Program, including for the projects administered by Federal Lands Highway. For VE studies conducted during the preconstruction phase, FHWA tracks the number of studies conducted, proposed and implemented recommendations, and the value of the implemented recommendations. Table 8.2 summarizes recent savings realized by conducting VE studies.

MnDOT has recognized tens of millions of dollars in project cost savings from completed VE studies. These savings represent a return on investment of 84:1 when considering the cost of conducting the VE studies. Table 8.3 is a summary of 5 years of VE studies from October 1, 2012 to June 30, 2018.

Caltrans realized cost savings of $62 million on nine projects that completed VE studies during FY 2017–18. The VE recommendations, in most cases, reduced the cost of the project. However, in a few cases the recommendations resulted in an increase to the cost of the project but resulted in improved project performance. Table 8.4 identifies the value of the alternative per project.

8.7.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.7.6 Implementation Considerations

Large, complex projects must have at least two VE studies, first at a scoping or corridor level, followed up with a second study later in the project-development phase.

Table 8.2. Summary of past VE savings on Federal-Aid and Federal Lands Highway Programs.

Measure	FY 2019	FY 2018	FY 2017	FY 2016	FY 2015	FY 2014
Number of VE Studies	246	175	160	198	135	215
Cost to Conduct VE Studies and Program Administration	$12.5 M	$7.3 M	$6.6 M	$7.3 M	$6.4 M	$8.7 M
Estimated Construction Cost of Projects Studied	$32 B	$22.7 B	$20.8 B	$13.9 B	$14.1 B	$20.9 B
Total Number of Proposed Recommendations	2,310	1,376	1,451	1,565	1,233	1,664
Total Value of Proposed Recommendations	$5.5 B	$3.1 B	$2.8 B	$2.6 B	$2.5 B	$3.0 B
Number of Approved Recommendations	801	578	636	579	504	697
Value of Approved Recommendations	$3.1 B	$1.1 B	$1.1 B	$868 M	$831 M	$1.73 B
Project Cost Saved (%)	10.00	5.00	5.00	6.20	5.90	8.32
Return on Investment	247:1	157:1	159:1	119:1	129:1	200:1

NOTE: B = billion; M = million; VE = value engineering.

Table 8.3. Summary of MnDOT VE savings.

Measure	10/1/2012–6/30/2014	7/1/2014–6/30/2015	7/1/2015–6/30/2016	7/1/2016–6/30/2017	7/1/2017–6/30/2018
Number of VE Studies	13	10	16	4	5
Cost of Conducting VE Study	$634,000	$463,000	$865,000	$252,908	$286,579
Estimated Total Project Cost	$ 923 M	$ 397 M	$ 817 M	$122 M	$447 M
No. of Proposed VE Recommendations	107	58	128	27	32
No. of Approved Recommendations	72	43	95	15	14
Recommendation Acceptance Rate (%)	67	74	74	56	44
Total Value of Proposed VE Savings	$191.7 M	$38.8 M	$123.5 M	$11.7 M	$79.5 M
Savings from Approved Recommendations	$60.1 M	$17.29 M	$78.36 M	$9.9 M	$44.8 M
Total value of approved recommendations					**$210.45 M**
Total cost to hold the VE studies					**$2.5 M**
ROI = value of approved recommendations divided by cost to conduct VE studies					**84:1**
Total number of VE studies over 10 years					**48**

NOTE: M = million; MnDOT = Minnesota Department of Transportation; ROI = return on investment; VE = value engineering.

Table 8.4. Caltrans VE studies for FY 2017–18.

Project Name	VE Study Construction Cost	VE Study Savings	Associated Costs	Project Savings
Sac 5 HOV Lanes and Rehab *Improvement: Combined two nearby projects and adjusted work windows to allow for precast slab replacement*	$168,000,000	$1,534,000	$72,000	$1,462,000
Sac 5 HOV Lanes and Rehab *Project combined with the previous project*	$165,000,000	$2,751,000	$52,000	$2,699,000
Mon 101 Pavement Rehab, PM 36.9 to 47.7 *Improvement: Increased ramp closures to allow for pavement curing in lieu of precast slabs*	$49,800,000	$ 6,445,000	$42,000	$6,403,000
Mon 101 Seismic Retrofit *The results of the geotechnical studies eliminated the need for cast-in-steel-shell piles. Another alternative was eliminated after a project scope reduction.*	$29,800,000	$0	$46,000	($46,000)
Mon 101 PM 87.3 to PM 91.5 *None of the study alternatives was accepted because of geometric concerns.*	$35,200,000	$0	$49,000	($49,000)
Ker 99 Roadway Rehab *None of the study alternatives was implemented because they did not add value* .	$79,000,000	$0	$52,000	($52,000)
LA 60 Pavement Rehab *The VE study identified user benefits that outweighed the slight increase in cost.*	$109,000,000	($1,080,000)	$52,000	($1,132,000)
Riv 10 Pavement Replacement *Improvement: Changed pavement type because of median rebuild and saved Thrie-beam barrier verses replacement*	$239,000,000	$47,200,000	$47,000	$47,153,000
SBD 60 Pavement Replacement *Improvement: Changed pavement type because of lane closure time frames*	$92,000,000	$5,200,000	$48,000	$5,152,000
Total	$ 966,800,000	$62,050,000	$460,000	**$61,590,000**

NOTE: HOV = high-occupancy vehicle; VE = value engineering.

It is important to hold the VE study early enough during the project-development phase to incorporate acceptable VE recommendations. The letting may be delayed if there is not enough time to incorporate recommendations into the plans. Per industry best practice, the ideal time to do a VE study is in or near the scoping and preliminary design phase or near the time when design alternatives are being examined and the public is fully engaged. Enough engineering must have taken place such that the design framework is sufficient to operate from, but it is best if significant commitments have not been made.

VE studies are strongly suggested to be a minimum of 4 days, with 5 days most desirable. Teams typically are multidisciplinary and consist of 5 to 8 individuals who are not personally involved in the design of the project. Depending on the size and complexity of the project, the number of members in a VE team may exceed that range. However, a minimum of 5 individuals is required, as a team of fewer than 5 tends to limit the amount and variety of creative input.

8.7.7 Design Features and Requirements

As VE is a project management strategy, the parameters of each study will depend upon the project and the team involved.

8.7.8 State of the Practice

FHWA collects information annually on VE accomplishments achieved within the Federal-Aid Highway Program, including the projects administered by Federal Lands Highway. For VE studies conducted during the preconstruction phase, the FHWA tracks the number of studies conducted, proposed and implemented recommendations, and the value of the implemented recommendations. Additionally, similar information is compiled for the VE change proposals submitted by contractors during the construction of the projects. This information is available in the Federal-Aid Value Engineering Summary Reports at https://www.fhwa.dot.gov/ve/vereport.cfm.

In FY 2018, 175 VE studies were conducted by all the state DOTs. States with the most VE studies conducted are California (20), Florida (23), Michigan (10), North Carolina (10), and Texas (28).

8.7.9 Cost

The cost to conduct a VE study varies depending on the complexity of the project and can range anywhere from $15,000 to over $1 million.

8.7.10 Resources and References

AASHTO. *Guidelines for Value Engineering*, 3rd edition, 2010.

California Department of Transportation (Caltrans). *Annual Efficiencies Report to the California Transportation Commission: Fiscal Year 2017–2018*, n.d.

8.8 Accelerated Bridge Construction

8.8.1 Description

According to FHWA, ABC uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the on-site construction time that occurs when building new bridges or replacing and rehabilitating existing ones.

The use of prefabricated bridge elements and systems (PBES) and SPMTs are typical in ABC projects. PBES are structural components of a bridge (e.g., footings, piers, pier caps, abutments, bridge decks, railings) that are built off site or adjacent to the alignment. An SPMT is a platform vehicle used for transporting massive objects, such as bridges, large bridge sections, and other objects too big or heavy for trucks. SPMTs are used to expedite bridge superstructure removal and construction. After the bridge is removed with the SPMT, the PBESs are transported into position and placed using the SPMT.

8.8.2 When to Use

ABC is applicable for critical or high-volume facilities for which the societal costs of closure or loss of mobility are considered significant.

To provide a rational and consistent method of selecting appropriate ABC projects, FHWA and some states developed the following decision-making tools.

The first ABC decision-making approach was developed by FHWA in 2005 based on a framework for PBES decision-making. In this framework, a flowchart and matrix incorporating decision criteria are used to help decision makers choose between conventional and ABC alternatives. The flowchart assists the users in making a high-level decision on whether a prefabricated bridge might be an economical and effective choice for the specific bridge under consideration (Figure 8.2). The matrix provides users with additional details and may provide additional assistance in making a high-level decision about the type of construction and approach to apply to a particular project.

A number of state DOTs have developed their own ABC decision-making tools as they work to implement ABC in their states. Foremost in this effort is the 2012 pooled-fund project led by the Oregon DOT to develop a decision tool to help determine whether a project is a good candidate for ABC. This software, the ABC Decision Tool, is being used in several states.[13]

UDOT developed an Excel-based ABC rating procedure and decision flowchart in 2010, with an update in 2014. This tool assesses the project under consideration against eight main factors: ADT, delay/detour time, bridge classification, user costs, economy of scale, use of typical details, safety, and railroad impacts.[14]

Similarly, in 2017 MnDOT developed a three-stage process to assist in determining which bridges are best suited for ABC. Complete details for each of the three stages are included on the Bridge Office ABC website at http://www.dot.state.mn.us/bridge/abc/.

8.8.3 Benefits

According to FHWA EDC-2, benefits to employing ABC include the following:

- **Reduced construction time.** Decreasing construction time directly benefits the public by significantly reducing traffic delays and road closures.
- **Reduced agency costs.** ABC can be the most cost-effective means of construction, especially when total project costs, including ROW acquisition, project administration, maintenance of traffic, environmental mitigation utility relocation, and escalation or railroad-flagging costs are considered.

---

[13] The user manual for the Oregon DOT ABC decision-making software is found at https://www.fhwa.dot.gov/bridge/abc/dmtool/software_manual.cfm.

[14] The UDOT ABC Decision Making Process tool can be downloaded at https://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:4356,.

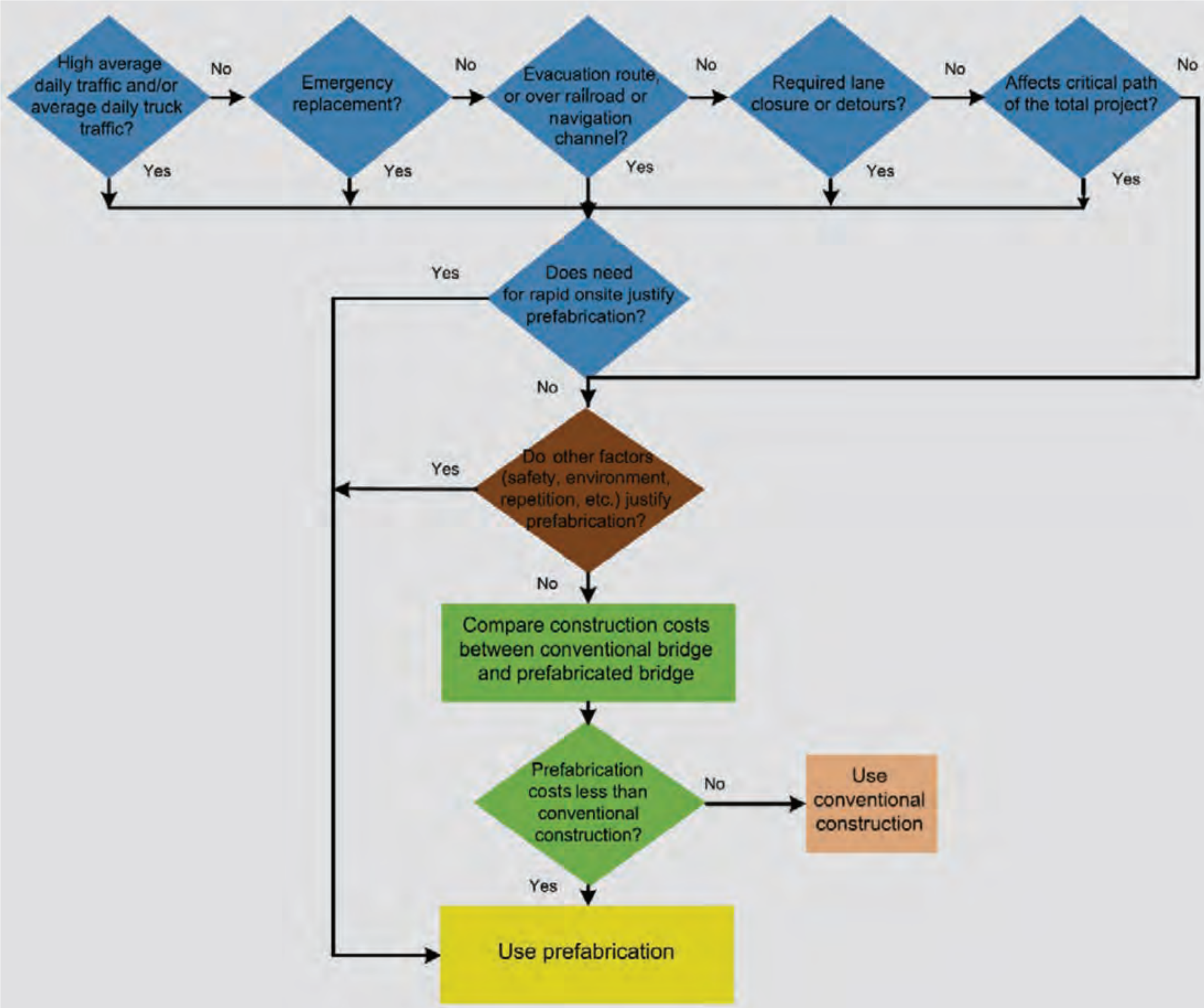


Figure 8.2. Flowchart for high-level decision on whether a prefabricated bridge should be used in a certain project (Credit: FHWA).

- **Reduced user costs.** ABC dramatically reduces work zone RUC associated with bridge construction projects on existing roadways.
- **Improved motorist and worker safety.** Limiting the duration of traffic impacts reduces the exposure to work zone crashes, increasing safety for both construction workers and the traveling public.
- **An effective solution to environmentally sensitive areas.** ABC technologies may also be an effective solution or alternative in areas where construction may be constrained or delayed by environmental considerations or limitations.

8.8.4 Expected Effectiveness

ABC projects have reported significant reductions in construction time, thereby reducing road-user delays and reducing workers' exposure. The FHWA Highways for Life Demonstration

Projects web page (https://www.fhwa.dot.gov/hfl/projects/) provides a list of projects constructed using the ABC technique. A review of example projects indicates that ABC had the following advantages:

- Reduced construction time by more than 2 months, preventing an estimated 58 crashes (reconstruction of I-25 Bronco Arch Bridge, Denver, Colorado, July 2015).
- Reduced construction time by 8 months resulting in user cost savings of approximately $2.24 million, preventing an estimated 15 crashes (I-70 bridge replacement, Denver, Colorado, October 2014).
- Reduced construction time by 39 months, resulting in user cost savings of approximately $136 million (reconstruction of Fourteen Bridges on I-93, Medford, Massachusetts, October 2014).

8.8.5 Crash Modification Factor

A CMF is not applicable; however, alternative contracting and construction strategies reduce construction time and impact to motorists and workers, which improves overall work zone safety.

8.8.6 Implementation Considerations

Acceleration of construction should not sacrifice the quality of construction or design. Any process performed too quickly has the potential to sacrifice quality. This is particularly true in the application of prefabricated materials. Such materials can often be constructed off site and out of the presence of construction inspectors. Thus, careful inspection of the respective materials is extremely important. Plant inspection agreements and fabrication certifications can be established to ensure this careful inspection.

It is important that the values for incentives and for penalties established for the contract be properly balanced. Furthermore, agencies need to be able to accurately estimate reasonable completion dates and critical milestones. Finally, the work needs to be carefully planned, with appropriate safety precautions incorporated, to ensure production pressures do not lead to shortcuts that reduce safety or increase risk to workers.

8.8.7 Design Features and Requirements

The majority of the design and construction specification needs for an ABC project are contained in the AASHTO Load and Resistance Factor Design Bridge Design Specifications and the AASHTO Load and Resistance Factor Design Bridge Construction Specifications.

8.8.8 State of the Practice

California, Colorado, Florida, Iowa, Minnesota, Oregon, Utah, and Washington are examples of state DOTs that frequently use an ABC approach. Examples of ABC projects are widely available on state DOT websites and are not repeated here to avoid duplication. Instead, readers are requested to refer to the web pages discussed below for more information on ABC.

UDOT has championed and widely implemented ABC, the use of ABC is now common practice throughout the state, and Utah is seen as a national leader for ABC. Since 2010, UDOT has used ABC on more than 200 bridges. Examples of ABC projects implemented by UDOT can be found on their Project Highlights web page at https://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:2125,.

In 2013, RITA (under U.S. DOT) provided funding to establish and operate the ABC University Transportation Center (ABCUTC) at Florida International University. ABCUTC includes detailed documents on ABC/PBES projects that have been successfully built within the United States. The detailed information includes plans, schedule, photos, and a project summary report. The list of ABC projects can be found at http://utcdb.fiu.edu/search?.

The FHWA Highway for Life Demonstration Project web page (https://www.fhwa.dot.gov/hfl/projects/) provides a list of projects constructed using the ABC technique. The FHWA EDC initiative has assisted in the development of many projects employing ABC technologies. In 2010, the EDC-1 bridge innovations were PBES and geosynthetic reinforced soil-integrated bridge systems (GRS-IBS). In 2011–2012, more than 1,000 bridges were built in an accelerated manner using some form of PBES technology. In 2012, the EDC-2 bridge innovations were PBES, GRS-IBS, and lateral-slide technologies. In 2013–2014, the number of bridges built with PBES technologies increased significantly. In 2014, the 11 EDC-3 innovations include GRS-IBS and ultra high performance concrete connections for prefabricated bridge elements.

8.8.9 Cost

The costs for accelerated construction depend on the project characteristics. However, projects reviewed indicated that construction time is reduced, resulting in savings in RUC and an overall safer project.

8.8.10 Resources and References

Anderson, S. D., and I. Damnjanovic. *NCHRP Synthesis 379: Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion*. Transportation Research Board of the National Academies, Washington, D.C., 2016. https://doi.org/10.17226/23075.

Culmo, M. P. *Accelerated Bridge Construction: Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems*, FHWA-HIF-12-013, FHWA, U.S. DOT, November 2011.

Doolen, T., A. Saeedi, and S. Emami. *Accelerated Bridge Construction (ABC) Decision Making and Economic Modeling Tool,* Federal Highway Administration, FHWA-OR-TPF-12-06, December 2011.

Lee, J. H., and B. McCullouch. *Review Construction Techniques for Accelerated Construction and Cost Implications,* Project No. C-36-67 WWWW, Purdue University, West Lafayette, Ind., August 2009.

NCHRP Project 20-68A, Scan 07-02, "Best Practices in Accelerated Construction Techniques." National Cooperative Highway Research Program, Transportation Research Board. Washington, D.C., 2009.

Pyeon, J., and E. B. Lee. *Systematic Procedures to Determine Incentive/Disincentive Dollar Amounts for Highway Transportation Construction Projects*, California Department of Transportation, CA-MTI-12-2908, June 2012.

WisDOT. *Transportation Synthesis Reports: Accelerated Construction Techniques*, Wisconsin Department of Transportation, October 22, 2004.

CHAPTER 9

Traffic Control Devices

The 2009 MUTCD, Part 6, and state manuals govern standards, guidance, and other site-specific information pertaining to installing, maintaining, and operating traffic control devices (TCDs). TCDs, such as warning signs, arrow panels, and channelizing devices, are required for all work zones, irrespective of work zone type or duration. Therefore, this guidebook does not address these common TCDs; however, the following TCDs are covered in this section:

- Smart arrow boards
- Lighting devices

9.1 Smart Arrow Boards

9.1.1 Description

A smart arrow board is an arrow board containing data-processing capabilities to send real-time data from the field (e.g., location, direction board is facing, active/inactive display), which can then be disseminated through traveler information mechanisms such as TMCs, 511 systems, and social media dissemination systems. An example of a smart arrow board feedback to 511 and mobile units is shown in Figure 9.1.

Consistent reporting of accurate, useful information about lane closures to inform travelers is a challenge for many state DOTs. Longer-duration construction and maintenance activities are typically entered into road condition reporting systems or advanced traffic management systems (ATMSs) to alert TMC operators and the traveling public. However, fast-changing and shorter-duration activities are challenging and time consuming to enter. These events are therefore not always entered to alert TMC operators or the traveling public of lane or shoulder closures. Generic reports (e.g., "intermittent lane closures from May 15 through June 30") posted to traveler information systems, such as 511 web or mobile apps, provide limited value to travelers. Though construction and maintenance field staff often have access to up-to-date lane closure information, on-site conditions and other responsibilities make frequent reporting of this information a low priority.

9.1.2 When to Use

Smart arrow boards can be used on any roadway and project type for which shoulder or lane closure is required, regardless of how long a work zone remains in place.

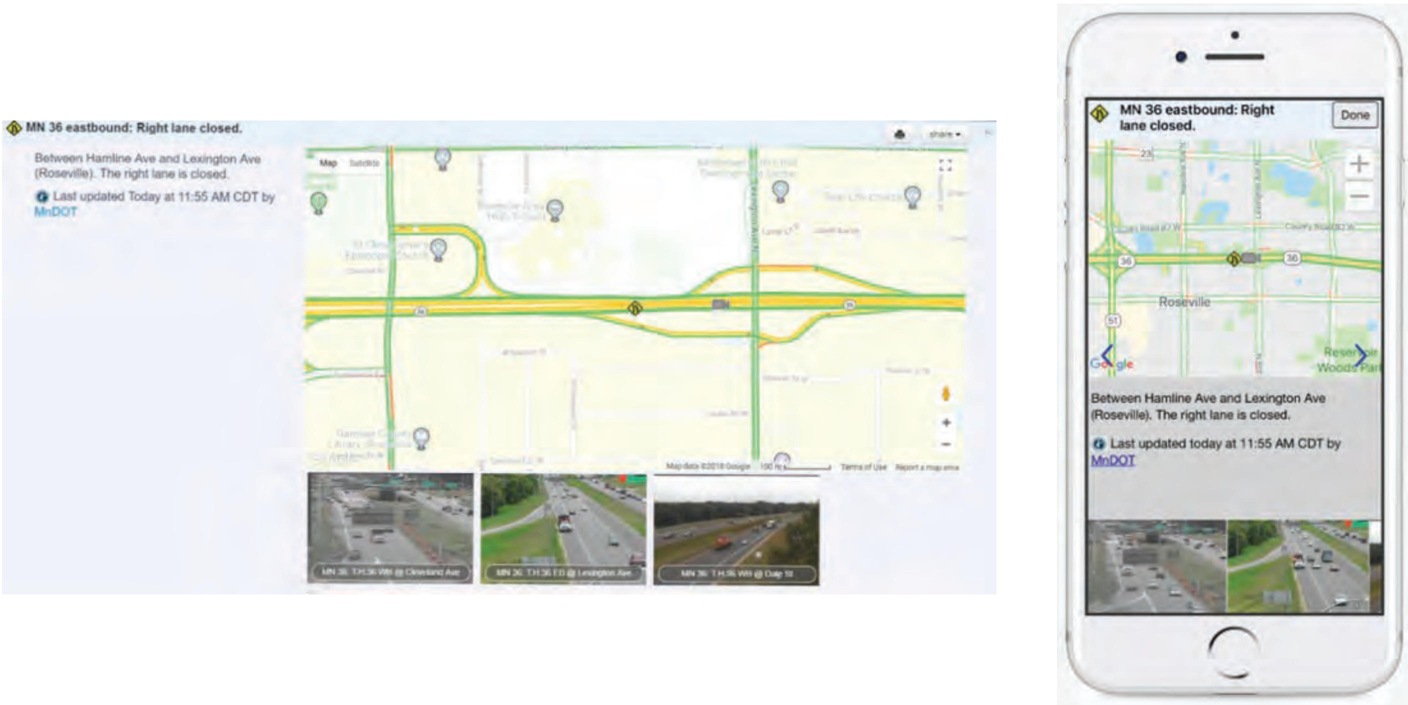


Figure 9.1. Screenshot of 511 desktop and mobile display during a stationary lane closure (Credit: MnDOT).

9.1.3 Benefits

The use of smart arrow boards provides the following benefits (Enterprise 2017):

- Detailed, consistent, and reliable real-time information about lane closures disseminated to travelers upstream of the closure through message signs, traveler information mediums, and connected vehicle applications.
- Improved situational awareness by TMC operators of real-time lane closures in the field.
- Improved construction-management opportunities, including the ability to verify contractor work status to document lane closure times for use on lane-rental projects or for enforcing restricted hours or to cross-check any lane closure updates required of the contractor.
- Increased archived data available for evaluation, performance management, and research to better understand work zone mobility impacts and exposure for reporting purposes, to plan future work zones, and to improve performance-based specifications.
- Foundational communication technology to broadcast display status and lane closure-related information to connected and automated vehicles.
- Depending on the amount of manual involvement by field staff, the potential for faster response time for maintenance needs, including times when a trailer-mounted arrow board is hit by a passing vehicle or blown out of place by strong winds, given notifications to field staff of system functionality.

9.1.4 Expected Effectiveness

An evaluation of smart arrow boards was conducted by MnDOT in 2018. MnDOT piloted 20 smart arrow boards (trailer mounted and truck mounted) used by Twin Cities metro area maintenance shops, with the functionality to export status and location for stationary and mobile/rolling closures. The project then integrated the reported arrow board status information with the MnDOT Intelligent Roadway Information System (IRIS) and the MnDOT Condition Acquisition and Reporting System (CARS).

MnDOT hired a vendor to collect and communicate arrow board data to the vendor server. At the same time, MnDOT staff programmed updates to IRIS for it to access the vendor server and process the available arrow board information. Finally, MnDOT updated CARS for it to access the arrow board information in IRIS, process the information, and generate reports for the 511 website and apps.

Figure 9.1 illustrates the desktop and mobile display on 511 at 11:55 a.m. during the stationary lane closure, and the mobile worksite reports in the 511 display that is automatically updated every 1–2 minutes.

The project provided the following benefits:

- Detailed lane closure information disseminated through traveler information mechanisms such as 511 phone, web, and social media dissemination systems.
- Regional TMC operators alerted in real time of closures so they may post messages to the appropriate signs, notifying travelers of upcoming lane closures.
- Improved information for performance reporting and measurement owing to improved accuracy of lane closure information.

Since the completion of the pilot, MnDOT has turned the system live. Maintenance vehicles and trailers with the arrow monitoring units installed are displaying arrow board status when activated on MnDOT's 511 website, mobile app, and twitter feeds.

9.1.5 Crash Modification Factor

A CMF is not available for this strategy.

9.1.6 Implementation Considerations

The smart arrow boards must meet the requirements found in the 2009 MUTCD, Part 6F.61. There are two options for smart arrow board protocol:

- Option 1, which receives data from an intermediary server, and
- Option 2, in which data are polled directly from the arrow board.

An Enterprise project completed a system engineering process for smart arrow boards. The results of this effort can be found at http://enterprise.prog.org/Projects/2015/workzone_notifications_in_travelerinfo.html.

9.1.7 Design Features and Requirements

In general, the smart arrow board reporting system consists of two largely independent systems, as depicted in Figure 9.2: (1) arrow boards and (2) the traveler information dissemination systems and data archives used by transportation agencies to collect, process, disseminate, and store traffic data and information for use by the traveling public and agency stakeholders.

9.1.8 State of the Practice

At the time of the development of this guidebook, Iowa and Minnesota are the only two states currently deploying or planning to deploy smart arrow boards in work zones. A brief overview of their programs follows.

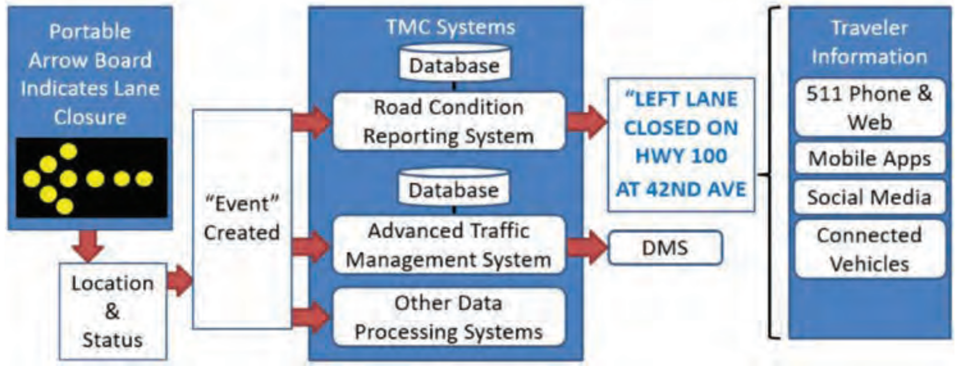


Figure 9.2. Smart arrow board concept of operations (Credit: Enterprise 2017).

9.1.8.1 Iowa

In August 2019, the Iowa DOT announced plans to adopt smart arrow board technology to collect near real-time data on the status of lane closures in construction and maintenance work zones. As a part of this, Iowa DOT took on the following responsibilities:

- Work with Iowa chapter members and arrow board manufacturers to finalize specifications and test smart arrow boards before the end of 2019.
- Evaluate smart arrow boards beginning in September 2019 to validate the system requirements and specifications.
- Develop and publish supplemental specifications by October 2020.
- Deploy smart arrow boards on Interstate projects let on or after January 20, 2021.
- Deploy smart arrow boards on all Iowa DOT projects let on or after January 19, 2022.

9.1.8.2 Minnesota

MnDOT developed a smart arrow board evaluation plan (Enterprise 2017) and piloted the program in 2018, as mentioned in Section 9.1.4.

9.1.9 Cost

The cost for a trailer-based smart arrow board ranges between $10,000 and $12,000. The cost for a truck-mounted smart arrow board ranges between $6,000 and $8,000.

9.1.10 Resources and References

Enterprise. *Real-Time Integration of Arrow Board Messages into Traveler Information Systems-Evaluation Plan*, Transportation Pooled Fund Study TPF-5 (231), September 2017.

Iowa DOT. *Smart Arrow Board Deployment Plan*, Iowa Department of Transportation, August 2019.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

MnDOT. *Real-Time Integration of Arrow Board Messages into Traveler Information Systems: Final Requirements Testing Report*, Minnesota Department of Transportation, December 2018.

Virshbo, K., J. Schroeder, G. Coffee, and D. Rowe. *Follow the Arrow Boards: Generating Roadwork Reports Automatically from GPS-Equipped Arrow Boards at Work Sites for Situational Awareness and Traveler Information*, Presented at the Intelligent Transportation Society of America 2018 Annual Meeting, Detroit, Mich., June 4–7, 2018.

9.2 Lighting Devices

9.2.1 Description

Roadway lighting devices enhance nighttime work zones by illuminating the work area to help drivers see TCDs, roadway alignment, pavement markings, and workers. Refer to Section 6.2 for information on night work.

The two most commonly used temporary lighting systems are the following:

- **Portable light plant towers.** This lighting consists of numerous luminaires mounted to a mast arm capable of holding the luminaires at various mounting heights. The mast arm is attached to a trailer with a generator that can be towed by a vehicle. To prevent glare, lights are aimed downward at the work—not toward the traffic—and rotated outward no greater than 30 degrees from straight down, unless the light has been designed specifically to prevent glare.
- **Balloon lighting.** This type of lighting consists of a large balloon-type luminaire that provides a large area of evenly distributed light and is relatively glare free (Figure 9.3). Balloon lights can be mounted on slow-moving equipment or portable light towers.

9.2.2 When to Use

The use of lighting devices is considered under the following scenarios:

- Any nighttime applications during which a lane is taken intermittingly for construction.
- Construction is undertaken on a multilane highway or Interstate.
- The work zone is in a rural area with no additional highway lighting.
- The project involves nighttime asphalt paving and bridge closures.

9.2.3 Benefits

The provision of lighting devices provides the following benefits:

- Improves work zone conspicuity and worker visibility.
- Provides better guidance for drivers traveling through the work zone.

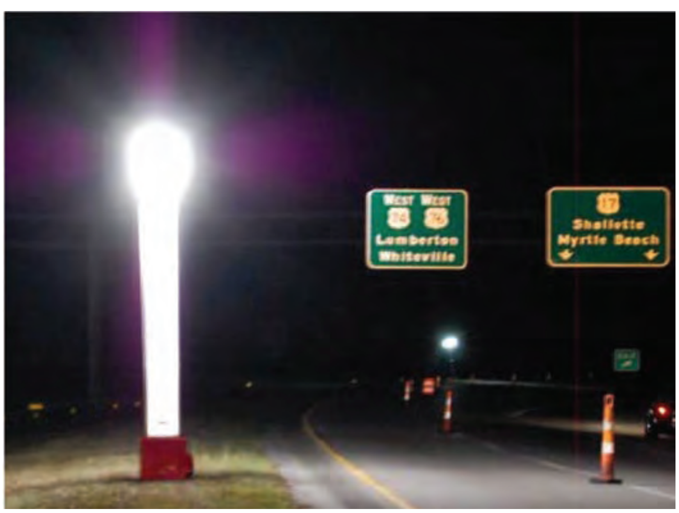


Figure 9.3. Balloon lighting (Credit: NCDOT).

- Creates uniform speeds throughout the work area.
- Allows construction work to be completed safely and effectively.
- Improves the overall safety of the workers and the traveling public.

9.2.4 Expected Effectiveness

Improved visibility and awareness of traffic control information are expected to reduce conflicts related to drivers not being able to see TCDs well or soon enough to comply with the sign message or to follow the appropriate path. Poor visibility of TCDs often contributes to nighttime crashes, and improving drivers' expectancy of the roadway conditions should improve safety.

Work zone presence lighting has been evaluated in North Carolina, Michigan, Tennessee, Virginia, and Georgia with positive results. The average speed reduction is 5.74 mph with the highest speed reduction over 7 mph (Table 9.1).

9.2.5 Crash Modification Factor

A CMF is not available for this strategy.

9.2.6 Implementation Considerations

The FHWA *Nighttime Lighting Guidelines for Work Zones* (2013) identified the following factors when selecting the types of lighting best suited for the work zone:

- **Mobile work zones, such as a paving operation.** If the work zone is mobile, then the length of the work activity for one night may dictate either that the lighting plan be continuous for the length of the work zone or that a mobile system be used so that the lighting moves with the various work activities.
- **Stationary work zones.** Work duration would determine the type of lighting in this situation. A long-duration work zone could use roadway luminaires mounted on temporary poles, while shorter-duration work zones could use trailer-mounted light towers or balloon lighting at fixed locations.

Table 9.1. Work zone presence lighting evaluation summary.

State	Route	Work Zone Speed Limit (mph)	Average Speeds (mph)		Average Speed Reduction (mph)
			With Presence Lighting	Without Presence Lighting	
North Carolina	US-17	55	57.70	51.94	5.76
Michigan	US-23	55	56.92	51.27	5.65
Michigan	I-94	60	65.19	57.94	7.25
Michigan	I-94	60	67.78	62.82	4.96
Michigan	I-94	60	68.48	62.82	5.66
Tennessee	I-40	65	68.76	63.82	4.94
Tennessee	I-40	70	74.76	68.89	5.87
Virginia	I-64	65	67.47	60.62	6.85
Georgia	I-85	60	64.76	60.05	4.71

- **Glare**. Glare needs to be considered from each direction and on all approaching roadways and opposing lanes of traffic, even those separated by grass medians. The goal is to minimize glare from the lighting systems for both the workers and any adjacent motorist.
- **Light trespass.** Trespass occurs when light spills onto private property. This could be a problem in a residential area—depending on how long the lighting system is in place—and could require shielding as a preventative measure.
- **Backup lighting.** Backup lighting must be stored on the project site and readily available for use at all times during nighttime operations. The backup systems must meet the same criteria as the primary system.

9.2.7 Design Features and Requirements

Work zone illumination needs to be considered during the design phase whenever night construction would be required or allowed. This requires the following actions during the project design phase:

- Determine the area to be illuminated.
- Determine the work activities to be performed.
- Select the type of light source.
- Determine required lighting level.
- Select fixture locations.
- Determine luminaire wattage.
- Select luminaires and aiming points.
- Check design for adequacy.

According to the 2009 MUTCD (Section 6F.82, Floodlights, and Section 6G.19, Temporary Traffic Control During Nighttime Hours), recommendations are for 5 foot candles of illumination for general activities, 10 foot candles for activities around equipment, and 20 foot candles for activities requiring high precision and extreme care. Both of these statements in the MUTCD are identified as support conditions.

NCHRP Report 498: Illumination Guidelines for Nighttime Highway Work (Ellis, Amos, and Kumar 2003) developed illumination guidelines based on work zone task illumination requirements.

Level I illuminance is important in areas where the work crew is in motion, moving from spot to spot. This level of illuminance is appropriate for tasks requiring low accuracy, tasks involving slow-moving equipment, and areas where workers need to see large objects such as work zone equipment or fixed objects on the roadside.

Level II illuminance is recommended for areas on or around construction equipment to provide a safer environment for the workers operating the equipment, allowing them to perform tasks that require a moderate level of accuracy.

Finally, **Level III illuminance** is appropriate for those tasks that require a greater level of visual acuity or for tasks with a higher level of difficulty.

The recommended illumination levels are summarized in Table 9.2.

9.2.8 State of the Practice

Providing additional temporary lighting in work zones with the sole intent of increasing motorist safety is currently not a typical work zone practice. Lighting is typically provided in practice to illuminate the work area and increase the visibility of the workers.

Table 9.2. Recommended illumination levels by task.

Examples of Tasks	Illumination Level	Average Minimum Maintained Illuminance
All work operations areas; setup of lane or road closures, lane closure tapers, and flagging stations	Level I	54 lux (5 fc)
Areas on or around construction equipment; asphalt paving, milling, and concrete placement/removal	Level II	108 lux (10 fc)
Pavement or structural crack/pothole filling; joint repair, pavement patching/repairs; installation of signal/electrical/mechanical equipment	Level III	215 lux (20 fc)

Note: A foot-candle (fc) is a unit of illumination equal to one lumen per square foot, or 10.764 lux.
Source: Ellis, Amos, and Kumar (2003).

Florida, Missouri, Oregon, Washington, New York, Maryland, Mississippi, North Carolina, California, and Michigan have lighting standards for nighttime construction. Some of those standards have a limited specification about nighttime lighting and some of them, such as those in New York and North Carolina, are comprehensive regarding the practice of nighttime work zone lighting. A comparison of these limited provisions reveals that there is a lack of consensus among state DOTs on the lighting requirements for nighttime highway construction operations.

Table 9.3 summarizes the specifications used by seven agencies.

NCDOT has developed a typical application for work zone "presence" lighting, which is attached as Appendix H.

Table 9.3. Comparison of state DOT nighttime work zone lighting specifications.

Agency	Activity or Task	Specifications
Caltrans	All nighttime operations	10 fc
FDOT	Proper workmanship and inspections	5 fc
GDOT	• All nighttime operations • Average maintained horizontal illuminance	• 20 fc over the work area for tower lights • Minimum 50,000 lumens for a tower light • 460,000 lumens combined outputs of all fixtures on each tower light • Between 22,000 and 50,000 lumens for machine lights
IDOT	All nighttime operations	• Minimum of 5 fc throughout the work area • Minimum of 10 fc for flaggers
MoDOT	Active construction equipment and labor	• 5 fc
	Flaggers and other specified locations in lighting plan	• 0.6 fc
NJDOT	Tasks on and around equipment	• 100 lux • uniformity ratio of 5:1 or less
	Crack filling, saw cutting, joint sealing, etc.	• 200 lux • uniformity ratio of 5:1 or less
NCDOT	Tower lights	• 50,000–460,000 lumens • 20 fc

Note: A foot-candle (fc) is a unit of illumination equal to one lumen per square foot, or 10.764 lux. DOT = department of transportation.
Source: FHWA (2013).

9.2.9 Cost

The rental cost for portable light plant towers ranges from $500 to $900 per month, and the purchase cost ranges from $9,000 to $15,000 per unit. These costs vary depending on location, type, size, height, and other factors. Based on a similar range of factors, the cost for balloon lighting normally ranges from $2,000 to $3,800 per unit.

9.2.10 Resources and References

Anani, S. *Work Zone Illumination Design: Guidance Strategies to Specify Appropriate Work Zone Lighting Plan.* University of Wisconsin–Milwaukee, August 2015.

Bhagavathula, R., R. Gibbons, A. Medina, and T. Terry. *Examination of the Current Practice of Lighting in Virginia: Nighttime Work Zones and Improving Safety Through the Development of Nighttime Lighting Specifications: Summary Report*. FHWA/VTRC 18-R3, Virginia Department of Transportation, September 2017.

Bullough, J. D., and M. S. Rea. *Final Report Optimizing Work Zone Lighting*, NJ-2016-004, New Jersey Department of Transportation, October 2016.

Bullough, J. D., N. P. Skinner, J. D. Snyder, and U. C. Besenecke. *Nighttime Highway Construction Illumination,* C-08-14, New York State Department of Transportation, August 2014.

Ellis, R. D., Jr., S. Amos, and A. Kumar. *NCHRP Report 498: Illumination Guidelines for Nighttime Highway Work*. Transportation Research Board of the National Academies, Washington, D.C., 2003. https://doi.org/10.17226/21955.

FHWA. *Nighttime Lighting Guidelines for Work Zones: A Guide for Developing a Lighting Plan for Nighttime Work Zones.* DTFH61-06-G-00004, American Traffic Safety Services Association, April 2013.

Finley, M. D., G. L. Ullman, J. D. Miles, and M. P. Pratt. *Studies to Assess the Impact of Nighttime Work Zone Lighting on Motorists,* FHWA/TX-13/0-6641-1, Texas Department of Transportation, May 2013.

Gambatese, J. A., and A. Jafarnejad. *Use of Additional Lighting for Traffic Control and Speed Reduction in Work Zones*, FHWA-OR-RD-18-10, Oregon Department of Transportation, February 2018.

Huckaba, D. A. "Safer Nighttime Construction Zones Through Better Lighting: Illinois Develops and Applies Practical Guidelines," *TR News*, 260, Illinois Department of Transportation, January–February 2009.

Kite, S., and W. Lackey. *Work Zone Traffic Control Breakout Session*, North Carolina Department of Transportation, February 21–22, 2019.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

MDOT. *Special Provision for Lighting for Night Work*, Michigan Department of Transportation, APPR: December 21, 2010.

Shaw, J. W., W. Bremer, Y. Han, M. V. Chitturi, A. Bill, and D. A. Noyce. *Guidelines for Work Zone Designers—Illumination for Night Construction*, DTHF6114H00011, FHWA, U.S. DOT, June 2018.

CHAPTER 10

Motorist Information Strategies

Motorist information strategies provide road users with current or real-time information regarding the project work zone. This section covers three motorist information strategies:

- Speed feedback signs
- Construction truck entering and exiting system
- Real-time travel system

10.1 Speed Feedback Signs

10.1.1 Description

Speed feedback signs are electronic signs that use vehicle speed-sensing technology to detect and display a vehicle's current speed to the driver. The vehicle speed is usually displayed along with the regulatory speed with or without a message alerting the drivers to use caution. There are two types of speed feedback signs:

1. **Dynamic speed display signs.** An electronic LED display is activated by radar or some type of speed-sensing device and then displays, to approaching drivers, the speed at which they are traveling. Dynamic speed display signs (DSDSs) are typically installed in conjunction with a regulatory black-and-white speed limit sign mounted above the display. DSDSs are commonly referred to as "your speed is" signs, "driver feedback signs," "speed feedback signs," "speed display trailers," "radar speed display," or "speed monitoring devices." A DSDS can be fabricated as a separate static sign and dynamic display, or, as Figure 10.1 shows, a single static sign and dynamic display.
2. **PCMS with radar**. A PCMS fitted with a radar sensor (PCMR) detects the speed of passing vehicles and activates when the speed of a vehicle exceeds a preset threshold value. Based on the specific radar speed, the PCMR is often programmed to display different messages. The radar sensor calculates the speed of passing vehicles in real time and the PCMS displays a message based on the driver's speed. Common messages displayed include
   - YOUR SPEED *X* MPH/SLOW DOWN,
   - REDUCE SPEED IN WORK ZONE, and
   - EXCESSIVE SPEED/FINES DOUBLE.

   Figure 10.1 shows a typical PCMR.

10.1.2 When to Use

Speed feedback signs are recommended for use under the following conditions (MnDOT 2019; FHWA 2015; Veneziano et al. 2012):

DSDS (Credit: Ohio DOT)

PCMR (Credit: Arizona DOT)

Figure 10.1. DSDS (left) and PCMR (right).

- When the mean speeds or 85th percentile speeds exceed the PSL by at least 10 mph.
- When hazardous roadway conditions, such as a temporary unusually tight curve or a rough road surface, which require extra driving precautions, are present.
- When workers are directly adjacent to travel lanes and a lane or portion thereof is closed to traffic without protection of positive barrier.
- When the work zone increases or is perceived to increase speeding-related crashes.

Use of the speed feedback signs is not limited to any certain PSL value; however, they may have better utility in areas with higher speeds.

While speed feedback signs may be used on all types of highways and work zones, in either rural or urban environments, in multilane applications with moderate-to-heavy traffic, it may be unclear which vehicle's speed is being displayed. Consequently, speed feedback signs are best suited for use on roadways with a maximum of two lanes in each direction.

10.1.3 Benefits

The use of speed feedback signs provides the following benefits:

- Reduces the speed of vehicles traveling through a work zone.
- Encourages speed limit compliance.
- Creates uniform speeds throughout the work area.
- Improves the overall safety of workers and the traveling public.

The DSDS has the option to store the vehicle speed data for use later. This is a major benefit when determining actual speeds in work zones.

10.1.4 Expected Effectiveness

Studies have shown that speed feedback signs result in drivers reducing their speed. A wide range of speed-reduction results has been found in the field.

- Results of DSDS field studies:
  - 8–9 mph reduction in mean speeds (Teng et al. 2009).
  - 0.9–3.1 mph reduction in mean speeds and 2–4 mph reduction in 85th percentile speeds (Brewer, Pesti, and Schneider 2005).

  - 3.7 mph reduction in mean speeds (Meyer 2003).
  - 3–4 mph reduction in mean speeds and 2–7 mph reduction in the 85th percentile speeds, approximately 20 percent to 40 percent increase in vehicles complying with PSL (Pesti and McCoy 2001).
  - 1.5–9 mph reduction in passenger automobile mean speeds and 3–10 mph reduction in truck mean speeds (Fontaine and Carlson 2001).
  - 2.9–3.8 mph reduction in mean speeds, 5 mph reduction in 85th percentile speeds, and about 12 percent increase in percentage of vehicles complying with speed limit (Maze 2000).
- Results of PCMR field studies:
  - 2 mph reduction in both observed mean and 85th percentile speeds (Roberts and Smaglik 2014).
  - 3–7 mph average speed reduction (Ravani et al. 2012).
  - 1.1–9.8 mph reductions in mean speeds and 2–11.5 mph reductions in 85th percentile speeds (Kenjale 2006).
  - 7 mph reduction in mean speeds and 5 mph for 85th percentile speeds (Sarasua et al. 2006).
  - 0.6–2.5 mph reduction in average speeds (GDOT 2005).
  - 1.6–2.1 mph reduction in automobile mean speeds and 1.3 mph reduction for trucks; 85th percentile speeds reduced by 2 mph for automobiles and by 1 mph for trucks (Brewer, Pesti, and Schneider 2005).
  - 5–8 mph reduction in speeds (Dixon and Wang 2002).

10.1.5 Crash Modification Factor

The CMF for a work zone DSDS is shown in Table 10.1. More information on development of WZCMFs can be found in Chapter 13.

10.1.6 Implementation Considerations

Speed feedback signs are placed adjacent to the work zone speed limit sign and in advance of roadway conditions that require speed reduction. It is advisable to place the speed feedback sign on a tangent section of roadway between 1,000 and 2,500 ft upstream of the work activity or hazardous condition.

Long work zones (>1 mi) may warrant the deployment of two or more speed feedback signs or the relocation of one sign several times nearer the active work area to improve its effectiveness. For long-term deployments, a solar-powered speed feedback sign may be considered if a fixed power supply source is not available.

Speed feedback signs are preferred for short-term use (<30 days). However, if the signs are going to be active for several weeks, periodic police enforcement may be considered to maintain their effectiveness.

Table 10.1. CMFs for DSDSs.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error
All	All	Not specified	Not specified	0.54	0.2

NOTE: While speed feedback displays may be used to manage work zone speeds, there were no studies available that examined safety effects in work zones specifically. The CMF was derived from a meta-analysis of past studies on non–work zone roads, so its applicability to a work zone situation is unclear. CMF = crash modification factor; DSDSs = dynamic speed display signs.

10.1.7 Design Features and Requirements

Each time a speed feedback sign is set up, the speed measuring device must be checked and adjusted (if necessary) to ensure accuracy. Speed measuring devices should provide a minimum detection distance of 1,000 ft and must have an accuracy of ±1 mph.

The speed feedback sign should remain blank when no traffic is detected. For speeds detected over a set maximum speed (generally 10 mph over the PSL on low-speed roadways [<45 mph] and 20 mph over on high-speed roadways [>45 mph]), the display should go blank. This measure is intended to discourage drivers from seeing how fast they can get the speed display trailer to read.

The display must be amber with a black background and dim automatically for nighttime operations.

The DSDS mounting height, lateral offset, and orientation must conform to applicable guidelines from the 2009 MUTCD, Sections 2A.18, 2A.19, and 2A.20. The digital speed display must show two digits (00 to 99) in mph, and the lowest portion of the display should be high enough to be visible over concrete barriers or safety drums.

Speed feedback sign placement should be incorporated at the project design stage to ensure signs are placed in a safe location with adequate driver visibility.

10.1.8 State of the Practice

DSDSs are used frequently in Illinois, Iowa, Minnesota, Oregon, and Washington. In 2014, IDOT began requiring contractors to furnish a DSDS whenever workers are present and lanes are restricted by construction.

The speed display trailer special provisions for Illinois and Iowa are attached as Appendix I1 and I2, respectively.

The use of PCMRs is infrequent, and literature shows their use limited to pilot projects in Arizona, California, Maryland, Oregon, and Washington.

10.1.9 Cost

A DSDS ranges between $7,000 and $10,000. Upper-cost DSDSs include flashing lights with an electronic message such as “SLOW DOWN.” For an additional $5,000, data collection with storage capability can be included.

A PCMR ranges between $10,000 and $12,000.

10.1.10 Resources and References

10.1.10.1 DSDS

Chen, Y., X. Qin, and D. A. Noyce. Evaluation of Strategies to Manage Speed in Highway Work Zones. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.

Chowdhury, T. D., and O. A. Abaza. *Effectiveness of VSL Signs in Reducing Crash Rates on Roadway Construction Work Zones in Alaska,* 19th International Conference on Traffic Guidance and Transportation, New York, October 5–6, 2017.

Cruzado, I., and E. T. Donnell. Evaluating Effectiveness of Dynamic Speed Display Signs in Transition Zones of Two-Lane, Rural Highways in Pennsylvania, Pennsylvania State University, *Traffic Control Devices, Visibility, and Highway-Rail Grade Crossings*, Vol. 2122/2009, pp. 1–8, *Transportation Research Record: Journal of the Transportation Research Board*, No. 0361-1981, December 2009.

Edara, P., C. Sun, C. Keller, and Y. Hou. *Evaluating the Benefits of Dynamic Message Signs on Missouri's Rural Corridors*, CMR 13-004, Missouri Department of Transportation, December 2011.

FHWA. *Planning Guidance for Intelligent Transportation Systems (ITS) Devices*, FHWA-JPO-14-14,5 Enterprise Transportation Pooled Fund Study TPF-5 (231), U.S. DOT, September 2015.

Fontaine, M. D., and P. J. Carlson. Evaluation of Speed Displays and Rumble Strips at Rural-Maintenance Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1745, 2001, pp. 27–38.

Gambatese, J. A., and A. Jafarnejad. *Evaluation of Radar Speed Display for Mobile Maintenance Operations*, OR-RD-16-09, Oregon Department of Transportation, December 2015.

Gambatese, J., and F. Zhang. *Safe and Effective Speed Reductions for Freeway Work Zones Phase 2*, FHWA-OR-RD-15-04, Oregon Department of Transportation, September 2014.

Gambatese, J. A., and F. Zhang. *Safe and Effective Speed Reductions for Freeway Work Zones Phase 3*, FHWA-OR-RD-15-09, Final Report, Implementation Research, Oregon Department of Transportation, 2015.

Jeihani, M., A. Ardeshiri, and A. Naeeni. *Evaluating the Effectiveness of Dynamic Speed Display Signs*, Morgan State University, September 2012.

Maze, T. *Speed Monitor Display*, Iowa State University, Midwest States Smart Work Zone Deployment Initiative, 2000.

McAvoy, D. S. *Work Zone Speed Reduction Utilizing Dynamic Speed Signs*, Ohio University, 2011.

Meyer, E. *Radar Speed Display*, Midwest States Smart Work Zone Deployment Initiative, 2003.

MnDOT. *Intelligent Work Zone Toolbox,* Office of Traffic, Safety, and Operations, Minnesota Department of Transportation, 2019.

Manual on Uniform Traffic Control Devices. FHWA, U.S. DOT, 2009. http://mutcd.fhwa.dot.gov/. [MUTCD]

Pesti, G., and P. T. McCoy. Long-Term Effectiveness of Speed Monitoring Displays in Work Zones on Rural Interstate Highways. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1754, 2001, pp. 21–30.

Teng, H., X. Xu, X. Li, V. Kwigizile, and A. R. Gibby. Evaluating of Speed Monitoring Displays for Work Zones in Las Vegas, Nevada, University of Nevada, Volume 2107 / 2009 Safety Maintenance and Surface Weather, *Transportation Research Record: Journal of the Transportation Research Board*, No. 036-1981, October 2009, pp. 46–56.

Veneziano, D., Z. Ye, K. Westoby, I. Turnbull, and L. Hayden. Guidance for Radar Speed Sign Deployments. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

10.1.10.2 PCMR

Brewer, M. A., G. Pesti, and W. H. Schneider IV. *Identification and Testing of Measures to Improve Work Zone Speed Limit Compliance*, Texas A&M Transportation Institute, Report 0-4707-1, October 2005.

Dixon, K., and C. Wang. *Development of Speed Reduction Strategies for Highway Work Zones*, FHWA-GA-02-9810, Georgia Department of Transportation, July 2002.

Garber, N. J., and S. T. Patel. *Effectiveness of Changeable Message Signs in Controlling Vehicle Speeds in Work Zones,* Virginia Transportation Research Council, FHWA/VA-95-R4, September 1994.

Garber, N. J., and S. Srinivasan. *Effectiveness of Changeable Message Signs in Controlling Vehicle Speeds in Work Zones: Phase II*, VTRC 98-R10, Virginia Transportation Research Council, December 1998.

GDOT. *Evaluating Speed Reduction Strategies for Highway Work Zones* (Smart Work Zones), Georgia Department of Transportation, January 2005.

Kenjale, A. D. *Use of Speed Monitoring Display with Changeable Message Sign to Reduce Vehicle Speeds in SC Work Zones*, All Theses, Paper 49, 2006.

Ravani B., C. Wang, W. A. White, and P. Fyhrie. *Evaluation of Methods to Reduce Speed in Work Zones*, AHMCT Research Center, University of California–Davis, 2012.

Roberts, C. A., and E. J. Smaglik. *Reduction of Speed in Work Zones Using ITS DMS Instant Feedback to Drivers: Vehicle Speed Versus Traffic Fine*, FHWA-AZ-14-681, Arizona Department of Transportation, August 2014.

Sarasua, W. A., J. H. Ogle, W. J. Davis, and M. Chowdhury. *Better Management for Speed Control in Work Zones*, FHWA-SC-06-10, South Carolina Department of Transportation, December 2006.

10.2 Construction Truck Entering and Exiting System

10.2.1. Description

A construction truck entering and exiting system is a SWZ system that automatically detects when construction vehicles enter or exit the work zone and provides advanced notification to motorists (Figure 10.2). The system works in real time and only activates when a construction

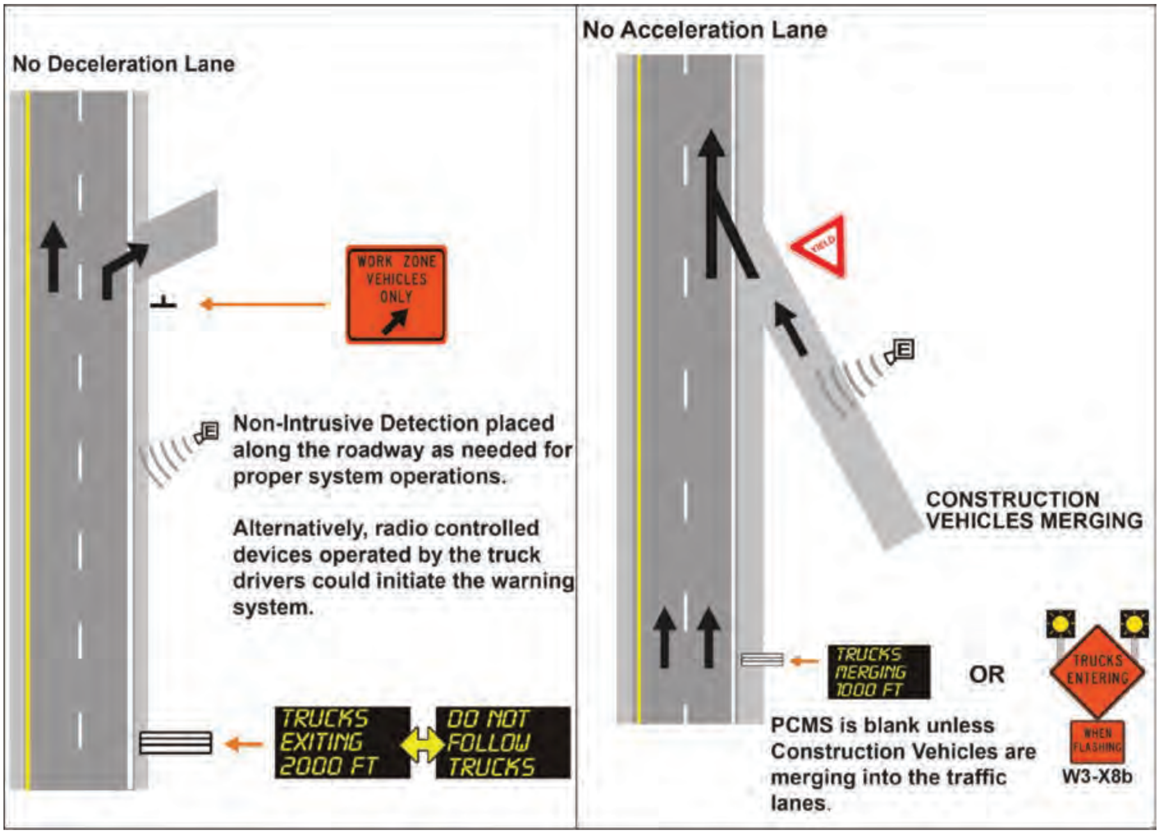


Figure 10.2. Construction truck entering and exiting system layout (Credit: MnDOT).

vehicle is entering or exiting a work zone. When a traffic sensor detects a construction vehicle either entering or exiting, motorists are alerted of a truck slowing down or entering the flow of traffic via either a PCMS or flashing static signs.

10.2.2. When to Use

WisDOT, in its FDM 11-50-5 TMP Process, lists the following criteria for consideration when determining if a truck entering and exit system should be installed:

- A construction vehicle uses a live traffic lane to either decelerate or accelerate because a deceleration or acceleration lane cannot be provided.
- The construction stage will be in place for an extended period.
- The construction entrance is visibly obscured to drivers.

According to the MnDOT Intelligent Work Zone Toolbox (2019 edition), a truck entering and exiting system should be considered for work zones under the following conditions:

- The trucks must utilize the main-line roadway to accelerate.
- A truck merge lane cannot be provided on the project.
- There is a sight restriction where trucks must enter the open traffic lane.
- There is insufficient space for a truck acceleration lane before entering the open traffic lane.
- Trucks must decelerate in the main-line roadway to enter the work space. This may result in vehicles following trucks into the work space, or traffic being required to adjust speed or change lanes.
- ADT on the roadway is above the level at which truck drivers can easily find a gap in traffic and accelerate within the traffic lane without causing traffic to suddenly adjust speed or change lanes.

10.2.3 Benefits

The use of a construction truck entering and exiting system provides the following benefits:

- Alerting motorists of slow construction vehicles entering and exiting the work zone.
- Reducing the frequency of motorists following construction vehicles into the work zone.
- Reducing rear-end crashes caused by abrupt slowdowns.

10.2.4 Expected Effectiveness

Research found no published literature relating to field evaluations of construction truck entering and exiting systems.

10.2.5 Crash Modification Factor

A CMF is not applicable for this strategy.

10.2.6 Implementation Considerations

Deployment consideration will address estimated traffic volumes, the type of vehicle conflicts anticipated, and project geometrics such as the merging, stopping, and site distance for the travelers to the hazardous condition. The system needs to be timed such that a PCMS message is viewable and understandable to drivers, and the traveler can perform appropriate evasive actions, such as slowing down and stopping, changing lanes, or changing travel routes. An appropriate PCMS distance will allow drivers time to change lanes or to slow appropriately to allow the truck to merge.

One issue is how to distinguish between construction trucks and all other equipment that moves within the work zone so that false triggers do not occur. This can be handled by carefully limiting the detection zone.

10.2.7 Design Features and Requirements

A basic system consists of a portable traffic sensor to detect construction vehicles, a PCMS, and a wireless communication link to trigger the sign. These systems are typically stand-alone, so they do not usually have a link to a TMC. Communication between the construction vehicle detector and the PCMS must occur in real time (milliseconds). Therefore, a point-to-point wireless transmission must be used as the transmission times for cellular communications are not fast enough.

Agencies can use a static sign option as well for trucks entering traffic, which would include individual beacons attached at the top of the sign that would flash when a truck is entering or exiting the main line.

10.2.8 State of the Practice

A construction truck entering and exiting system is one technology application promoted by the FHWA SWZ, as part of the FHWA EDC initiative. Many resources, including bid specifications, deployment plans, and case studies, are available on the National Work Zone Safety Information Clearinghouse (https://www.workzonesafety.org/swz/). States using these systems include Colorado, Iowa, Michigan, Minnesota, Ohio, and Texas.

The Gap is an 18-mi stretch of Interstate 25 in Colorado, running from south of Castle Rock to Monument. It is the only four-lane section of I-25, connecting Colorado's two largest

Figure 10.3. I-25 Construction truck warning system (Credit: CDOT).

cities—Denver and Colorado Springs. On average, nearly 80,000 vehicles travel the I-25 South Gap corridor daily with delays and crashes a common occurrence. Construction on the $350 million project, which is currently the longest construction zone in the state, began in Fall 2018; project completion is scheduled for 2022.

With an average of three trucks delivering or picking up material every 5 minutes daily throughout the 18-mi work zone, CDOT deployed a construction truck entering and exiting system to warn drivers. When a construction truck passed a sensor attached to a portable sign, a PCMS (Figure 10.3) further back in the corridor was triggered to warn motorists to slow down and yield to the truck.

10.2.9 Cost

The cost for deployment of a truck warning system depends highly on the project duration and the number of devices used (e.g., message boards, traffic sensors, speed trailers, cameras). In general, the rental cost is the same for a PCMS or a traffic sensor or camera—approximately $1,000 per week. For longer-duration projects, the rental costs can be substantially lower.

MnDOT reported the cost estimate, based on 2018 MnDOT rental prices, for a truck warning system using 1 PCMS and 1 sensor at $2,000 per week, $3,500 per month, or $13,000 per 6 months (MnDOT 2018). MnDOT also reported an approximate cost of $44,000 (or 0.37 percent of the total construction cost) for a truck warning system utilizing 6 PCMSs, 6 sensors, and 16 advance flashers deployed over 6 months. Similarly, Hawaii DOT reported an approximate cost of $400,000 (or 0.05 percent of total construction cost) for a truck warning system that deployed 8 PCMSs, 15 sensors, and a license plate reader system (TxDOT 2018).

10.2.10 Resources and References

FHWA Every Day Counts (EDC) Initiative: SWZs, Technology Applications: Entering/Exiting Vehicle Notification web page. https://www.workzonesafety.org/swz/swztechnology-application/types-of-applications/enteringexiting-vehicle-notification/.

MnDOT. *Intelligent Work Zone Toolbox,* Office of Traffic, Safety, and Operations, Minnesota Department of Transportation, 2019.

MnDOT. *Cost Estimates for ITS/IWZ Scoping*, June 6, 2018, https://www.dot.state.mn.us/its/docs/scopingdecisiontree.pdf, accessed May 26, 2020.

TxDOT. *Smart Work Zone Guidelines: Design Guidelines for Deployment of Work Zone Intelligent Transportation Systems (ITS)*, Texas Department of Transportation, October 2018.

WisDOT. *Facilities Development Manual (FDM) 11-50-5 Transportation Management Plan Process*, Wisconsin Department of Transportation, May 15, 2019.

10.3 Real-Time Travel System

10.3.1 Description

A real-time travel system (RTTS), also known as a travel time system, a work zone information system, or a travel time information and prediction system, is a portable automated system that predicts and displays travel time for motorists in advance of and through freeway construction work zones on a real-time basis (Figure 10.4). RTTSs use roadside sensors to collect real-time traffic-flow data, process the data, calculate estimated travel time between different points on the freeway, and display travel time information on several portable electronic CMSs positioned at predetermined locations along the freeway.

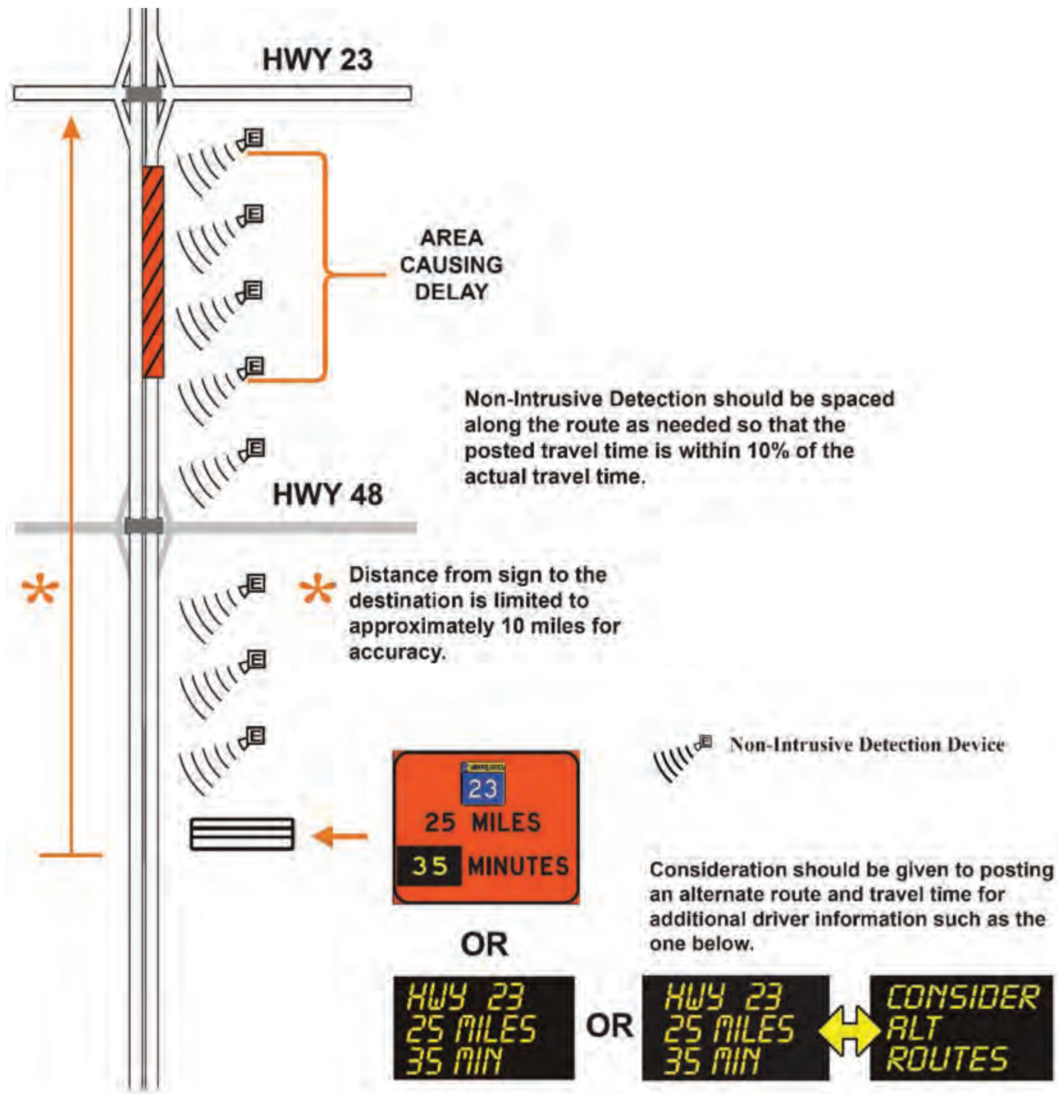


Figure 10.4. Real-time travel system layout (Credit: MnDOT).

In general, the system would display a message to travelers that, from their current location, it will take *X* minutes to reach a given location ahead of them (e.g., Hwy 23/25 miles/35 mins).

10.3.2 When to Use

RTTS may be considered for use under the following situations:

- The work zone may cause 10 minutes or more of additional travel time.
- The work zone causing the delay is more than 5 mi beyond the PCMS location (preferably 10 mi or more, such that multiple alternate routes are available).

Long-term projects are more ideal situations for using RTTSs because the system costs will be more easily justified. However, any situation that necessitates communication with drivers while they are in or approaching a work zone may be appropriate for RTTS applications.

NJDOT developed warrants as a guideline for determining the suitability of an RTTS. If the total score is less than 35, an RTTS should not be deployed. Scores between 35 and 45 should be reviewed by the executive manager of mobility and systems engineering. Scores above 45 should have an RTTS deployed as part of the contract. Table 10.2 shows the NJDOT warrants and their corresponding scoring criteria for RTTS.

10.3.3 Benefits

By obtaining traffic information and displaying travel times to motorists, an RTTS allows motorists to make an informed decision on which routes to take. If travel times are long because of roadwork or an incident, motorists can use an alternate route, thus reducing demand on the route. By providing motorists with traffic-condition information, the system also reduces the stress and anxiety caused by congested conditions.

Although an RTTS is not directly an operational TTC device for a project, as it provides no direct traffic control, DOTs might consider it for deployment as part of an agency's public relations and traveler information system.

An RTTS is extremely useful where construction will create long vehicle delays for extended periods of time, and it may persuade some travelers to use alternate routes.

10.3.4 Expected Effectiveness

The use of RTTS in work zones has been studied extensively with the following results:

- Reductions of more than 30 percent in deceleration rates (Hourdos 2019).
- 28 percent motorist diversion on seeing an RTTS (Luttrell et al. 2008).
- 9 percent diversion during peak hour and benefit–cost ratio between 2.1:1 and 3.2:1 (Edara, Sun, and Hou 2013).
- MDSHA real-time Travel Time Prediction System (ARAMPS).
  - 92 percent accuracy in travel time prediction during both morning and evening peak periods (Chang, Zou, and Wang 2006).
- Automated Work Zone Information System
  - 95 percent accuracy in travel time prediction and 7 percent–21 percent increase in alternate route selection (Lee and Kim 2006).
- Traffic information and prediction system
  - 28 percent–41 percent accuracy in travel time prediction (Pigman and Agent 2004).
  - 88 percent accuracy in travel time prediction within ±4 minutes, 65 percent–70 percent accuracy within ±2 minutes (Zwahlen and Russ 2002).

Table 10.2. NJDOT warrants for RTTS.

No.	Condition	Scoring Criteria and Point Score
1	Based on proposed work zone, will there be a long-term loss of traveled lane continuously for 3 or more months?[a]	Yes: 10 points No: 0 points
2	Based on proposed work zone, will there be a temporary loss of traveled lane continuously for 3 or more months?[b]	Yes: 10 points for 6 hours of the day 9 points for 5 hours of the day, etc. No: 0
3	Does section of the highway containing proposed work zones include parallel local and express lanes?	Yes: 10 No: 0
4	Are viable alternate routes available so motorists can avoid work zone?	Freeway: 10 US route: 7 State route: 5 Local road: 3 No: 0
5	Does one-way AADT or ADT exceed 60,000 in the direction of proposed work zone?[c]	Yes: 1 × each 10,000 above 60,000
6	Does traffic volume per lane exceed 1,500 vph during day?[d]	Yes: 1 × each 100 over 1,500
7	Will traffic volume exceed 1,500 vphpl in the remaining lanes if answer to question 1 is an affirmative?[e]	Yes: 1 × each 100 over 1,500
8	Is highway section containing proposed work zone a known location of congestion for the congestion management system?	Makes top 10: 10 Makes top 20: 9 Makes top 30: 8, etc.
9	Is section of the work zone near major traffic generators?[f]	Based on severity: 0–5 Seasonal: 10
10	Is work zone proposing temporary bridge, contraflow lanes, or cattle chute?	Based on complexity: 0–5
	Total Score	

NOTE:
[a]This includes the conditions in which a traveled lane is lost permanently from the proposed work zone and continuously for an extended period of time. (Loss of highway lane continuously for 3 months).
[b]This includes the condition where the loss of highway lane is temporary, limited to peak periods of the day, and only for an extended period of time. (Loss of highway lane only during certain hours of the day for an extended period of time.)
[c]If AADT is not available, determine the ADT based on the nearest section of the highway where 24 hours volume was recorded. The information needs to be based on an average of at least three regular weekdays during the months when schools are in session. If the information is not available, use 10.
[d]If per-lane volume information is not available, divide the highest volume of any peak hour during the day (6:00 a.m.–8:00 p.m.) by the number of highway lanes in the section of the work zone.
[e]If the proposed work zone will reduce the number of lanes, divide the highway volumes through the work zone by the number of remaining available lanes.
[f]If the roadway section is near major traffic generators, such as shopping malls, office complexes, etc. For recreational or seasonal traffic generators, use 10.

AADT = annual average daily traffic; ADT = average daily traffic; vph = vehicles per hour; vphpl = vehicles per hour per lane.
SOURCE: NJDOT, Mobility and Systems Engineering, Operations Bulletin No. 006B, 2013.

10.3.5 Crash Modification Factor

No CMF is applicable for this strategy.

10.3.6 Implementation Considerations

The following aspects might also be considered when deploying RTTS:

- DOTs can integrate RTTS with a regional TMC or other state and project websites.
- Costs associated with the purchase or lease of RTTS components can be significant.

- Agencies will need to perform comprehensive testing of the system.
- An RTTS may also be supplemented with other informational devices such as a highway advisory radio.

10.3.7 Design Features and Requirements

The RTTS consists, at a minimum, of the following:

- Sensors to monitor and record traffic data.
- A PCMS to display real-time messaging to the general public.

It is important to design primary locations for the messaging so that travelers may choose alternate routes based on the displayed time for their planned route. Secondary locations for messaging would provide the traveler with travel time information. Although alternate routes cannot be taken from secondary locations, travelers will be provided with real-time information about their traffic delay situation.

10.3.8 State of the Practice

RTTS is one of the technology applications promoted by the FHWA's SWZ during Round 3 of the EDC initiative. Many resources, including bid specifications, deployment plans, and case studies, are available on the National Work Zone Safety Information Clearinghouse website (https://www.workzonesafety.org/swz/).

Arizona, Illinois, Iowa, Ohio, Michigan, and Minnesota use RTTSs on certain corridors continuously as a standard practice, increasing the exposure of the motoring public to this concept. These states have mature systems that generate accurate and dependable results.

10.3.8.1 Maricopa County Department of Transportation

For Round 3 of the FHWA EDC initiative, the Maricopa County Department of Transportation (MCDOT) developed an SWZ technical feasibility concept for arterial roadways (Kimley-Horn 2016). The agency developed a general concept that identified the components to be used at all MCDOT SWZ deployments, regardless of the specific characteristics of the work zone (length, location, duration, etc.). The recommended devices and order of core components for MCDOT work zones are not expected to change. However, it is expected that the actual location of each component in the work zone will be based on the specific characteristics of the work zone and the roadway in question. Figure 10.5 depicts the core components and their relevant order for deployment in all MCDOT work zones.

In March 2019, MCDOT piloted the SWZ concept using an RTTS on the MC-85 reconstruction of arterial roadways for 3 months. Alternative routing was an important goal for this SWZ deployment. The MCDOT TMC monitored all system operations, examining and overriding variable messages, monitoring and changing traffic signal operations, responding to alerts from the system, and coordinating with all partners as part of the project.

Figure 10.6 provides the layout where specific technologies were placed to support the MC-85 work zone Phase 1 initiative in both directions. At the time this guidebook was written, MCDOT was conducting a performance evaluation of the SWZ deployment system from both an operational standpoint (how well devices are working) and a benefits standpoint (whether SWZ goals are being met).

10.3.8.2 Louisiana

An RTTS was deployed during reconstruction of the Israel LaFleur Bridge (I-210) in 2018 to maintain the bridge's integrity and extend its life. As expected, the work led to an increase

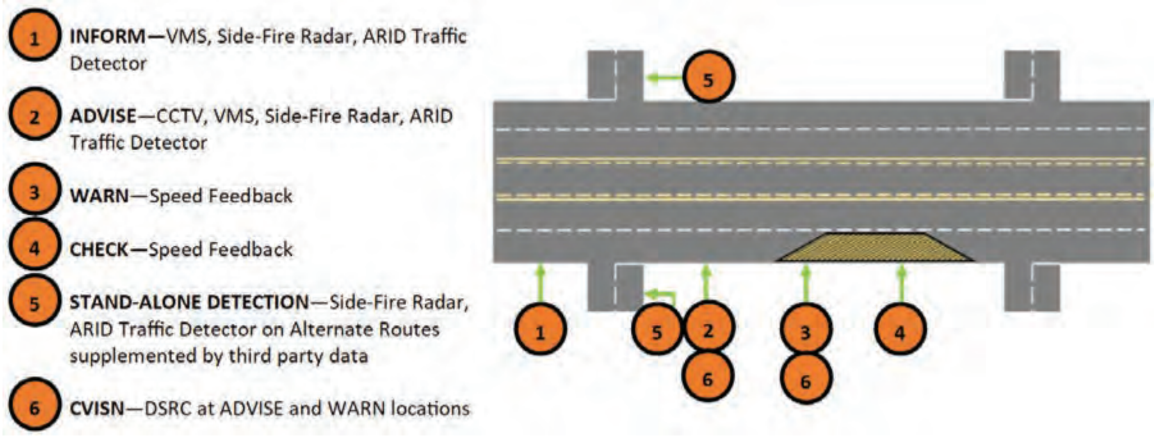


Figure 10.5. MCDOT smart work zone concept layout (Credit: MCDOT).

in traffic congestion along I-210, I-10, and the area surrounding Lake Charles. Twenty-three PCMSs that contained alternative route messages, travel time messages, or both—positioned 2 to 20 mi before the actual work zone—were deployed on this project.

10.3.8.3 Minnesota

During Summer 2012, three large construction projects occurred along a 70-mi stretch of I-35 between Hinckley and Duluth, Minnesota. MN-23, which runs parallel to I-35, was designated as an alternate route to help reduce congestion on I-35 during peak travel periods. Figure 10.7 illustrates the extent of the project area.

To provide motorists with travel time information in the construction work zones, MnDOT deployed an RTTS consisting of 7 roadside static signs with inserted changeable modules that

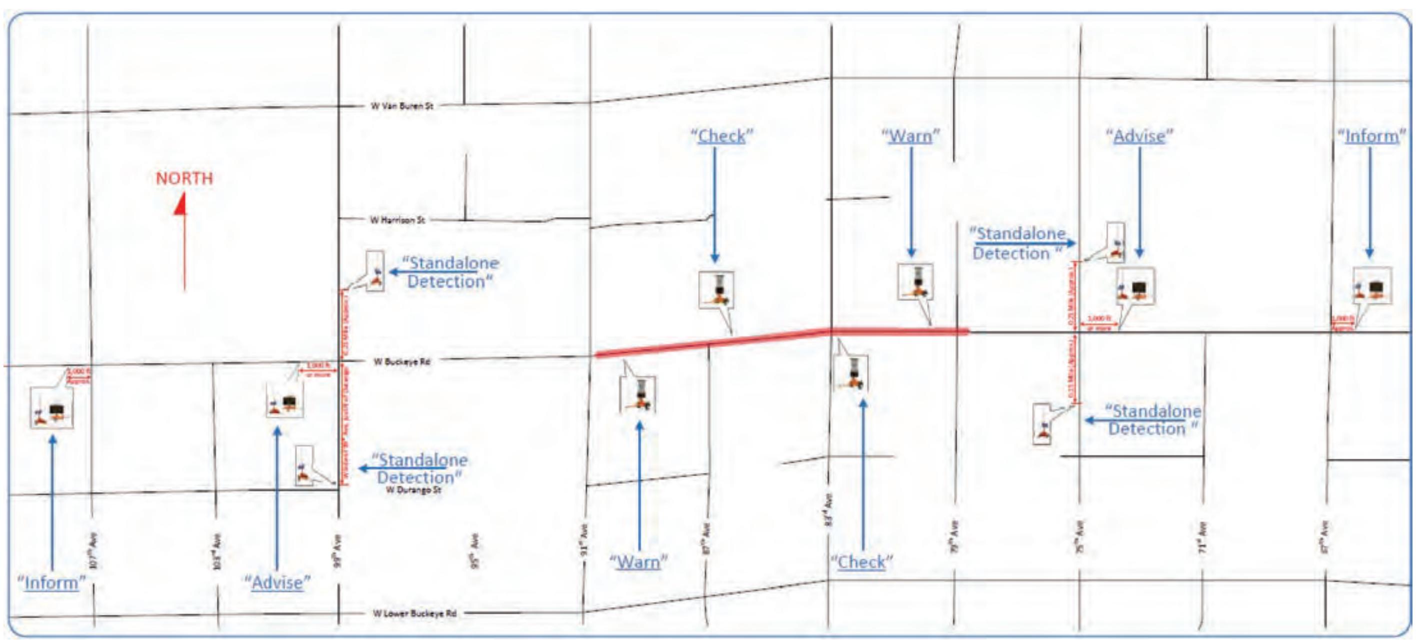


Figure 10.6. MCDOT smart work zone components during MC-85 reconstruction (Credit: MCDOT).

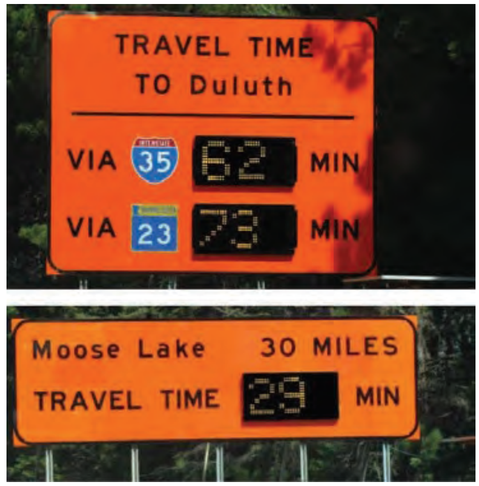


Figure 10.7. I-35 project location and RTTS signs (Credit: FHWA).

displayed real-time travel times to motorists. The RTTS was in operation 24/7 with updates to the travel time signs occurring every 5 minutes.

10.3.9 Cost

The cost for deploying an SWZ, such as the RTTS, depends on the project duration and the number of devices (e.g., message boards, traffic sensors, speed trailers, cameras) used. In general, the rental cost is the same for a PCMS or a traffic sensor or camera—approximately $1,000 per week. For longer-duration projects, the rental costs can be substantially lower.

WisDOT reported a cost estimate for an RTTS project that used 14 PCMSs, 16 sensors, and 2 cameras to be $113,000 for 5 months in 2017 (TxDOT 2018). TxDOT estimated RTTS deployment costs in 2015 on a project involving 8 PCMSs, 8 sensors, 8 trailers, and 8 cameras at $835,690 for 34 months (or 1 percent of total construction cost). TxDOT in 2016 estimated a project involving 4 PCMSs, 8 sensors, 4 trailers, and 4 cameras at $410,000 for 24 months (~1 percent of total construction cost).

10.3.10 Resources and References

Bushman, R., and C. Berthelot. Response of North Carolina Motorists to a Smart Work Zone System. Presented at 84th Annual Meeting of the Transportation Research Board, Washington, D.C., 2005.

Chang, G. L., and K. P. Kang. *Evaluation of Intelligent Transportation System Deployments for Work Zone Operations*, Maryland State Highway Administration, August 2005.

Chang, G. L., N. Zou, and J. Wang. *Development and Field Evaluation of a Real-Time Travel Time Prediction System*, Maryland State Highway Administration, MD-07-SP508B4D, December 2006.

Chen, Y., X. Qin, and D. A. Noyce. Evaluation of ATIS in Suburban Freeway Work Zone, Presented at the ITS America Annual Conference and Exposition, New York, November 16–20, 2008.

Chu, L., H. K. Kim, Y. Chung, and W. Recker. Evaluation of Effectiveness of Automated Work Zone Information Systems. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1911, 2005, pp. 73–81.

Edara, P., C. Sun, and Y. Hou. *Effectiveness of Work Zone Intelligent Transportation Systems*, University of Missouri–Columbia, InTrans Project 06-277, December 2013.

FHWA Every Day Counts (EDC) Initiative: Smarter Work Zones, Technology Applications: Real-Time Traveler Information web page. https://www.workzonesafety.org/swz/swztechnology-application/types-of-applications/real-time-traveler-information/.

Hourdos, J. *Evaluation of the Smart Work Zone Speed Notification System*, Minnesota Department of Transportation, June 2019.

Kimley-Horn and Associates, Inc. *MCDOT Smart Work Zone Technical Feasibility Concept Document,* Maricopa County, Arizona, Department of Transportation, June 2016.

Lee, E., and C. Kim. Automated Work Zone Information System on Urban Freeway Rehabilitation: California Implementation. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1948, 2006, pp. 77–85.

Luttrell, T., M. Robinson, J. Rephlo, R. Haas, J. Srour, R. Benekohal, J-S Oh., and T. Scriba. *The Benefits of Using Intelligent Transportation Systems in Work Zones: A Summary Report,* FHWA-HOP-08-021, FHWA, U.S. DOT, April 2008.

Meyer, E., Construction Area Late Merge (CALM) System. *Midwest Smart Work Zone Deployment Initiative Project Year 2002 Evaluations.* Kansas Department of Transportation, Topeka, 2004.

Pigman, J. G., and K. R. Agent. *Evaluation of Traffic Information and Prediction System (TIPS) as Work Zone Traffic Control*, Research Report KTC-04-10/FR128-03-1F, Kentucky Transportation Center, University of Kentucky, March 2004.

Savolainen, P. T., D. S. McAvoy, V. Reddy, J. B. Santos, and T. K. Datta. Evaluation of Motorist Awareness System. Presented at 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.

Tudor, H. L., A. Meadors, and R. Plant. Deployment of Smart Work Zone Technology in Arkansas. Presented at 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2002.

TxDOT. *Smart Work Zone Guidelines: Design Guidelines for Deployment of Work Zone Intelligent Transportation Systems (ITS)*, Texas Department of Transportation, October 2018.

Zwahlen, H. T., and A. Russ. Evaluation of the Accuracy of a Real-Time Travel Time Prediction System in a Freeway Construction Work Zone. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1803, 2002, pp. 87–93.

CHAPTER 11

Public Awareness Strategies

Public awareness strategies refer to the various methods of communicating with road users, the general public, communities, businesses, appropriate public entities, and other identified stakeholders. Public awareness strategies consist of two strategies:

- Program-level public information strategies
- Project-level public information strategies

11.1 Program-Level Public Information Strategies

11.1.1 Description

Program-level public information strategies raise general awareness about motorist and worker safety and mobility issues and the need for drivers to be vigilant while driving in work zones. These strategies are not for one specific project, but are usually implemented for an entire state, district, or geographic region. Examples of program-level public information strategies are work zone safety and education campaigns, work zone safety curricula, and lane closure websites.

11.1.2 When to Use

Program-level public information strategies can be used any time since they are designed to inform the public generally, as opposed to providing traveler information. However, scheduling these strategies during construction season is most likely to maximize the exposure of the message to the target audience.

11.1.3 Benefits

Individual program-level public information strategies provide the following benefits:

- Work zone safety and education campaigns and curricula
  - Reduce driver frustration and road rage–type aggression, and may also lead to safer driving behaviors
  - Encourage general safety when driving around work zones
  - Help travelers know what signs mean and what resources there are for advanced planning
- Lane closure websites
  - Provide commuters with up-to-date traffic and construction information
  - Give the public advance warning to make decisions
  - Promote diversion of traffic to alternate routes
  - Decrease public dissatisfaction with work zones

11.1.4 Expected Effectiveness

There is no published evidence correlating the effect of program-level public information strategies on work zone safety or mobility. However, providing updated information on work zone activities reduces driver frustration and results in increased goodwill for an agency.

11.1.5 Crash Modification Factor

A CMF is not applicable for this strategy.

11.1.6 Implementation Considerations

Work zone safety and education campaigns may not reach most of the targeted audience if appropriate dissemination methods are not used. A range of media may be needed, including television, radio, newspapers, social media, and other measures deemed appropriate for a particular geographic area. Further, projects will also need to target information to those who speak languages other than English or require alternative formats to accommodate disabilities. Ensuring that all motorists have updated and reliable information on work zone activities can be time consuming.

11.1.7 Design Features and Requirements

Work zone safety campaigns are designed to create awareness among road users that work zones require more caution; the campaigns can be implemented using websites and media campaigns (social media, radio, and television). These campaigns target such work zone safety issues as flagger instructions, early merging, and driver awareness and comprehension of work zone messages.

Educating drivers, pedestrians, and other road users on the meaning of work zone TCDs and appropriate actions to take in work zones can be achieved through training videos and brochures. Education tools may include meanings of work zone TCDs and instruction on what actions drivers are to take when they encounter specific TCDs.

A lane closure website may include details on location of closure; description of lane closure type; direction of closure; number of lanes in direction of closure for weekday, weekend, and night construction; and the date and time work will begin and end.

11.1.8 State of the Practice

The typical program-level public information strategies are work zone safety and education campaigns, work zone safety curricula, and lane closure websites. Selected examples of state DOT practices in the aforementioned categories follow.

11.1.8.1 Work Zone Safety and Education Campaigns

The National Work Zone Awareness Week (NWZAW) is an example of a work zone safety and education initiative at the national level. For the past 20 years, the NWZAW has been taking place each year in the spring to bring attention to motorist and worker safety and mobility issues in work zones. It is held in partnerships between FHWA, AASHTO, state DOTs, national road safety organizations, private companies, and individuals. National Go

Orange Day, introduced in 2016 and held on the Wednesday of NWZAW, is a staple of NWZAW and encourages individuals and organizations across the country to wear orange to express their support for work zone safety. The activities conducted as part of the NWZAW are documented and available widely on the NWZAW web page (http://www.nwzaw.org/), and thus are not covered in this section.

In addition to a national event conducted each year, most states host their own NWZAW events. For example, OKDOT, as part of the 2019 NWZAW, launched the "In the Game of Cones, Safety Always Wins" campaign, a playoff of the popular television show Game of Thrones. As part of this campaign, OKDOT developed and posted content on Facebook and Twitter feeds, as well on digital billboards in both Oklahoma City and Tulsa metro areas during April 1–14, 2019 (Figure 11.1).

Along with events associated with the NWZAW, some agencies have made efforts to emphasize work zone safety more broadly by hosting awareness events throughout the year. Work Zone Wednesday, a weekly effort to remind the public to drive carefully in work zones, is an example of one such event.

The Michigan Work Zone Safety Task Force was officially launched in October 2018 as a collaborative effort between MDOT and Michigan's heavy/highway construction industry. It is the goal of the task force to reduce and eliminate work zone injuries and deaths for construction workers and motorists. As part of this effort, the Work Zone Wednesday campaign was launched in February 2019. Michigan's campaign is a weekly Facebook and Twitter effort to get drivers' attention and make them think about safety behind the wheel. Figure 11.2 shows example posts from the 2019 campaign.

In 2016, OKDOT began Work Zone Wednesday messaging during its Work Zone Awareness campaign. The first 2 months proved to be so successful and memorable with drivers that OKDOT decided to carry on this weekly tradition for years in order to improve driver safety habits. Every 2 months, a committee of OKDOT employees plans messages that are informational or seasonal or have to do with a current pop culture trend. The message is displayed every Wednesday on the 52 digital messaging boards throughout the state, reaching more than 3.1 million drivers. Figure 11.3 shows example posts from the 2019 campaign.

Figure 11.1. Oklahoma DOT NWZAW campaign (Credit: Oklahoma DOT).

Feb 6, 2019 Post　　May 1, 2019 Post　　Oct 30, 2019 Post

Figure 11.2. Michigan Work Zone Wednesday example posts (Credit: Michigan Work Zone Safety Task Force).

11.1.8.2 Minnesota Work Zone Safety Curricula

The MnDOT Work Zone Safety Awareness Program (WZSAP) is a public education program that promotes safe driving in winter and summer highway work zones. The WZSAP is a free multimedia program that includes slides, overheads, a PowerPoint presentation, and video segments. Most of the 30- to 40-minute presentation offers motorists guidance on navigating work zones. Additional information on the WZSAP can be found at http://dot.state.mn.us/const/wzs/speakers.html.

The Minnesota Local Technical Assistance Program also provides a free online tutorial, Orientation to Work Zone Safety, designed to provide work zone employees with an understanding of the most basic aspects of safety in a work zone and encourage them to develop safe habits. Orientation to Work Zone Safety begins with how a worker should prepare before entering the work zone, and it ends when the worker is off site and out of the work zone area. Additional information on the program can be found at http://www.mnltap.umn.edu/training/online/workzone/index.html.

March 20, 2019 Post　　April 24, 2019 Post　　May 29, 2019 Post

Figure 11.3. Oklahoma DOT Work Zone Wednesday example posts (Credit: Oklahoma DOT).

11.1.8.3 Lane Closure Websites

A lane closure website summarizes planned lane closures for public information, listing the routes involved as well as the closure start and end dates, in both text and graphical forms.

Several states have developed lane closure websites to disseminate accurate work zone lane closure information to the public. For example, the Wisconsin Lane Closure System web site is found at https://transportal.cee.wisc.edu/closures/.

FDOT developed the Lane Closure Information System (https://www.fdotlcis.com/) in 2010. Figure 11.4 shows a snapshot of FDOT's lane closure system.

Similarly, Caltrans uses a planned lane closure website (https://lcswebreports.dot.ca.gov/main?district=Statewide) to report lane closure status. Figure 11.5 shows a snapshot of a Caltrans lane closure system.

11.1.9 Cost

The budget for program-level public information strategies depends on several factors: the agency's in-house capability, selected strategies that are already established within the agency and can be readily used, and the role of partners.

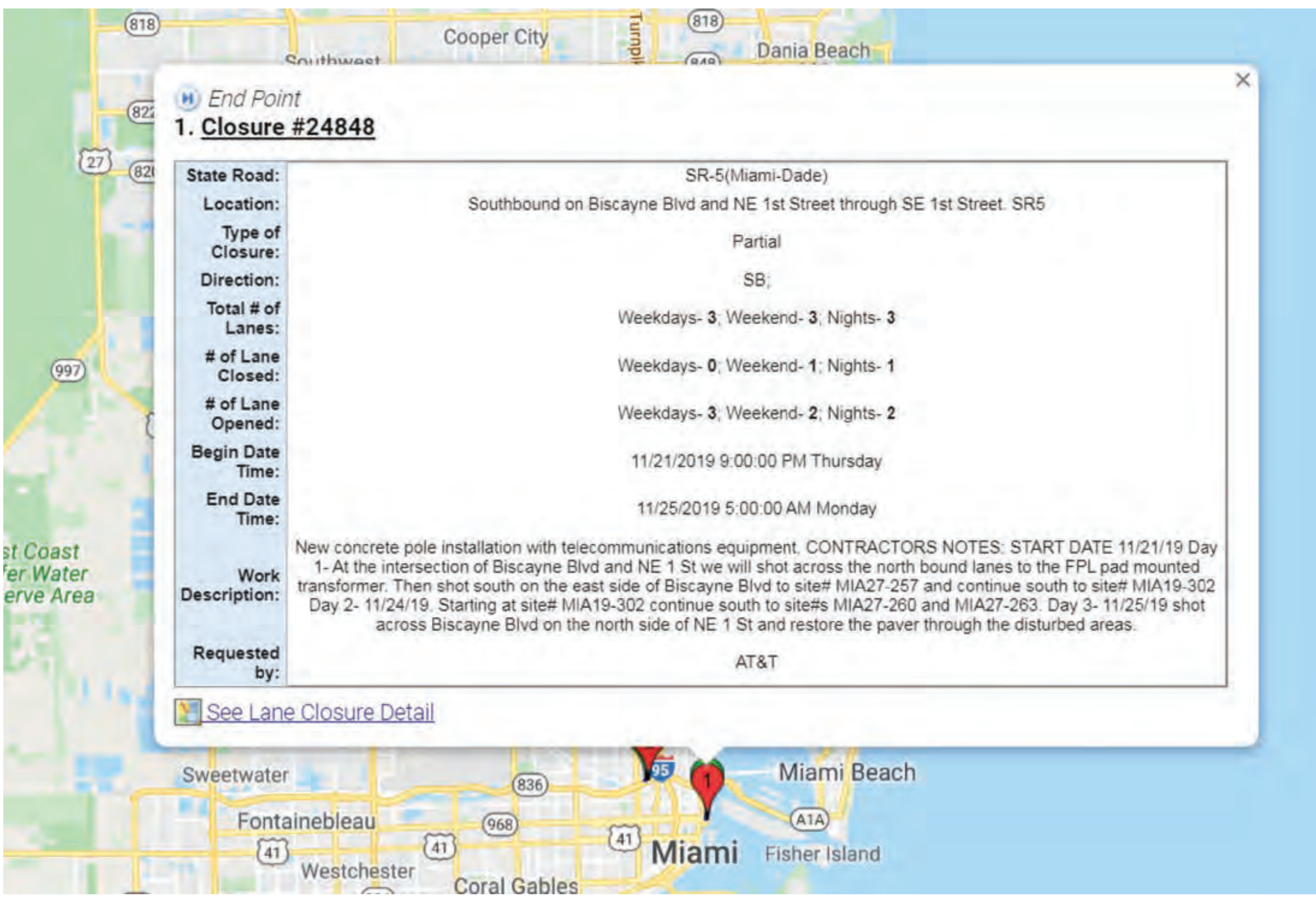


Figure 11.4. Florida lane closure information system (Credit: FDOT).

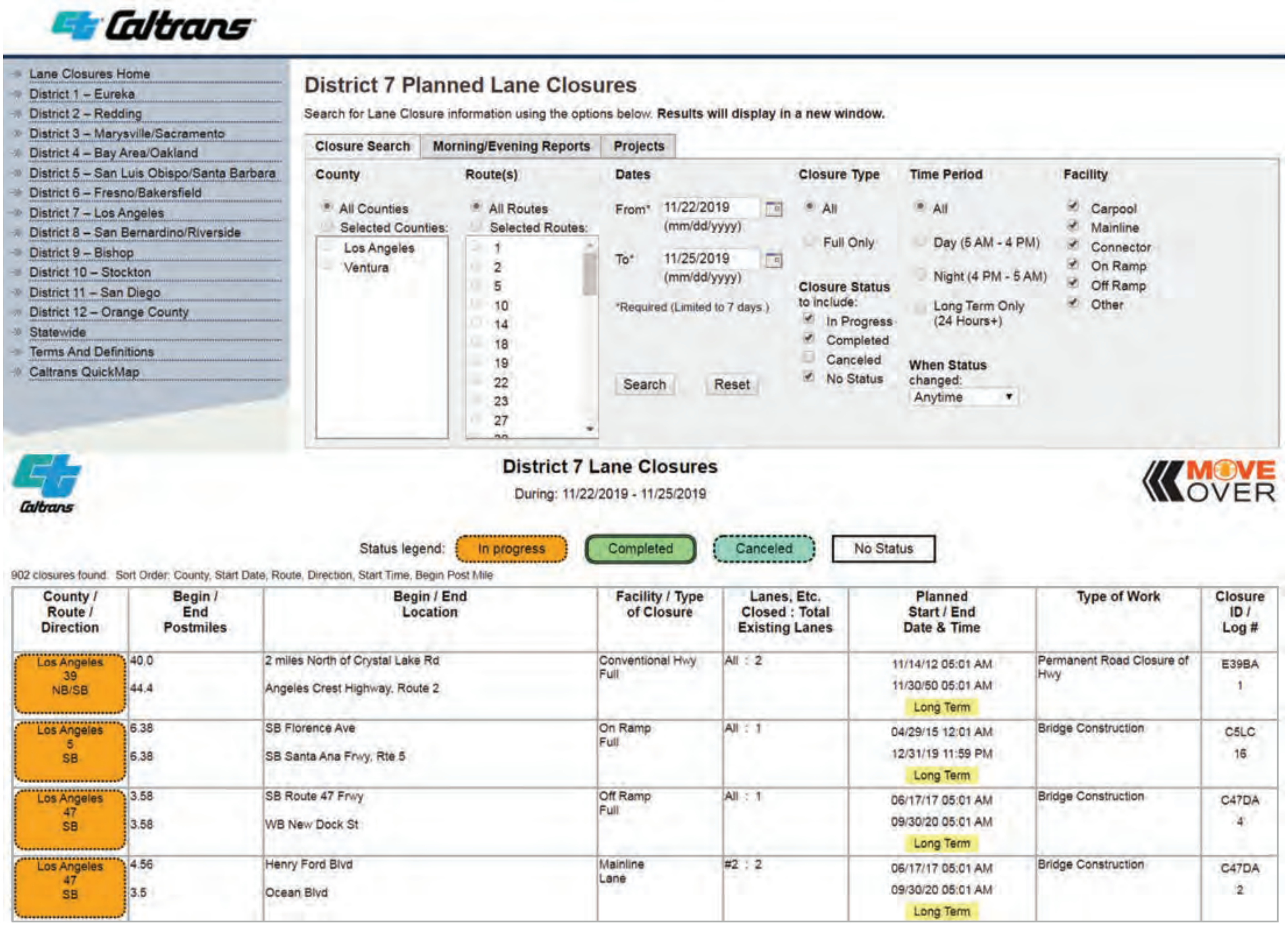


Figure 11.5. Caltrans lane closure system (Credit: Caltrans).

11.1.10 Resources and References

FHWA. *Guidelines on Improving Work Zone Safety Through Public Information and Traveler Information.* No. DTFH61-06-G-00007, FHWA, U.S. DOT, March 2011.

FHWA. *Work Zone Public Information and Outreach Strategies,* FHWA-HOP-05-067, FHWA, U.S. DOT, November 2005.

Fry, P. J. *Safety Evaluation of Billboard Advertisements on Driver Behavior in Work Zones*, Ohio University, May 2013.

Gallo, A. A. *Development of Performance Assessment Guidelines for Virginia's Work Zone Transportation Management Plans,* University of Virginia, May 2012.

Higgins, L., A. Nelson, T. Geiselbrecht, and B. Ullman. *Understanding the Decision-Making Process for Drivers Faced with Lane Restriction or Closures on Wisconsin Highways*, 0092-11-15, Wisconsin Department of Transportation, February 2013.

IDOT. *Best Practices in Public Involvement*, Indiana Department of Transportation, 2014.

Minooei, F., N. Sobin, P. Goodrum, and K. Molenaar. *Community Outreach Tools and Strategies for Accelerated Highway Construction Projects Implementation Guide,* TPF-5(260), University of Colorado Boulder, January 2016.

O'Leary, A. A., C. A. Kyte, E. D. Arnold, Jr., and M. A. Perfater. *An Assessment of the Virginia Department of Transportation's Public Involvement Practices and the Development of a Public Involvement Toolkit: Phase II,* VTRC 03-R17, Virginia Department of Transportation, June 2003.

Ross, J. H., and A. J. Pietz. *Maximizing Investments in Work Zone Safety in Oregon,* OR-RD-12. Oregon Department of Transportation, May 2011.

Sanders, D. A., J. J. Sluss, Jr., and S. Radhakrishnan. *Deployment Plan 511 Traveler Information Services,* OTC Report 2005-1, Oklahoma Transportation Center, January 2005.
Shaw, J. W., T. Klockziem, and D. A. Noyce. *Overview of State DOT Online Work Zone Safety Public Service Announcements (PSAs),* Paper No. 15-4135, University of Wisconsin–Madison, January 2015.
Vermont Agency of Transportation. *Engaging the Public Outreach Guidelines for Projects, Plans, and Other Agency Activities,* Vermont Agency of Transportation, June 2017.

11.2 Project-Level Public Information Strategies

11.2.1 Description

Project-level strategies are used to communicate with road users, the general public, area residents and businesses, and appropriate public entities about a specific road construction project and its implications for safety and mobility in the area.

11.2.2 When to Use

All work zones can incorporate some form of project-level public information strategy. For small, short-duration work zones, the public information and outreach effort may be limited to routine efforts (e.g., press releases, community meetings). Longer, more disruptive projects may warrant more elaborate public information strategies and may require significant data collection and analysis. The size and nature of a public information and outreach campaign will be determined by the anticipated effects of the project.

Agencies might consider a range of elements when determining the size and nature of the public information strategies to be implemented:

- Traffic delay and safety at the corridor and network levels, including effects on parallel corridors and alternate routes.
- Disruptions of other modes of transportation, including pedestrian and bicycle traffic and transit.
- Other public and private entities (such as schools and universities).
- Planned special events (such as sporting events, holiday parades, and concerts).
- Businesses and residences.

A combination of several strategies may make sense for some projects, while only one or two of the strategies may be necessary for other projects. Typically, there will be a significant amount of interaction between different means of communication. For example, informational materials such as brochures and fact sheets can be posted on project websites, making them more widely accessible. Ultimately, these agency-provided project materials may reach the public indirectly through reporting in newspapers, on radio, and on television.

Ultimately, the decision about which mechanisms to use for a specific project depends on the target audiences, message to be communicated, available budget, agency resources and expertise with these strategies, and other factors.

11.2.3 Benefits

The use of project-level public information strategies provides the following benefits:

- Raises awareness of the special safety and mobility challenges that the public will encounter in a specific work zone.
- Creates traffic avoidance during construction (i.e., reduces demand).
- Increases road-user awareness (of, e.g., road closure, pedestrian/bike detour).

- Decreases impatient driver behaviors (e.g., speeding and road rage).
- Builds trust with the public and promotes project support.

Table 11.1 provides a summary of the benefits and implementation considerations for the individual project-level public information strategies.

11.2.4 Expected Effectiveness

It is difficult to separate the effectiveness of individual project-level public information strategies because individual strategies are not mutually exclusive or cumulative. However, a 2015 pooled-fund study (Minooei et al. 2016) indicated static signs and variable sign boards have the highest usage rate among outreach tools used to increase public awareness. This can be justified in that one of the main functions of these tools is to notify motorists of safety issues in work zones. The next three most frequently used tools of communication are project websites, social media, and radio advertisements (Figure 11.6).

The same study (Minooei et al. 2016) also found mobile applications to be the most effective outreach tools in reducing traffic demand (Figure 11.7). This can be attributed to their ability to provide real-time information that allows motorists to plan in advance of their travels. The next most effective tools for traffic avoidance are social media, project-specific television advertisements, interviews with television news reporters, and text message alerts.

Table 11.1. Summary of individual project-level public information strategies.

Strategy	Benefits	Implementation Considerations
Project Website	• Access to real-time information • Ability to access all project-related materials in one place • May be easy to update	• Significant effort will be required to inform public of website's existence. • Information needs to be current and accurate (static and real-time). • Costs vary based on complexity of website. • Mechanisms to collect data or information may need to be created to feed site. • A process for tracking public use is necessary.
Public Meetings, Workshops and Community Events	• Good exposure to public • Gives agency a chance to raise credibility with public • Gives public a chance to voice their concerns	• Need to make sure right audience is at the events. • Need to be wary of making "empty promises." • Need to keep database of stakeholders updated.
Paid/Earned Media	• Can reach many people at one time • Same ad can be used in many different newspapers • Agency controls content and timing of the message	• Declining readership of print media. • May only target local/regional motorists. • Costly to implement. • Coverage more likely for mega projects.
Social Media	• Low cost • Easy to distribute and update	• Outreach limited to those who download and use social media apps.
Printed Materials	• Low cost • Easy to distribute	• Information can become stale quickly. • Often targets local motorists only. • Needs to be designed in a manner that makes drivers want to read the information.
E-mail/Text Alerts	• Low cost • Can reach many people at one time	• Audience is limited to those people who sign up for the service. • Need to determine criteria for when to send alerts.

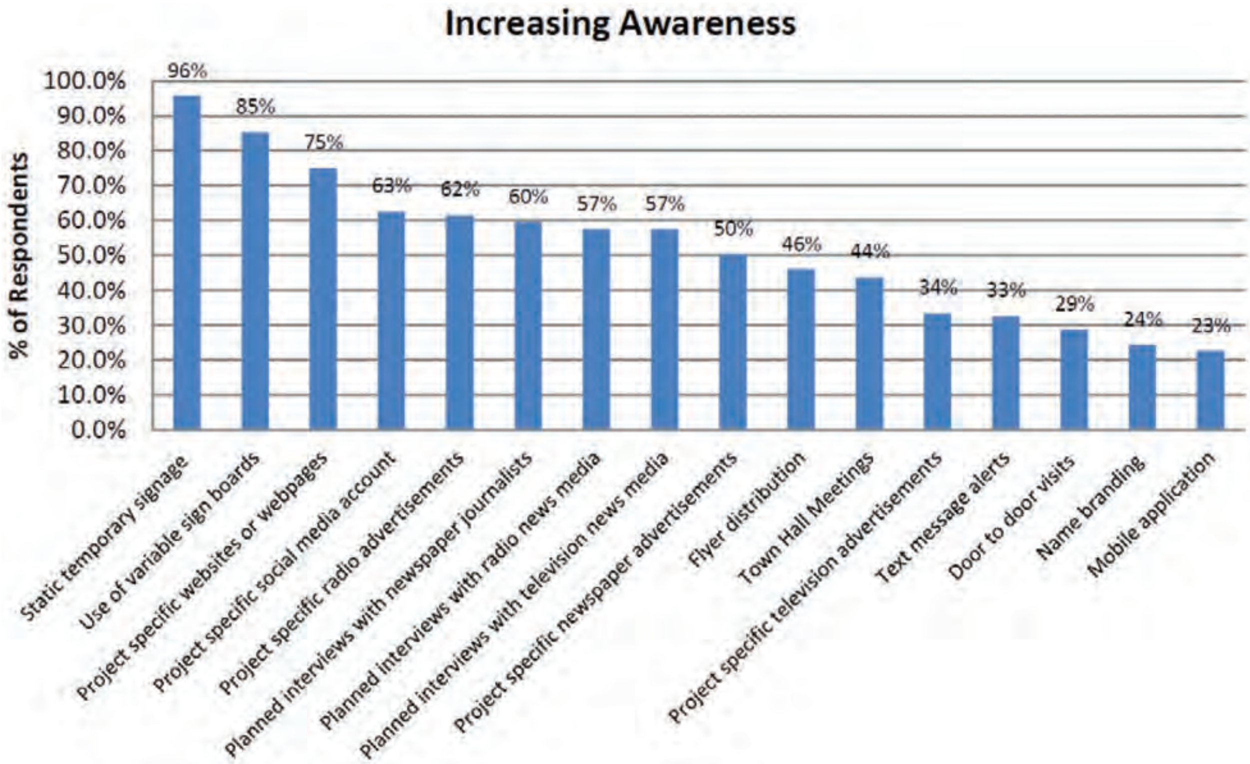


Figure 11.6. Effectiveness of outreach tools to increase awareness (Credit: University of Colorado).

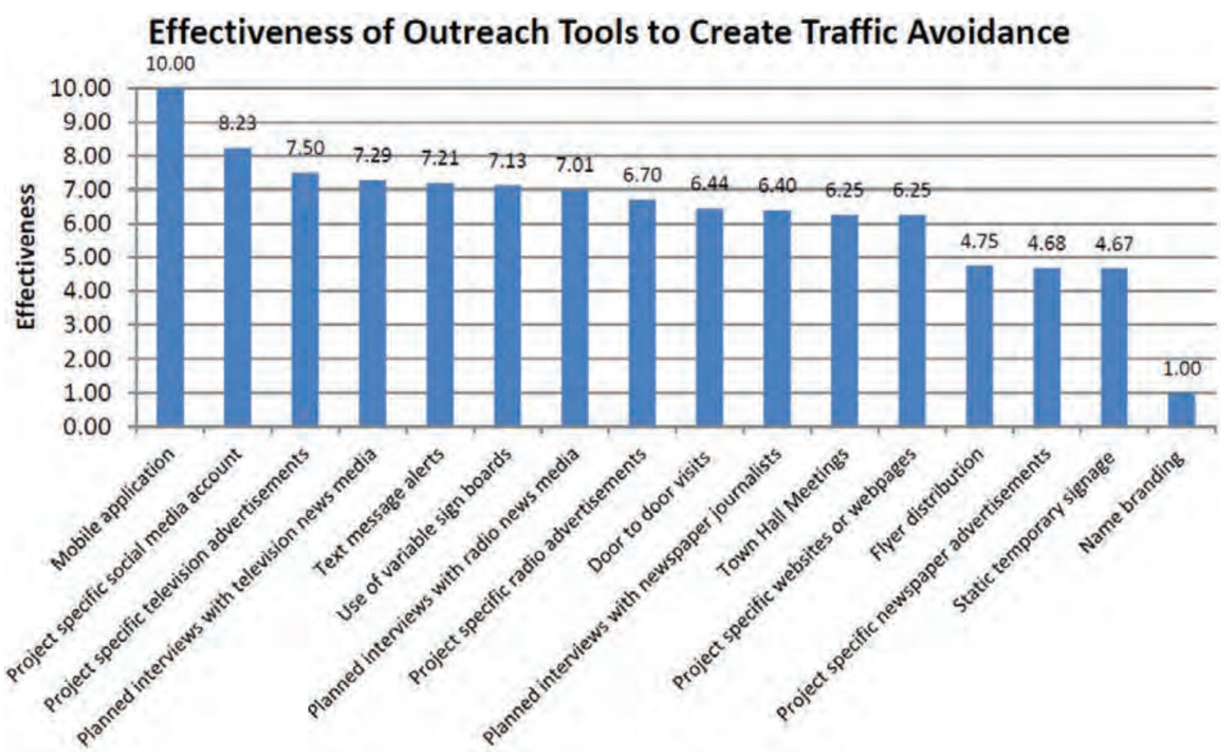


Figure 11.7. Effectiveness of outreach tools to create traffic avoidance (Credit: University of Colorado).

11.2.5 Crash Modification Factor

A CMF is not available for this strategy.

11.2.6 Implementation Considerations

Projects need to start developing and implementing public information strategies well before road construction begins and to monitor the effectiveness of the strategies throughout the life of the project. Successful deployments of public information strategies generally include the following key steps:

Step 1. Determining the appropriate size and nature of the public information and outreach campaign.
Step 2. Identifying resources necessary to support the campaign.
Step 3. Identifying partners to assist in developing and implementing the campaign.
Step 4. Identifying target audiences for the campaign.
Step 5. Developing the messages for the campaign.
Step 6. Determining communication strategies for disseminating the messages to the target audiences.
Step 7. Determining communication timing for the campaign.
Step 8. Evaluating the effectiveness of the campaign.

11.2.7 Design Features and Requirements

The following are commonly used mechanisms to disseminate work zone project-level public information strategies:

- **Project website**. Project-specific websites can provide both static and real-time information, including many other forms of project information, such as all types of written material, traffic camera images, travel times, photographs, maps, and links to other sources of information. Moreover, many features can be made interactive with links to map icons and pop-up textual information and camera views.
- **Public meetings, workshops, and community events**. This strategy involves presenting project information to the public, the community, and businesses and soliciting their input concerning potential concerns, impacts, and management strategies.
- **Paid or earned media**. Paid announcements of an upcoming major project may use newspaper, radio, or television ads. Paid advertisements can also be used for progress updates or to provide information regarding major changes to the work zone configuration.

  Agencies use free media (also known as earned media), such as news stories and traffic information, to the maximum extent. Large projects are typically considered newsworthy by local media outlets, so it is relatively easy to get news coverage.
- **Social media.** Provide breaking traffic alerts and road closure information via social media (namely Facebook and Twitter).
- **Printed materials**. Printed materials can include information on project phasing, events, and other important work zone details. They can be in the form of brochures, newsletters, flyers, fact sheets, or maps. Dissemination methods include mailing, hand delivering, placing in newspapers and on project websites, and distributing at public meetings, workshops, and community events.
- **E-mail and text alerts.** Lane closures, delays, and incident/crash information can be distributed to travelers who have signed up for e-mail and text alerts. Information can be sent to an e-mail account or a cell phone.

11.2.8 State of the Practice

Examples of project-level public information websites follow:

- Transform 66 Outside the Beltway, Virginia (http://outside.transform66.org/)
- Improving 295, District of Columbia (https://www.improving295dc.com/)
- Rehabilitation of the Whitney Young Memorial Bridge, District of Columbia (https://www.eastcapbridge.com/)

11.2.9 Cost

The budget for a project-level public information strategy will depend on several factors, including the size and nature of the campaign, the communication strategies selected, whether the selected strategies are already established within the agency and can be readily used, and the role of partners. In general, expenditures for project-level public information strategies typically range from 0.3 percent to 1 percent of the entire project budget.

11.2.10 Resources and References

FHWA. *Guidelines on Improving Work Zone Safety Through Public Information and Traveler Information.* No. DTFH61-06-G-00007, FHWA, U.S. DOT, March 2011.

FHWA. *Work Zone Public Information and Outreach Strategies,* FHWA-HOP-05-067, FHWA, U.S. DOT, November 2005.

Fry, P. J. *Safety Evaluation of Billboard Advertisements on Driver Behavior in Work Zones,* Ohio University, May 2013.

Higgins, L., A. Nelson, T. Geiselbrecht, and B. Ullman. *Understanding the Decision-Making Process for Drivers Faced with Lane Restriction or Closures on Wisconsin Highways*, 0092-11-15, Wisconsin Department of Transportation, February 2013.

IDOT. *Best Practices in Public Involvement,* Indiana Department of Transportation, 2014.

Minooei, F., N. Sobin, P. Goodrum, and K. Molenaar. *Community Outreach Tools and Strategies for Accelerated Highway Construction Projects Implementation Guide,* TPF-5(260), University of Colorado Boulder, January 2016.

O'Leary, A. A., C. A. Kyte, E. D. Arnold, Jr., and M. A. Perfater. *An Assessment of the Virginia Department of Transportation's Public Involvement Practices and the Development of a Public Involvement Toolkit: Phase II*, VTRC 03-R17, Virginia Department of Transportation, June 2003.

Sanders, D. A., J. J. Sluss, Jr., and S. Radhakrishnan. *Deployment Plan 511 Traveler Information Services,* OTC Report 2005-1, Oklahoma Transportation Center, January 2005.

Shaw, J. W., T. Klockziem, and D. A. Noyce. *Overview of State DOT Online Work Zone Safety Public Service Announcements (PSAs),* Paper No. 15-4135, University of Wisconsin–Madison. January 2015.

Vermont Agency of Transportation. *Engaging the Public Outreach Guidelines for Projects, Plans, and Other Agency Activities,* Vermont Agency of Transportation, June 2017.

CHAPTER 12

Other Practices

This section discusses decision-making tools, other practices, emerging technologies, and successful policies and procedures of selected agencies. The following practices are covered in this section:

- Smart work zone implementation tools
  - 12.1 FHWA Work Zone ITS Implementation Guide and Tool
  - 12.2 TxDOT Go/No-Go Decision Tool
  - 12.3 MnDOT Work Zone ITS Decision Tree
- Alternate contracting decision tools
  - 12.4 Project Delivery Selection Matrix
  - 12.5 Procurement Procedures Selection Matrix
  - 12.6 Project Delivery Method Selection Guidance
- Work zone safety and mobility assessment at the agency and project levels
  - 12.7 Ohio DOT Mobility and Safety Performance Measures
  - 12.8 MDSHA Work Zone Performance Monitoring Tool
  - 12.9 Iowa DOT Statewide Smart Work Zone Program
  - 12.10 Safety Assessment Tool for Construction Phasing Plans
- Traffic control devices
  - 12.11 Special-color Pavement Markings
  - 12.12 Automated Truck-Mounted Attenuator
  - 12.13 Green Lights on TMAs
- Work zone operations
  - 12.14 Rolling Roadblock Procedure for Temporary Lane Closures
  - 12.15 Work Zone Cell Phone Restrictions
- Lane closure policies and permitting systems
  - 12.16 Colorado Lane Closure Strategy
  - 12.17 MnDOT Lane Closure Manual
  - 12.18 ODOT Permitted Lane Closure Schedule
  - 12.19 Wisconsin Web-Based Lane Closure Permitting Systems
  - 12.20 Caltrans Lane Closure System
- e-Construction and partnering
  - 12.21 e-Construction and Partnering

12.1 FHWA Work Zone ITS Implementation Guide and Tool

FHWA developed the *Work Zone ITS Implementation Guide* in 2014 to assist in the design and implementation of ITSs in work zones (Ullman, Schroeder, and Gopalakrishna 2014). The guide provides the key steps required to successfully implement SWZ applications, by illustrating how the systems-engineering process should be applied to determine the feasibility and design of a work zone ITS for a given application. Each key step is defined in each chapter—assessment of needs; concept of development and feasibility; detailed system planning and design; procurement; system deployment; and system operation, maintenance, and evaluation. Within the *Work Zone ITS Implementation Guide*, FHWA drafted general scoring criteria that agencies could use to assess the feasibility of using smart work zone technologies.

12.2 TxDOT Go/No-Go Decision Tool

TxDOT has identified six SWZ systems for use in its work zones:

1. Queue detection
2. Speed monitoring
3. Construction vehicle alerts
4. Travel time systems
5. Over-height warning systems
6. Temporary incident-detection systems

Because the criteria for system selections are unique to each project, TxDOT has developed an Excel-based SWZ decision tool to streamline the process of selecting an SWZ system for a project. The Go/No-Go Decision Tool scores the extent to which several criteria (e.g., work zone duration, traffic volumes, functional classification, estimated queue lengths, sight distance at back of queue, over-height vehicle/low clearance structure) are satisfied.

The tool then automatically assigns the criteria scores to each of the six SWZ systems and presents a summary to help staff decide which to use. This score produces a logical basis for including any combination of SWZ systems into the project design, which effectively defines the SWZ scope. Figure 12.1 shows a snapshot of the decision tool.

Appendix M provides the decision tool workbook scoring criteria.

12.3 MnDOT Work Zone ITS Decision Tree

MnDOT developed a scoping decision tree to enable early and improved identification of intelligent work zone technology needs, including

- Identifying resource needs, including time and resource allocations and efficiencies;
- Improving project cost estimating and project scheduling;
- Permitting technology interoperability;
- Evaluating infrastructure readiness and compatibility; and
- Deploying cost-effective solutions for future expansion and full integration of ITS.

Appendix N presents the work zone scoping decision tree.

12.4 Project Delivery Selection Matrix

CDOT developed a PDSM to provide a risk-based and objective selection approach to choosing from the three common project-delivery methods of DBB, D-B, and CM/GC. The PDSM provides support and justification for the choice of delivery method for a particular project. The evaluation uses project attributes, goals, and constraints to compare primary and secondary evaluation factors. Then, the selection tool uses a nonnumerical rating system for each evaluation factor, so that the cumulatively highest ranked method becomes the optimal delivery method. Figure 12.2 shows the PDSM process flowchart. Appendix J1 includes the full PDSM tool and provides an example of a PDSM decision.

Scoring Factors	Scoring Range Criteria	Score
Impact from local traffic generators	Significant-local facilities are large enough to have official destination signs on the Interstate highway such as conference centers, sports arenas etc., so they produce large surges in traffic before/after large events **(20 points)** Moderate-Local businesses or public facilities generate traffic volumes that routinely backup the on/off ramps such as morning and evening rush hours **(10 points)** Minimal-Any circumstance that causes occasional backups on the on/off ramps such as congested local arterials or rail crossings **(5 points)** None **(0 points)**	
Estimated Queue Length (Calculated, or see Max Queue Length tab for rough estimate)	> 7 miles **(130 points)** 3.5 to 7 miles **(110 points)** 0 to 3.5 miles **(85 points)** None **(0 points)**	
Sight Distance at back of Queue	Sight distance issues exist where the back of queue will likely occur. **(30 points)** Not applicable **(0 points)**	
Existing traffic issues	Higher than normal crash rates, gridlock or frequent exit ramp backups **(30 points)** Not applicable **(0 points)**	
Availability of Alternate routes	Convenient alternate routes with capacity are available. (**3 points**) No alternate routes available **(0 points)**	
Merging conflict or hazards on the approach to work zone	External merging conflicts or hazards on the approach to or within the work zone. (**15 points**) Not applicable **(0 points)**	
Complex traffic control layout	Multiple crossovers, sharp curves or lane splits **(3 points)** Not applicable **(0 points)**	
Adjacent/consecutive project	There are adjacent active projects effectively creating a mega-project that totals... longer than 10 miles or longer than 2 years (**3 points**) between 5 to 10 miles or between 1 and 2 years (**2 points**) between 2 to 5 miles or between 6 months to 1 year (**1 point**) less than 2 miles or less than 6 months (**0 points**)	
Scattered/short term project	The project includes multiple short term lane restricting activities that are scattered across the state. (ex. bridge painting) **(3 points)** Not applicable **(0 points)**	
Extreme weather condition	Work zone has a known history of sudden extreme weather condition, sandstorm, etc. Or project duration covers several harsh weather season. **(3 points)** Not applicable **(0 points)**	
Connected vehicle	>5% **(3 points)** <5% **(0 points)**	
Existing ITS Systems	Project falls inside an existing Advanced Traffic Management System? The TMC has the intent to incorporate the travel time and delay estimating system into the TMC operations? The TMC can remotely control their existing advance traveler information systems? **(Each question worth 1 point)**	
Heavy vehicles	>12% **(3 points)** >9% **(2 points)** >6% **(1 point)** <=6% **(0 points)**	
	Raw Score	**0**
	Normalized Score (0 to 100)	**0**

Figure 12.1. TxDOT Go/No-Go Decision Tool scoring criteria (Credit: TxDOT).

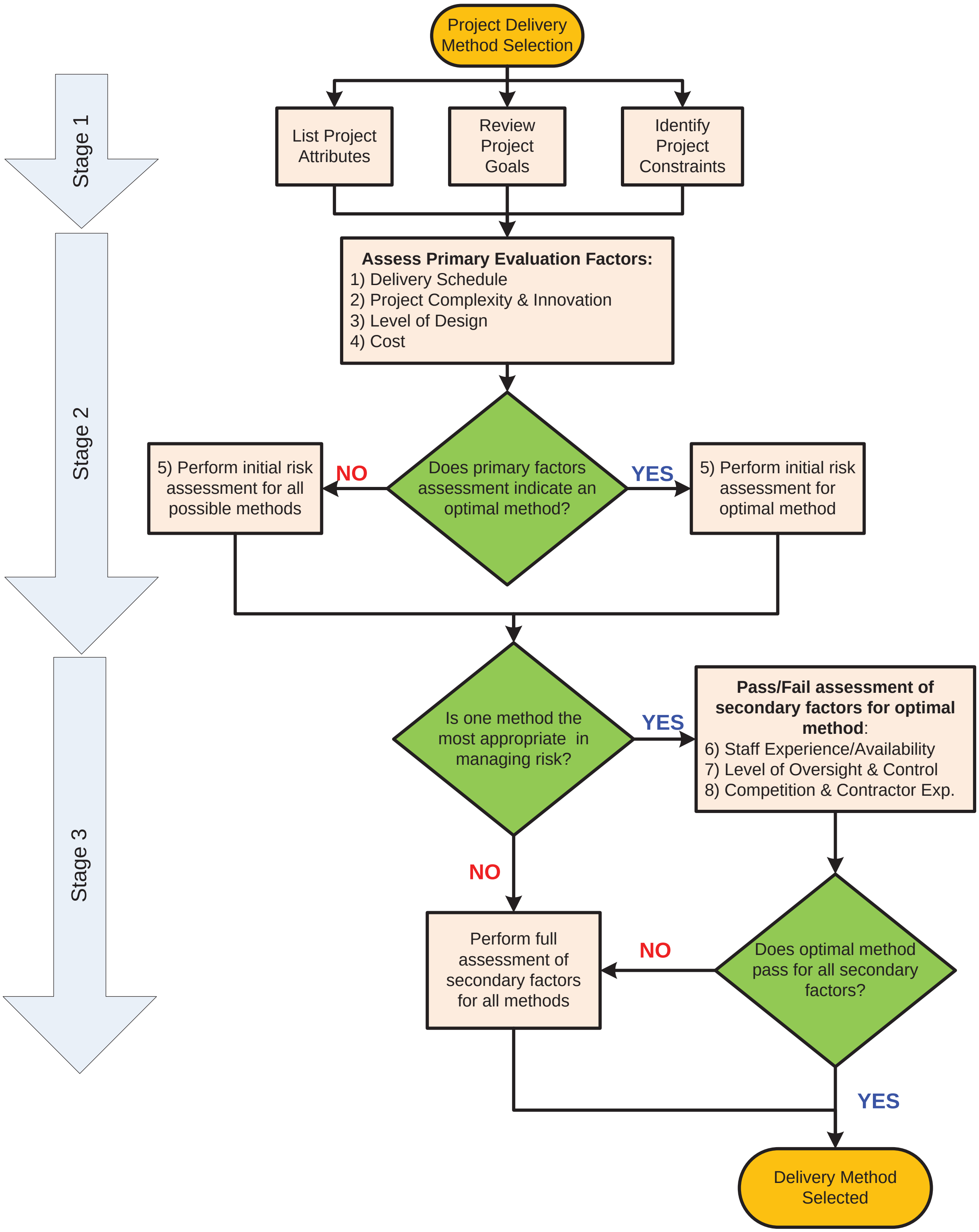


Figure 12.2. Project delivery selection matrix flowchart (Credit: University of Colorado).

12.5 Procurement Procedures Selection Matrix

The CDOT procurement decision-support tool, called the Procurement Procedures Selection Matrix (PPSM), provides a risk-based and objective selection approach to choosing a procurement procedure from the three common procurement criteria of low bid, best value, and best qualified. The PPSM then provides support and justification for the procedure chosen. The selection process, similar to the process used for selecting a delivery method, uses specific project attributes, goals, and constraints to evaluate factors critical to the decision. The evaluation factors use a qualitative rating system, and the overall highest-ranked procedure becomes the most appropriate procurement procedure. Figure 12.3 shows the PPSM process flowchart. Appendix J2 includes the full PDSM tool and provides an example of a PDSM decision.

12.6 Project Delivery Method Selection Guidance

Using CDOT's PDSM as a foundation, WSDOT developed the Project Delivery Method Selection Guidance (PDMSG). The previous selection process automatically assumed DBB as the project-delivery method (PDM) unless approval to use D-B or CM/GC as the contracting

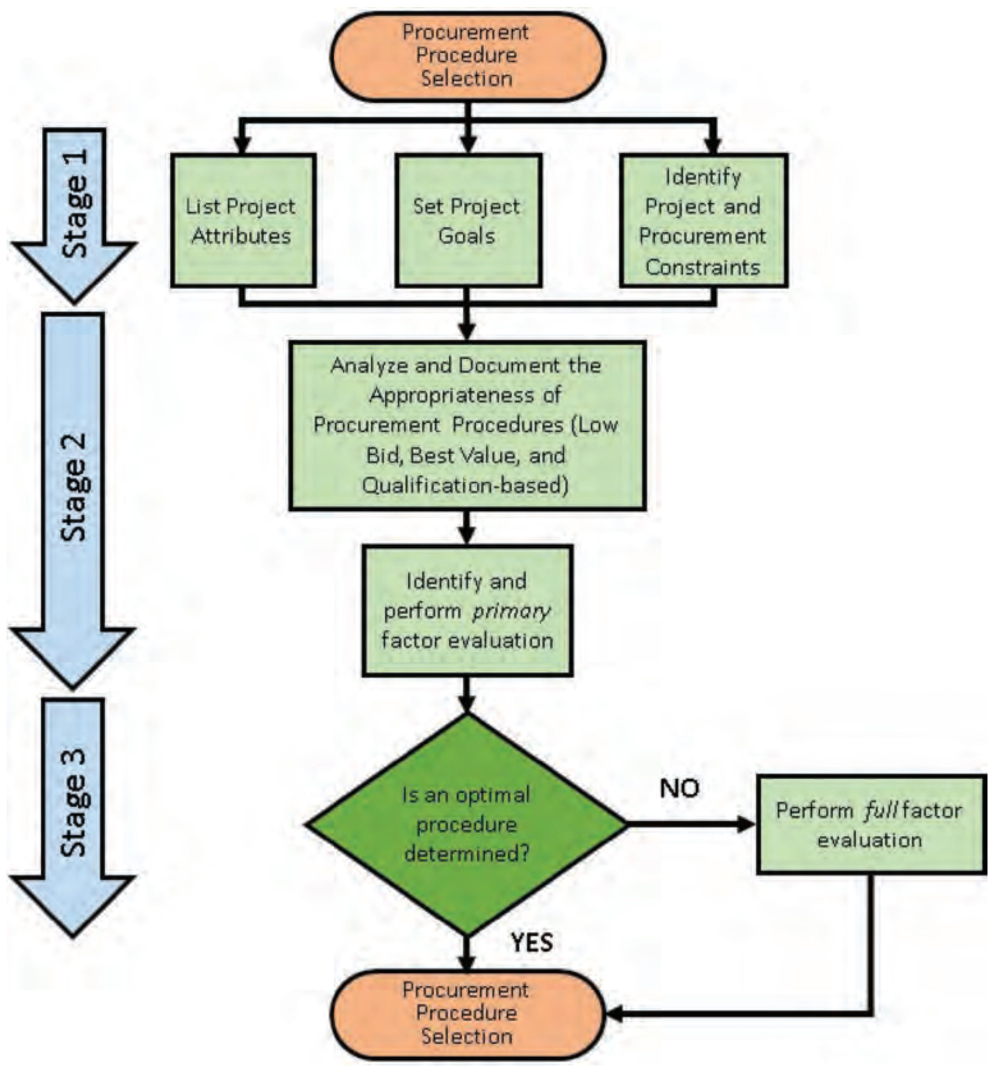


Figure 12.3. Procurement procedures selection matrix flowchart (Credit: University of Colorado).

method was pursued. The PDMSG provides progressive evaluation tools to determine the optimal PDM, with each tool scalable to the appropriate level of effort based on the type and size of the project. The original policy was that every project was required to be evaluated under PDMSG. WSDOT's direction now is that projects less than $2 million and preservation projects less than $10 million are programmatically excepted from PDMSG. All projects are evaluated in two steps:

Step 1. Before region program management offices approve the project profile, the probable PDM is established through collaboration with region subject experts and is documented in the Capital Program Management System.

Step 2. Once the project profile is approved and the design stage is about 10 percent to 30 percent complete, the final PDM is determined, a work order is set up for the project, and the project is assigned to a region project engineer's office.

A selection checklist (Appendix K1) is used during the final PDM to quickly identify projects that have an obvious optimal PDM. A selection matrix (Appendix K2), if needed as a second step, is used for more complex projects to determine the final PDM. A workshop is required for projects that cost $100 million or more to determine the final PDM.

12.7 Ohio DOT Mobility and Safety Performance Measures

12.7.1 District Work Zone Traffic Manager Notification Plan for Significant Impacts (by TMC)

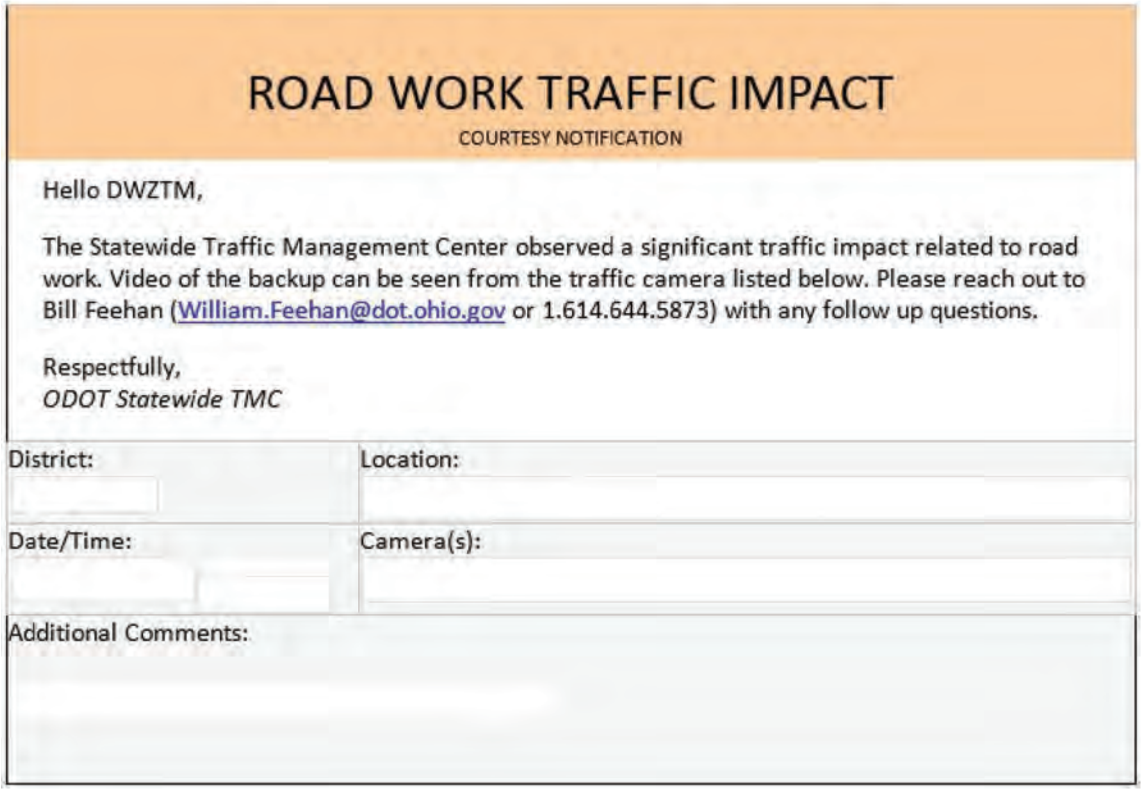
The ODOT statewide TMC sends a courtesy notification to the ODOT district work zone traffic manager (DWZTM; one designated per district) when a significant (>0.75 mi) queue results from work zone operations that were not previously planned (and approved). Upon notification, the DWZTM verifies the field conditions to determine if queuing is the result of work zone operations or some other incident and addresses the concern as appropriate. This procedure helps ODOT monitor and mitigate unexpected queuing.

Figure 12.4 is an example of a notification that would be sent when an unexpected significant impact was observed as a result of a work zone operation. The notification is limited to what the TMC operators are monitoring and does not include all of the projects and roadways.

12.7.2 Work Zone Mobility Report (a.k.a. volcanogram)

The ODOT volcanogram report includes graphs representing the number of hours in which traffic speeds dropped below 35 mph in or on either side of a work zone during each month. There are also monthly views to compare different months and to compare the same month across different years for the 2 years before construction began. The volcanogram indicates traffic speeds before and after work zones are in place and also gives a general idea of the delay pattern. If there is a sudden change in one month, the work zone traffic managers can determine if there is any issue or shift in configuration. There are also efforts to extend the reports a few miles on either side of the work zone to provide an overall review by including work zone effects propagated upstream and downstream, outside the normal work zone length.

Volcanogram reports are run for a select number of projects each year. Figure 12.5 provides an example. The black vertical bars represent the limits of the work zone, and the report can show more than one project if they are closely located. For comparison, the chart contains historic lines representing the same number of hours to that point in the 2 years before construction (each month is a different band or layer in the graph, and the historic lines also represent the



ROAD WORK TRAFFIC IMPACT

COURTESY NOTIFICATION

Hello DWZTM,

The Statewide Traffic Management Center observed a significant traffic impact related to road work. Video of the backup can be seen from the traffic camera listed below. Please reach out to Bill Feehan (William.Feehan@dot.ohio.gov or 1.614.644.5873) with any follow up questions.

Respectfully,
ODOT Statewide TMC

District:

Location:

Date/Time:

Camera(s):

Additional Comments:

Figure 12.4. Snapshot of ODOT queue notification (Credit: ODOT).

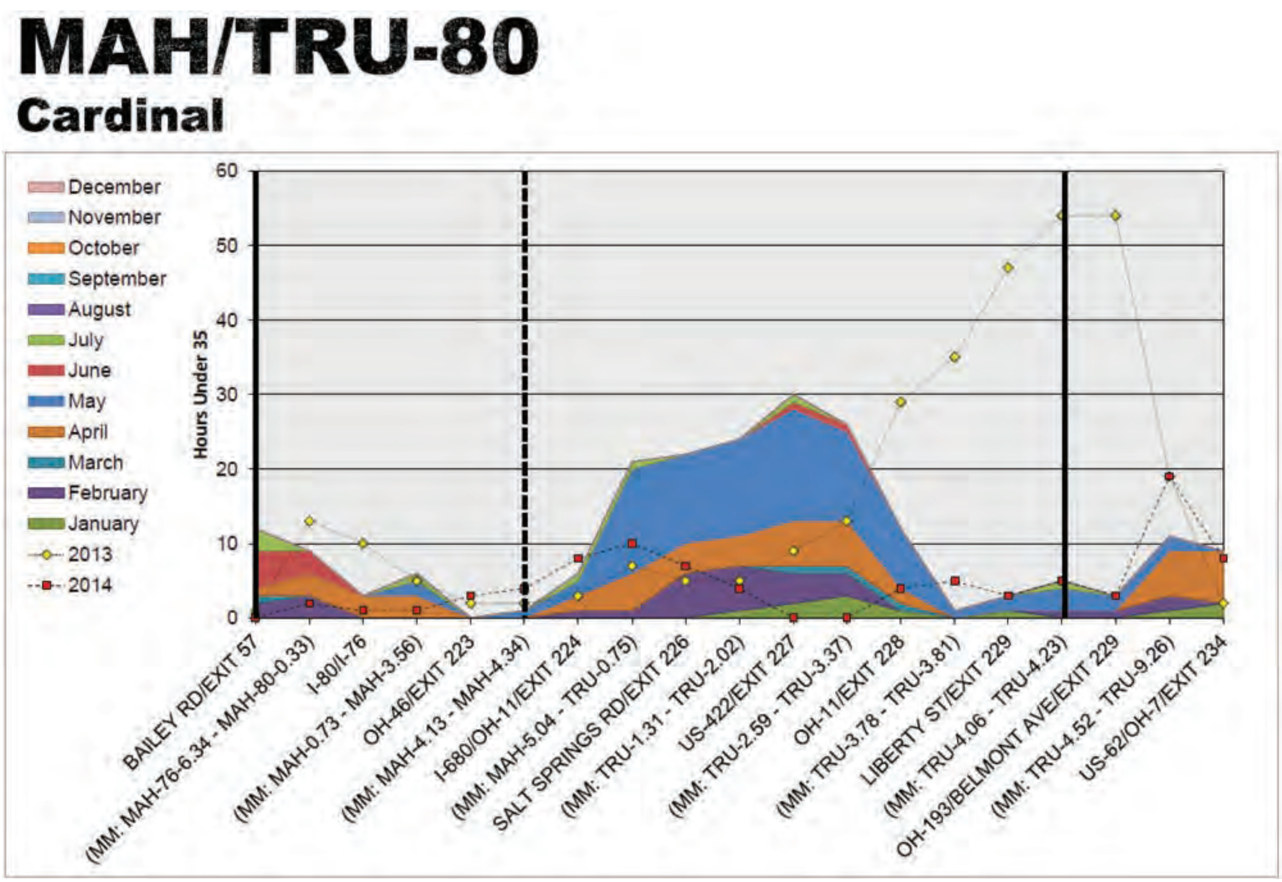


Figure 12.5. ODOT work zone mobility report, a.k.a. volcanogram (Credit: ODOT).

total number of hours for same month for the respective historic year). ODOT also looks for irregularities in the bands or an unusually high number of hours under 35 mph in reference to the trend for the corridor. As the scale adjusts for each zone based on the overall numbers, users need to reference the *x*-axis scale to keep the number in perspective, rather than just going by the visual effect of the spikes.

Volcanogram reports are shared with the DWZTMs, who in turn share them with the project engineers. Any irregularities found and the resulting information received is shared with the Project Impact Advisory Council at its monthly meeting.

12.7.3 Work Zone Crash Summary (near real time)

Crash summaries are run each month on the same select projects that run volcanograms. Crash data are extracted electronically from the law enforcement agency. The data display the number of crashes throughout the corridor as well as by month and the historic maximum. The 3-year average before construction is also shown for reference.

DWZTMs receive work zone crash summaries and are encouraged to share them with project engineers. The DOT checks for irregularities and discusses with the districts to determine a reason for the irregularity and any improvements that can be made. Figure 12.6 is an example of a crash report summary.

12.7.4 Work Zone Crash Modification Factors Report

ODOT also runs a CMF report monthly on many of the same. These reports compare the number of crashes in a specific work zone with the expected crashes based on a CMF for work zone presence. The CMFs used are from *NCHRP Research Report 869* (Ullman et al. 2018) and are for work zones with no lane closure where worker presence is unknown. Figure 12.7 shows the formulas and a snippet from the report.

12.8 MDSHA Work Zone Performance Monitoring Tool

In 2015, MDSHA developed the web-based Work Zone Performance Monitoring (WZPM) tool to assist in compliance with requirements in the Final Rule on Work Zone Safety and Mobility. The WZPM tool uses agency-provided construction and incident data feeds merged with INRIX probe vehicle data to calculate real-time mobility and safety information within and around a work zone.

The WZPM tool uses probe vehicle data to show real-time flow information within and around a work zone. Users are able to view the current flow conditions, including speed, travel time, and queue length, through the work zone or within a user-selected number of miles upstream and downstream from the work zone. The real-time flow information is plotted and compared with historical conditions to identify slowdowns, delays, and poor mobility in general. In addition to flow information, the WZPM tool calculates user delay cost associated with each work zone to communicate the cost of time and fuel consumption, as well as the emissions drivers experience because of the work zone (Figure 12.8).

The WZPM tool pulls incident information from MDSHA's CHART real-time operations system to show nearby incidents and lane closures that may affect or may be affected by the work zone. The tool maintains a historical count of nearby incidents to provide additional information related to frequency of incidents and their relationship to the work zone. Live CHART CCTV feeds are also available to allow users to view the traffic conditions.

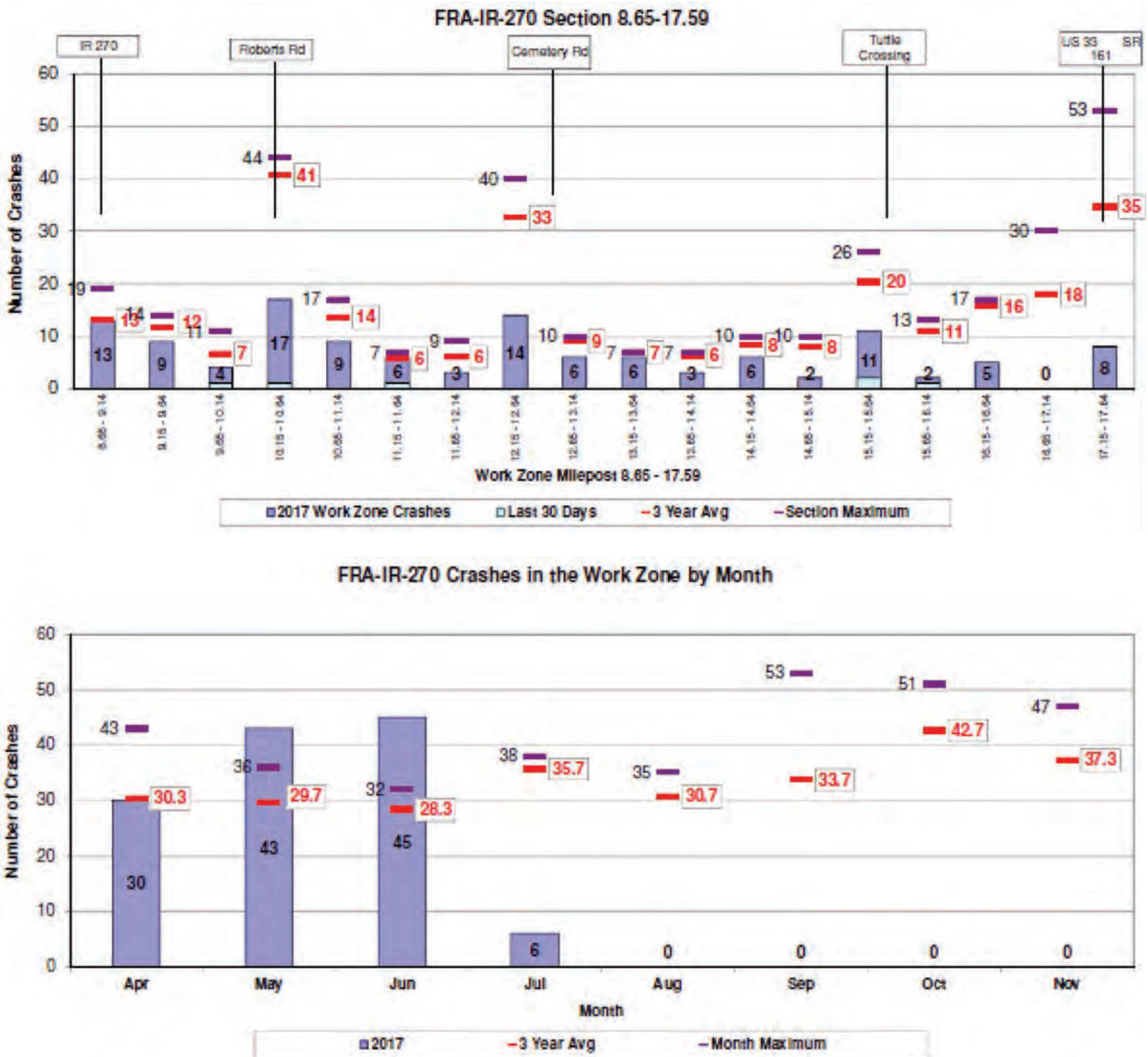


Figure 12.6. ODOT work zone crash summaries (Credit: ODOT).

Overall (worker presence unknown)	All	Four-lane freeways and expressways	5,000–70,000 AADT	$\frac{e^{-10.036+1.164\ln(AADT)}}{e^{-11.231+1.248\ln(AADT)}}$
Overall (worker presence unknown)	All	Six-lane freeways and expressways	50,000–150,000 AADT	$\frac{e^{-9.987+1.164\ln(AADT)}}{e^{-12.318+1.344\ln(AADT)}}$

Expected vs Actual Work Zone Crashes April-September 2018

District	County	Route	Begin Log	End Log	PID	AADT	Lanes in one direction?	Pre-WZ Crashes	WZCMF	Expected Crashes	Actual Crashes	Difference between Actual and Expected	% Difference
1	HAN	75	13.89	20.38	87005	48,214	3	60	1.48	89	72	-17	-19%
2	LUC	75	0.6	3.25	93594	80,877	3	36	1.35	48	47	-1	-2%
2	LUC	75	3.99	6.2	77254	99,327	2	63	1.26	79	111	32	41%
3	LOR	90	11.56	14.51	83449	66,735	2	22	1.30	29	54	25	86%

Figure 12.7. ODOT WZCMF formulas and report (Credit: ODOT).

	12AM - 4AM	4AM - 8AM	8AM - 12PM	12PM - 4PM	4PM - 8PM	8PM - 12AM	Daily Totals
Thu 9/04	$0.00	$0.2K	$20.9K	$51.7K	$3.0K	$10.29	$75.8K
Fri 9/05	$0.00	$0.2K	$34.7K	$0.9K	$1.5K	$0.00	$37.4K
Sat 9/06	$51.02	$9.51	$22.77	$7.7K	$2.3K	$2.8K	$12.8K
Sun 9/07	$58.28	$24.23	$0.00	$0.00	$11.18	$41.23	$0.1K
Mon 9/08	$1.99	$90.94	$19.5K	$18.3K	$5.4K	$9.20	$43.2K
Tue 9/09	$22.73	$0.00	$13.5K	$12.3K	$0.4K	$74.25	$26.3K
Wed 9/10	$0.00	$9.8K	$26.0K	$27.0K	$0.3K	$44.76	$63.2K
Hourly Totals	$0.1K	$10.4K	$114.7K	$117.8K	$12.8K	$3.0K	Grand Total: $258.8K

Figure 12.8. Snapshot of Maryland's Work Zone Performance Monitoring Tool (Credit: MDSHA).

12.9 Iowa DOT Statewide Smart Work Zone Program

In 2014, the Iowa DOT initiated a new effort to identify key work zones across the state as traffic-critical projects (https://sites.google.com/site/iowatcp/home). The Traffic Critical Projects program identifies key construction projects across the state that may cause significant safety or mobility issues to the traveling public. Using various mitigation methods, the program works to reduce or eliminate any potential safety or mobility concerns. A snapshot of the Traffic Critical Projects web page is shown in Figure 12.9.

Since its inception in 2014, the Traffic Critical Projects program has grown from 20 projects with 14 SWZ systems to 78 traffic-critical projects with 42 SWZ systems in 2017.

To best facilitate SWZ deployments on selected traffic-critical projects, Iowa DOT determined that a stand-alone, qualification-based procurement contract for an SWZ device vendor would provide the greatest benefit at lowest cost to meet Traffic Critical Projects program goals. Iowa DOT used a support consultant to help develop an RFP to select vendors to provide SWZ equipment throughout the state. A stand-alone SWZ vendor contract, separate from construction contracts, was employed to ensure the vendor had the required technical expertise to allow quicker and easier response to system operations and for flexibility to add or remove SWZs to projects not initially identified on the original Traffic Critical Projects list.

For system deployment, planned SWZ device locations are first verified and marked in the field for optimal visibility and to maintain state and federal sign spacing recommendations (Figure 12.10). The SWZ vendor then brings the equipment on site, placing devices at the marked locations in the corridor, and provides device details for software integration. Software integration involves entering the SWZ equipment into the traffic management software and incorporating alert-processing logic required for EQWS. This also included adding the SWZ PCMSs and cameras to the public 511 website and mobile application.

The SWZ tools being used include traffic sensors and cameras that can monitor the areas 24/7, sending data on traffic speeds, queue length, and images to the local TMC. Operators in the TMC can then communicate through message signs along the road, the 511 system, and Twitter and Facebook to alert the public to issues that might affect them. Live video from the cameras

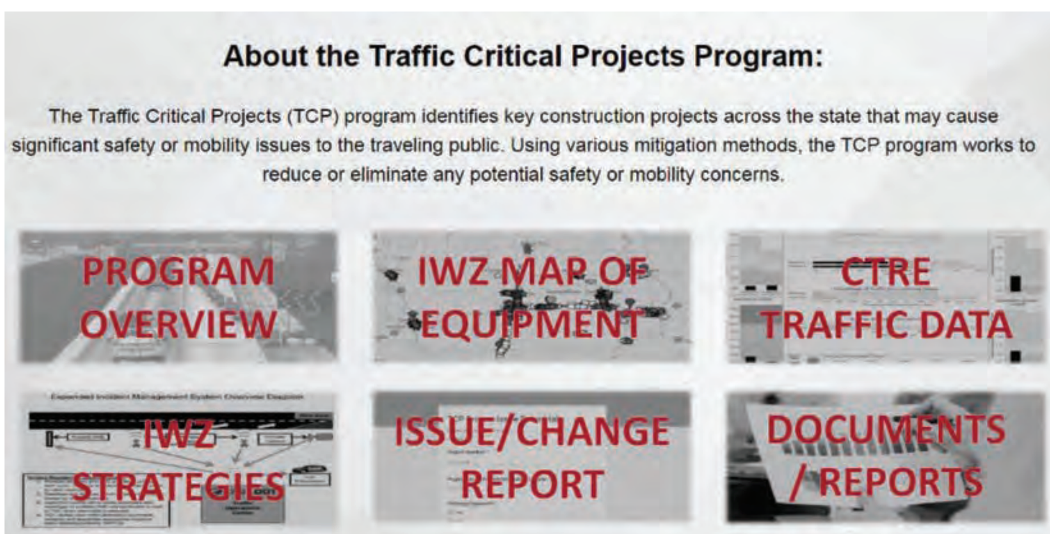


Figure 12.9. Snapshot of Iowa traffic critical projects program website monitoring (Credit: Iowa DOT).

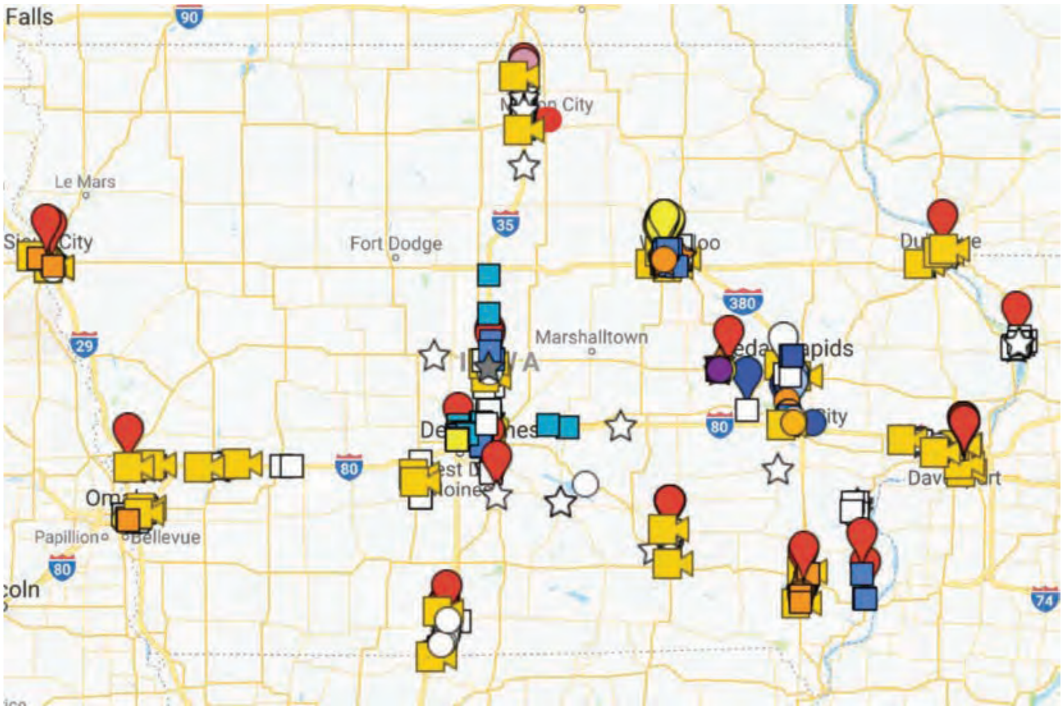


Figure 12.10. Iowa's Traffic Critical Projects and intelligent work zone device location map (Credit: Iowa DOT).

can also be viewed at http://www.511ia.org/. In addition to the SWZ tools alerting the TMC, engineers and inspectors working on specific projects will automatically receive text messages when slowdowns of more than 5 minutes happen in a work zone equipped with speed sensors.

By using real-time video feeds, receiving notifications of traffic backups or other disruptions in the flow of traffic from the queue detection units, or observing speed trends from INRIX and Google data, Iowa DOT is able to manage traffic in the work zone effectively. The portable and static message signs are used to manage queue backups, provide advance warning of delays, or move traffic to preplanned routes or detours.

Iowa DOT's statewide approach to intelligent work zones is unique. Many states deploy various intelligent work zone technologies on a project-by-project basis, but their systems may not be compatible across projects and their TMCs may not be able to monitor them. In Iowa's case, the TMC receives alerts when queues are detected and uses the SWZ cameras and message signs just like its permanent cameras and signs.

SWZ system evaluation and performance monitoring is made possible through a collaboration with Iowa State University's Center for Transportation Research and Education. In 2017, the Center used several layers of performance measures and data from within and just beyond the work areas to evaluate each project. The performance-monitoring tools developed allow users to view, in real time, the effects of work zones on traffic. The Center's web-based interactive tool has various modules, including an overview map, weekly performance, daily performance, speed heat maps, sensor performance, and hourly volumes.

Implementation of this program has had significant effects on how the Iowa DOT operates and maintains construction and maintenance work zones:

- **Performance measures.** Performance-monitoring tools were developed to view the effects of work zone projects on traffic and to monitor the traffic-sensor operating status. The data collected by cameras, sensors, and message signs are connected to a web-based performance-monitoring tool, which is updated every night to add information about the previous day to the view. All historical data are retained from the database, so information from any time interval can be queried at any point.

Traffic sensors have been the primary source of data for performance monitoring since the Traffic Critical Projects program was established. Sensors provide high-granularity data, which are beneficial when monitoring performance but could be highly variable based on the make or model of the sensors.

During the 2017 construction season, the Iowa State University Institute of Transportation (InTrans) significantly improved performance-monitoring results by using machine learning to eliminate common false traffic events, by using a fixed 45 mph threshold. Machine learning better identifies traffic events and has significantly improved the accuracy of the performance measures and decreased the number of false events detected by the previous systems. Recently, InTrans expanded the use of INRIX data to monitor projects and roadways where sensors are not deployed. INRIX probe data do not include volume, so the performance measures differ slightly from what is available using permanent or portable sensors. The amount of INRIX data is highly variable based on the type of roadway. InTrans receives a weekly snapshot of crash data from Iowa DOT, which provides the ability to perform further crash analysis regularly.

- **Text alerting.** InTrans developed a work zone text messaging alert system during the 2017 construction season. Machine learning was used to identify slow and stopped conditions within the work zone, which was then used to develop an algorithm to send text alerts of slowdowns in work zones across the state. A feed was developed to summarize this information for each work zone and is used in the TMC operations dashboard, as well as for text alerting to DOT staff.
- **Work zone capacity.** At the time this guidebook was written, InTrans was working with Iowa DOT to determine the capacity of different work zone configurations, including a capacity comparison for bridge-related work using a single lane versus two narrow lanes. Additionally, InTrans is looking at the effects towing and extra enforcement have on capacity.
- **Lane closure planning tool.** The lane closure planning tool provides convenient access to traffic data, which can be used to determine when a lane can safely be closed. The tool uses data from ITS sensors to update its database every month, which includes the hourly volume by month, day of week, and time of day. Hourly volumes are currently being expanded to include the average, minimum, maximum, and 25th and 75th percentiles. In addition to raw hourly volume, automobile-equivalent hourly volume is also calculated.
- **Open data service.** InTrans has developed an open data service intended to provide high-quality, near real-time data feeds for any public or private entity. Data feeds and services support both agency and external users over a wide range of use categories. The sources are varied and can include operation, roadway, weather, maintenance, and safety data. Several InTrans initiatives, including text alerting, the TMC operations dashboard, and the lane closure planning tool, use the open data service for their databases. This data service integrates multiple data sources available to the DOT.

12.10 Safety Assessment Tool for Construction Phasing Plans

The *Highway Safety Manual* (HSM) (AASHTO 2010) provides limited guidance for work zone safety evaluation. It only gives two CMFs to calculate the effect of an increase or a decrease of freeway work zone length and duration on the crash count.

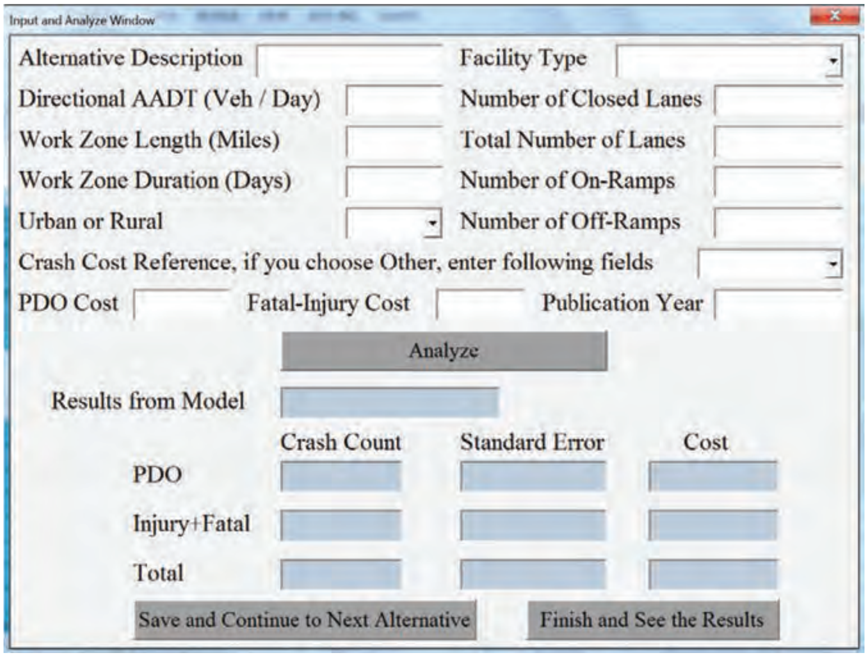


Figure 12.11. User input window of the safety assessment tool (Credit: University of Missouri).

A study (Brown et al. 2016) conducted for FHWA by the University of Missouri–Columbia addressed this gap in knowledge by developing a spreadsheet-based safety assessment tool for freeways, expressways, rural two-lane highways, urban multilane highways, arterials, signalized intersections, un-signalized intersections, and ramps.

Using data from Missouri work zones, the study developed 20 crash-prediction models. The tool predicts crashes by severity and crash costs for each work zone alternative based on input data provided by the user. All models were programmed in a user-friendly spreadsheet tool for practitioners. An illustrative example is presented to show how this software can be used for assessing the safety of different work zone plans. Figure 12.11 and Figure 12.12 show the software graphical user interface and an example of output, respectively.

12.11 Special-Color Pavement Markings

Roadway lanes are often repositioned to accommodate highway work operations; as a result, pavement markings need to be altered. Although there are various methods for removing or obscuring pavement markings, “ghost” markings often remain at the locations of the old lane lines. These ghost markings can be conspicuous under certain lighting conditions, creating the potential for road-user confusion. The Canadian province of Ontario and several European countries routinely use a special marking color (orange or yellow) to increase the salience of temporary lane lines. Special-color markings have also been used experimentally in Australia; New Zealand; Quebec City, Canada; and the United States.

WisDOT had difficult conditions at a high-volume freeway-to-freeway interchange project (Zoo Interchange) in winter, as salt residue on the roadway surface obscured the traditional white lane markings. To provide more clearly defined lanes in the work zone, WisDOT sought and was granted experimental permission by FHWA in 2014 to use orange paint (Figure 12.13).

Alternatives Comparison			
	Output		
	Freeway Shoulder	**Rural Two-Lane Resurfacing**	**Project 1**
Expected Number of PDO Crashes	7.8	0.17	7.49
Standard Error of PDO Estimates	4.085	0.412	6.819
Expected Number of Fatal and Injury Crashes	2.51	0.06	2.49
Standard Error of Fatal and Injury Estimation	1.852	0.245	2.608
Total Crash Cost, value in 2016	$928,800	$21,953	$917,653
Model Used: #	6	14 & 15	12
	Input		
	Freeway Shoulder	Rural Two-Lane Resurfacing	Project 1
AADT	50000	1950	30000
Duration	47	15	54
Length	3	2	3
Urban/Rural	Urban	Rural	Urban
Number of Closed Lanes	1		
Total Number of Lanes	3		
Number of On-ramps	1		
Number of Off-ramps	2		
Number of Signalized Intersections		1	1
Crash Cost Reference: Publication Year	HSM (2010)	HSM (2010)	HSM (2010)
PDO Crash Cost	$7,400	$7,400	$7,400
Fatal and Injury Crash Cost	$158,200	$158,200	$158,200
Fatality Type	Freeway	Rural Two-Lane	Expressway

Figure 12.12. Sample output of the safety assessment tool (Credit: University of Missouri).

Orange reflective epoxy paint has been used in Canada, New Zealand, and Europe but not previously in the United States.

However, a direct assessment of the Zoo Interchange site was difficult because of the fast-paced construction with frequent lane and alignment changes, high traffic volumes, and recurring congestion even before the project began. These complexities made it challenging to separate the driver behavior and traffic operations effects of the orange markings from those attributable to other site conditions and traffic management techniques.

Figure 12.13. WisDOT use of orange pavement markings (Credit: John Shaw/University of Wisconsin–Madison).

To assess the driver behavior aspects of orange markings in a simpler environment, WisDOT conducted a matched-pair with and without study on two bridge re-decking projects on I-94 near Oconomowoc (Shaw, Chitturi, and Noyce 2017; Shaw et al. 2018).

No significant differences were found between the distributions of lane position and speed data for the test and control sites. However, a driver survey indicated that the orange markings were more visible and easier to see. Based on the field data, driver surveys, and interviews of field engineers, there was no evidence that drivers miscomprehended the orange markings. The study concluded that "perhaps the most pragmatic approach is to reserve orange as an emphasis color for specific work zone locations that require difficult driving maneuvers. This approach is similar to the British practice of parsimoniously using special marking colors to provide emphasis in problematic areas, and would help reduce the potential for drivers to become desensitized to the special color."

12.12 Automated Truck-Mounted Attenuator

One type of positive protection developed and often used in work zones is the TMA. The TMA is positioned as a shadow vehicle, relative to the workers, work vehicles, or the immediate workspace. TMAs save lives and prevent injuries for both motorists and maintenance workers, but they put the TMA driver at risk of injury when the attenuator is hit.

Recent technology has allowed an option to remove the driver from the buffer vehicle designed to be struck by errant vehicles. The autonomous truck-mounted attenuator (ATMA), also known as the autonomous impact protection vehicle, consists of two vehicles, a leader and a follower. The leader vehicle is human driven and is equipped with an onboard computer, digital compass, transceiver, and GPS receiver. The lead vehicle wirelessly transmits high-accuracy data on its position, speed, and heading. The ATMA receives this transmission and copies the lead vehicle's movements using steering, throttle, and brake actuators. ATMAs can be retrofitted to existing TMAs. Figure 12.14 shows the leader and follower vehicles.

At the time this guidebook was written, ATMAs had been tested and were already in use in a few states, but only in a limited capacity as part of pilot programs, including the following:

- Act 117, passed in October 2018, allows for PennDOT and the Pennsylvania Turnpike Commission to implement highly automated work zone vehicles in active work zones.
- In August 2017, CDOT became the first transportation department in the United States to purchase and demonstrate an ATMA when a CDOT road-striping crew used the ATMA

Figure 12.14. Autonomous TMA (Credit: Royal Truck and Equipment, Inc.).

near Fort Collins. Colorado has also used its ATMA in rural areas away from heavy or mixed traffic.
- FDOT tested an ATMA in 2015.

ATMA technology is still in the late stages of development and there are several challenges to be addressed:

- The following vehicle copies the movements of the lead vehicle exactly; if the lead vehicle encounters an obstacle and has to change lanes, the ATMA won't change lanes until it also encounters the obstacle. This leaves the lead vehicle without protection until the ATMA also changes lanes.
- The lead and following vehicles sometimes lose communication when passing under overpasses or through tunnels.

12.13 Green Lights on TMAs

MoDOT (Brown et al. 2018) tested the use of green lights on TMAs to improve work zone visibility. This was the first quantitative study of green lights on TMAs in the United States, and MoDOT used simulator and field studies to test four different configurations.

The simulator testing phase examined amber/white (MoDOT typical), green only (MoDOT preferred), green/amber (MoDOT alternative), and green/white (design alternative) configurations. The field test evaluated the amber/white and green-only configurations (Figure 12.15).

Video data were collected for 2 days in a mobile work zone on US 50 in the Kansas City area. The mobile work zone consisted of a green-only rear advance TMA and an amber/white shoulder TMA for the first day and two amber/white TMAs for the second day.

During daytime, the leading vehicle passing speed for amber/white TMAs was slightly higher (64.5 mph) than for the green-only TMA (62.5 mph). During nighttime, vehicle passing speed for the green-only TMA was slightly lower (52.1 mph) compared with the amber/white TMAs (52.9 mph). The authors cautioned that driver behavior could have been influenced by the novelty effect of green-light TMAs and that a longer-duration study is necessary to examine the novelty effect.

The results did not point in a single direction for both the simulator and field tests, and all four configurations appeared to be viable.

12.14 Rolling Roadblock Procedure for Temporary Lane Closures

According to FHWA, a rolling roadblock, also known as a temporary road closure, rolling block, pacing operation, or traffic pacing, is a common highway traffic control technique used to temporarily slow or stop traffic upstream of construction, maintenance, and utility work activities requiring a short-term full closure of the roadway (FHWA, n.d.).

Rolling roadblocks allow for faster completion of roadwork activities by allowing workers full access on and above a roadway, and the opportunity for a safe environment by completely removing vehicles that would normally be close to workers.

Policies and procedures governing the use of rolling roadblocks for highway work activities vary by state. Additional resources are available to transportation agencies for improving rolling roadblock practices. Among these resources is *Guidelines on Rolling Roadblocks for Work Zone Applications*, developed by the American Traffic Safety Services Association. This guide establishes best practices in the use of rolling roadblocks and provides valuable information on

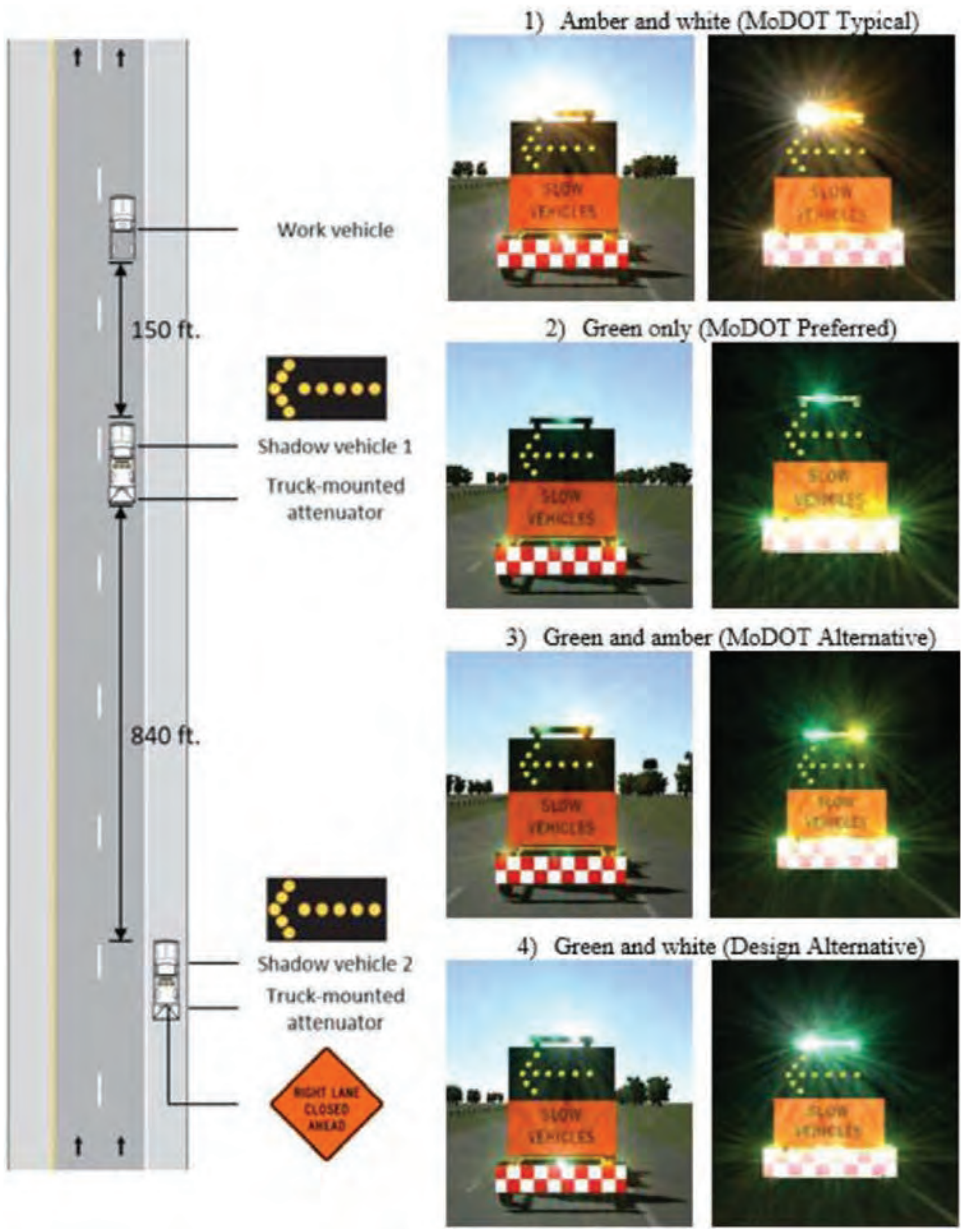


Figure 12.15. Simulator testing TMA configurations (Credit: University of Missouri).

planning and coordinating a rolling roadblock, executing a rolling roadblock, and developing a rolling roadblock planning checklist.

The Connecticut DOT allows rolling roadblocks during the installation of temporary lane closures on limited-access highways. Rolling roadblocks are allowed for installing and removing lead signs and lane tapers only, for a maximum duration of 15 minutes.

12.15 Work Zone Cell Phone Restrictions

As part of ongoing efforts to reduce distracted driving and increase safety for motorists and workers in work zones, Wisconsin passed legislation making it illegal to talk on a handheld mobile device while driving in a Wisconsin roadwork zone. The 2015 Wisconsin Act 308 went

Figure 12.16. Wisconsin work zone cell phone restriction sign (Credit: WisDOT).

into effect on October 1, 2016, and drivers caught in violation face fines of up to $40 on first offense and up to $100 for subsequent offenses. Appendix L provides bill text (2015 Assembly Bill 198). The sign associated with this law is shown in Figure 12.16.

Hands-free and Bluetooth devices are granted exemptions and remain legal to use. The law also grants an exception for drivers to use a handheld mobile device if dialing 911. Wisconsin continues to enforce zero tolerance for texting while driving through work zones.

Wisconsin does not prohibit drivers from using handheld cell phones while driving, outside work zones. However, Wisconsin law forbids driving any motor vehicle while composing or sending a text message or an e-mail message (primary law).

12.16 Colorado Lane Closure Strategy

The CDOT developed Lane Closure Strategy (LCSY) for each of its five regions to establish uniform criteria and authoritative guidance for scheduling lane closures. Each region's policy is unique—enabling CDOT to tailor its lane closure policies to a vast state that encompasses both rural mountainous areas and large urban areas.

The LCSY was formulated to strike an appropriate balance between delays to the traveling public in the work zone and the cost of construction and maintenance. The LCSY is applicable to single-lane closures (and multilane closures on five-or-more-lane roadways) related to construction and maintenance activities on roads CDOT controls. It is based on extensive data analyses and estimates of delays expected during lane closures. The LCSY addresses weekday and weekend traffic demand and considers temporal variations in traffic volume occurring over a typical 24-hour period. The LCSY also accounts for seasonal variations in traffic volumes, where appropriate. In the past, lane closure decisions were primarily based on field observations, previous experience, and engineering judgment.

LCSYs are recalibrated on a 3- to 5-year rotation to reflect changes in traffic volumes and available capacity (Region 1, 5th edition, was published in 2019; Region 2, 2nd edition, in 2013; Region 3, 3rd edition, in 2017; Region 4, 3rd edition, in 2017; and Region 5, 1st edition, in 2008).

LCSYs provide several types of information related to closures in each region, including the following:

- General background information on traffic conditions in the area.
- Allowable lane closure hours for all state highways in a tabulated form. The tables provide specific times at which closures will be allowed for each highway section. Sections are divided where lane geometry changes or daily traffic volumes change significantly.
- Procedures for implementing a lane closure for access permit and maintenance work.
- Procedures for implementing a lane closure for CDOT design projects.

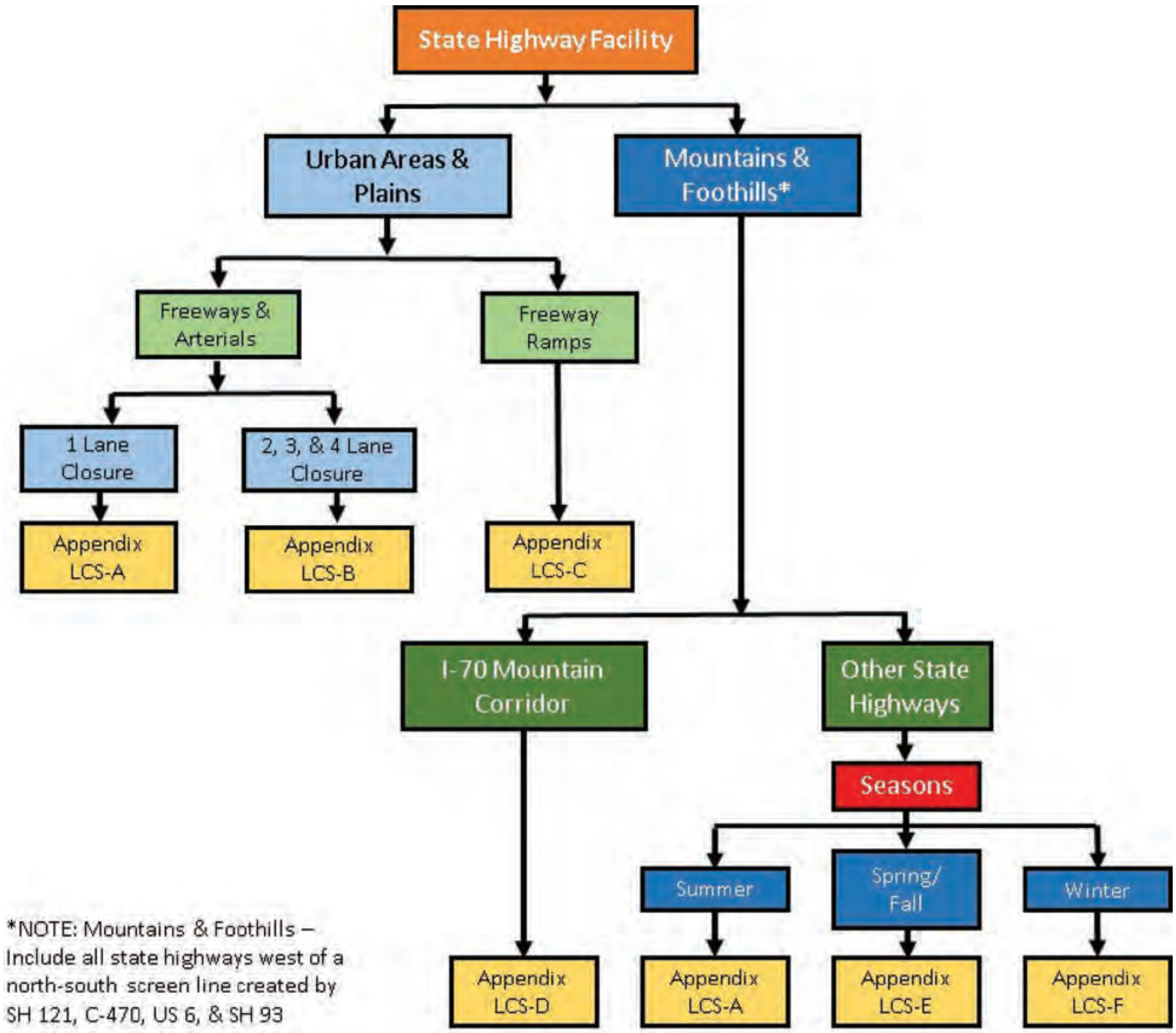


Figure 12.17. CDOT lane closure scheduling decision tree (Credit: CDOT).

- Procedures for changing the closure hours during the construction and variance request process.
- Flowcharts (Figure 12.17) to identify the allowable lane closure hours for a specific state highway under the following conditions:
  - All seasons.
  - Number of lanes closed—one, two, or three.
  - Freeway ramp-closure schedules.
  - I-70 mountain corridor closure schedules.

Using the information presented in the LCSY has improved the quality of lane closure decisions, simplified the decision process for the end user, and reduced the uncertainty associated with handling traffic during construction.

12.17 MnDOT Lane Closure Manual

MnDOT developed a lane closure manual to use when planning and scheduling lane and shoulder closures on MnDOT-owned and -operated freeways and expressways in the Metro District, District 6, and District 3. The lane closure manual determines the appropriate

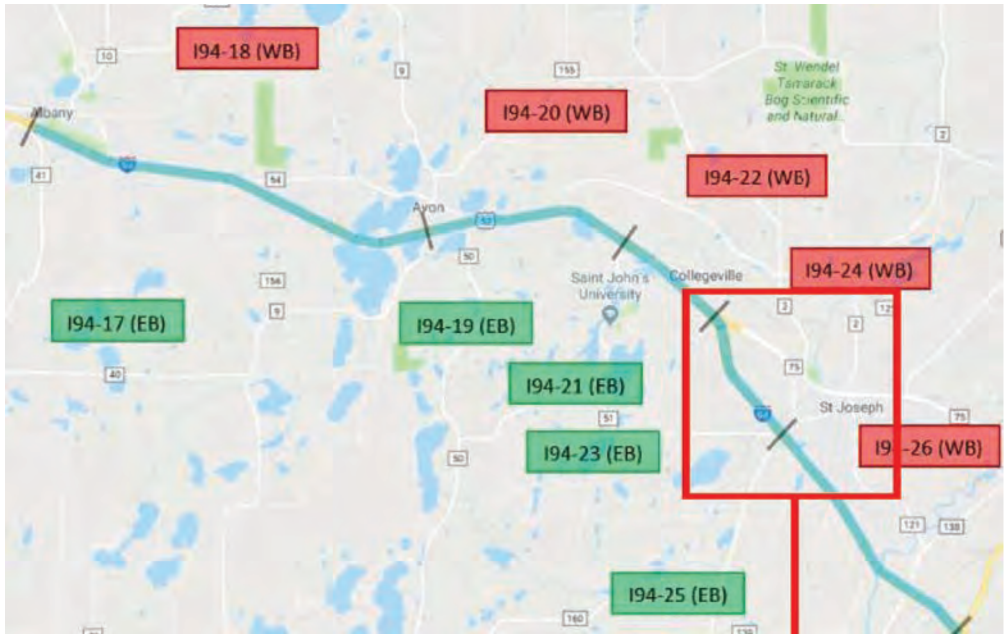


Figure 12.18. MnDOT lane closure manual roadway segments (Credit: MnDOT).

time of day for planned lane closures based on the number of available lanes and traffic-count data.

The purpose of the lane closure manual is to provide information useful for advance planning of lane closures that will minimize traffic impacts and motorist delays while promoting safety for work crews and the traveling public. Lane closures allowed by this manual are typically short term (12 hours or less) and do not involve a traffic detour or diversion. Traffic-flow volumes from regional TMC detectors and tube counters are collected, analyzed, and formatted to display allowable lane closure figures based on roadway location and time of day.

The manual is divided into sections by roadway, and each roadway is divided into segments. Segments are generally determined by the number of continuous lanes available along a highway corridor. The index maps illustrate where each roadway is broken down into numbered segments (Figure 12.18).

The numbered segment directs the user to the correct page of the manual that provides tabulated traffic data (Figure 12.19). MnDOT uses a system of shading to display the number of lanes that can be closed for each hour of the day. The allowable lane closure figures given in the lane closure manual have been smoothed to remove some of the seasonal data fluctuations.

12.18 ODOT Permitted Lane Closure Schedule

The ODOT lane closure policy is described within the Policy for Traffic Management in Work Zones (Standard Procedure No: 123-001). The policy was developed to systematically determine the effects created by work zones and will eliminate, minimize, or mitigate these effects to the greatest extent practical. ODOT lists the process of determining lane closure times on its permitted lane closure schedule website.

The permitted lane closure schedule is a web-based searchable database tool that provides a quick and efficient method for identifying which hours of the day lane closures should not result in violations of the allowable queue length threshold.

REPORT GENERATED 03/09/18

Minnesota Department of Transportation
District 3 Traffic Engineering
Allowable Lane Closure Report

I94-23

This report is based on counter data collected in 2017 interpolated using hourly distribution percentages from segment I94-31.

Road Segment Description

TH: TH 94 Dir: EB Description: From CSAH 75 to CSAH 2
True Mile: Begin 157.93 End 160.1 Lanes: 2 Signals: NO

Project ID: I94-23 Sequence #: 5526

Day Hours	MON	TUE	WED	THU	FRI	Average Weekday	Allowable Lane Closure	SAT	SUN	Day Hours
12-01AM	113	117	113	121	133	119	1	145	140	12-01AM
01-02	88	93	99	95	109	97	1	110	90	01-02
02-03	79	103	110	105	106	101	1	95	74	02-03
03-04	131	136	125	138	147	135	1	95	64	03-04
04-05	356	316	312	322	285	318	1	130	78	04-05
05-06	614	563	551	556	484	554	1	168	93	05-06
06-07	674	631	616	616	557	619	1	239	150	06-07
07-08	699	683	706	686	628	680	1	360	266	07-08
08-09	686	680	697	680	649	678	1	527	414	08-09
09-10	685	643	685	675	710	680	1	764	665	09-10
10-11	744	678	713	738	803	735	1	944	983	10-11
11-12N	807	711	759	798	898	795	1	983	1196	11-12N
12-01PM	848	764	785	833	978	842	1	978	1308	12-01PM
01-02	831	792	838	903	1040	881	1	939	1357	01-02
02-03	880	804	876	940	1091	918	1	923	1379	02-03
03-04	927	922	965	1005	1129	990	1	908	1341	03-04
04-05	968	975	1005	1042	1110	1020	1	863	1276	04-05
05-06	946	933	966	1003	1045	979	1	781	1133	05-06
06-07	690	669	668	717	820	713	1	662	1056	06-07
07-08	546	511	528	585	668	568	1	603	959	07-08
08-09	467	452	466	512	575	494	1	553	778	08-09
09-10	390	383	398	435	480	417	1	482	514	09-10
10-11	243	246	278	292	328	277	1	340	306	10-11
11-12M	174	168	185	205	224	191	1	210	174	11-12M
Totals:	13586	12973	13444	14002	14997	13800	Allowable Lane Closure	12802	15794	

0	= 0 lane closure allowed	Segment Average Week Day Prohibited Hours	0
1	= 1 lane closure allowed	Segment Average Week Night Prohibited Hours	0
2	= 2 lane closure allowed	Segment Average Daily Prohibited Hours	0
3	= 3 lane closure allowed		

Figure 12.19. MnDOT lane closure manual showing allowable lane closures (Credit: MnDOT).

ODOT Permitted Lane Closure Print

District: 12 | County: CUY | Route: IR-490 | DIR: EAST | Calculation Year: 2016 | Section: 77 to E.55 st. east

COUNTY BEGIN LOG 1.880
COUNTY END LOG 2.430
STATE BEGIN LOG 1.880
STATE END LOG 2.430

Calculation Method D ADT using statewide distribution
Road Class URBAN (Urban or Rural)
Terrain LEVEL
Lanes per direction 3

ATR# 585
ADT Year 2012
Percent Trucks 2
Annualized ADT 41230

Seasonal Traffic Adjustment

	Weekday	Weekend	
ADT	50901	38533	Summer
ADT	49675	37482	Spring/Fall
ADT	44815	31961	Winter
Capacity	1490	per lane	

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 and New Years. No lane closures are allowed after 12:00 noon on the weekday preceding a holiday. For holiday weekends no lane closures are allowed after 12:00 noon on the day preceding the Holiday weekend until 6:00 AM the day after the holiday weekend. (Ex. Holiday falls on a Monday then no lane closures from 12:00 noon on Friday until 6:00 AM Tuesday.) For Thanksgiving holiday no lane closures are allowed after 6:00 AM on the Wednesday preceding Thanksgiving until 6:00 AM on the following Monday. ***NOTE: If no lane closure tables load upon opening this segment (or if they load but they are blank) do not make assumptions on when lane closures are permitted. Please contact the District Work Zone Traffic Manager (DWZTM) responsible for this district for information on how to proceed.***

Ratio of Lanes 3:2 — Traffic Volume per open lane

Season	Summer Weekday	Summer Weekend	Spring/Fall Weekday	Spring/Fall Weekend	Winter Weekday	Winter Weekend
Hour of the Day	MON-FRI	SAT-SUN	MON-FRI	SAT-SUN	MON-FRI	SAT-SUN
0-1AM	115	87	112	84	101	72
1-2AM	76	58	75	56	67	48
2-3AM	64	48	62	47	56	40
3-4AM	64	48	62	47	56	40
4-5AM	115	87	112	84	101	72
5-6AM	305	231	298	225	269	192
6-7AM	636	482	621	469	560	400
7-8AM	929	703	907	684	818	583
8-9AM	802	607	782	590	706	503
9-10AM	649	491	633	478	571	408
10-11AM	624	472	609	459	549	392
11-12PM	662	501	646	487	583	415
12-1PM	700	530	683	515	616	439
1-2PM	713	539	695	525	627	447
2-3PM	802	607	782	590	706	503
3-4PM	929	703	907	684	818	583
4-5PM	993	751	969	731	874	623
5-6PM	993	751	969	731	874	623

Legend

* = Lane Closure(s) Not Permitted

3:2: Ratio Of Lanes
3 : Available Lanes
2 : Lanes Open

Season	Period
Summer	June 1 - Aug 31
Spring/Fall	Mar 1 - May 31 & Sept 1 - Nov 30
Winter	Dec 1 - Feb 29

Last Updated :01/25/16 3:42 PM

Ratio of 3:1 Lanes — Traffic Volume per open lane

Season	Summer Weekday	Summer Weekend	Spring/Fall Weekday	Spring/Fall Weekend	Winter Weekday	Winter Weekend
Hour of the Day	MON-FRI	SAT-SUN	MON-FRI	SAT-SUN	MON-FRI	SAT-SUN
0-1AM	229	173	224	169	202	144
1-2AM	153	116	149	112	134	96
2-3AM	127	96	124	94	112	80
3-4AM	127	96	124	94	112	80
4-5AM	229	173	224	169	202	144
5-6AM	611	462	596	450	538	384
6-7AM	1273	963	1242	937	1120	799
7-8AM	* 1858	1406	* 1813	1368	* 1636	1167
8-9AM	* 1603	1214	* 1565	1181	1412	1007
9-10AM	1298	983	1267	956	1143	815
10-11AM	1247	944	1217	918	1098	783
11-12PM	1323	1002	1292	975	1165	831
12-1PM	1400	1060	1366	1031	1232	879
1-2PM	1425	1079	1391	1049	1255	895
2-3PM	* 1603	1214	* 1565	1181	1412	1007
3-4PM	* 1858	1406	* 1813	1368	* 1636	1167

Figure 12.20. ODOT permitted lane closure schedule (Credit: ODOT).

The user searching for permitted lane closure times inputs the following information: year of the last ADT count, district number, county, route, and the section of that route. The search yields a table—similar to the screenshot in Figure 12.20—showing the permitted lane closure times.

The times of the day that lane closures are not permitted are indicated by the different shaded hours for each day of the week, for construction and nonconstruction seasons. The table also includes the lane capacity used when determining if a lane closure is permitted. These capacities vary from facility to facility.

The permitted lane closure schedule application, based on the Internet, is a convenient way to find lane closure times for certain facilities. The lane closure capacities are adjusted based on conditions of the facility, so a better approximation of the lane capacity is applied.

12.19 Wisconsin Web-Based Lane Closure Permitting Systems

The Wisconsin Lane Closure System (LCS) is a web-based system for tracking closures and restrictions on Wisconsin Interstate, U.S., and state highways. The purpose of the LCS is to

- Provide a standard interface for lane closure operations, closure tracking, and data retrieval for WisDOT regional offices statewide;
- Facilitate data sharing with WisDOT applications that require lane closure data from 511 traveler information, the statewide TOC, inconvenience map production, and oversize/overweight permitting;
- Improve the completeness, reliability, and timeliness of lane closure data on state highways;
- Archive LCS data in the WisTransPortal system for future analysis and integration with other WisDOT/UW-TOPS Lab traffic-engineering applications and research; and
- Integrate historical traffic-flow data and capacity information to calculate available closure thresholds.

The LCS is the single source of Wisconsin Interstate, U.S., and state highway lane and ramp-closure information. Closure and restriction information is entered for

- All let projects or design projects with impacts to an Interstate, U.S., or State highway;
- Any planned maintenance or permit/utility restrictions of closures on Interstates, U.S., and state highways;
- Major special events; and
- Any unplanned emergency lane closures.

The LCS shares data with several internal and external mediums: the Wisconsin 511 system, the WisDOT website, statewide TOC, daily/weekly e-mail reports, and third-party media (vehicle navigation systems, phone/tablet apps, websites, social media, and news reports).

Closure information can be entered into the LCS by any system user. WisDOT staff can enter the information or request that a consultant, contractor, or county enter the information. However, closures need to be entered into the LCS in compliance with the minimum advance notification time frames shown in Figure 12.21.

Depending on the type of closure and the user entering the closure, the closure will be either automatically accepted or sent through the acceptance process. If a user has acceptance authority, the system allows, but does not require, the user to immediately accept the entered closure information into the system. Once accepted, the information is live and therefore published as an active closure.

A user may only enter and act on a closure located within the same region as the user's region. The region options in LCS include SE (Southeast), SW (Southwest), NE (Northeast), NC (North Central), NW (Northwest), and ALL (All Regions).

CLOSURE TYPE AND REQUIRED MINIMUM ADVANCE NOTIFICATION	
Closure type with height, weight, or width restrictions (available width, all lanes in one direction <16')	MINIMUM NOTIFICATION
Lane and shoulder closures	7 calendar days
Full roadway closures	7 calendar days
Ramp closures	7 calendar days
Detours	7 calendar days
Closure type without height, weight, or width restrictions (available width, all lanes in one direction ≥16')	MINIMUM NOTIFICATION
Lane and shoulder closures	3 business days
Ramp closures	3 business days
Modifying all closure types	3 business days

Figure 12.21. WisDOT lane closure advance notification times (Credit: WisDOT).

Operational since April 2008, the LCS facilitates work zone acceptance and monitoring at WisDOT statewide TOC and regional transportation offices and provides real-time lane closure information to the Wisconsin 511 traveler information system.

12.20 Caltrans Lane Closure System

On January 15, 2016, Caltrans revised the 2015 Standard Specifications, Section 12-4.02C(2), Lane Closure System, to implement the use of the LCS mobile web page to report closure status.

The LCS was developed to reduce the steps needed to cancel or start closures and to allow contractors to interface directly with the LCS, helping expedite and improve the accuracy of lane closure status. Contractors are required to request closures using the Caltrans LCS and status closures using the Lane Closure System mobile web page.

Every 5 minutes LCS reports all approved closures planned for the next 7 days, plus all current lane, ramp, and road closures caused by maintenance, construction, special events, and so on.

The LCS disseminates construction information to the Caltrans online tools QuickMap, Commercial Wholesale Web Portal, and Performance Measurement System and the Caltrans Highway Information Network hotline.

When the contractor changes the status of a closure, the LCS sends an e-mail notification to the resident engineer and designated inspectors.

12.21 e-Construction and Partnering

Through Round 4 of the EDC, the FHWA has promoted e-construction and construction partnering as practices that can be used in concert to help deliver transportation improvements smarter and faster.

e-Construction is the creation, review, approval, distribution, and storage of highway construction documents in a paperless environment. These paperless processes include electronic submission of all documentation by all stakeholders, electronic document routing and approval (e-signature and workflows), and real-time management of all documents in a secure digital environment accessible to all stakeholders through mobile devices and web-based platforms.

e-Construction aims to employ established technologies that are readily available to the transportation community, such as digital electronic signatures, electronic communication, secure file sharing, version control, mobile devices, and web-hosted data archival and retrieval systems to improve construction documentation management.

Many state DOTs and industry practitioners are already using or testing some aspects of e-construction. Some are even in the process of mainstreaming many e-construction system practices.

MDOT has applied e-Construction routinely to DBB projects, while the Minnesota, Florida, Utah, Texas, Pennsylvania, and North Carolina DOTs have applied this technology to D-B projects. The Wisconsin and Iowa DOTs have applied e-construction to DBB projects.

MDOT, a leader in e-construction, estimates that the agency saves approximately $12 million in added efficiencies and 6,000,000 pieces of paper annually by using electronic document storage for its $1 billion construction program while reducing its average contract modification processing time from 30 days to three days (https://www.fhwa.dot.gov/innovation/everydaycounts/edc-3/econstruction.cfm).

The e-construction system has the potential to increase the quality, efficiency, environmental sustainability, and productivity of the construction industry at large, while saving printing costs, time, postage, and document storage and adding communication efficiencies.

Construction partnering is a project management practice whereby transportation agencies, contractors, and other stakeholders create a team relationship of mutual trust and improved communications. Partnering builds relationships and connections among stakeholders to improve outcomes and successful completion of quality projects that are built on time and within budget, focused on safety, and profitable for contractors.

Additional information, webinars, and peer exchange reports relating to e-construction and construction partnering can be found at https://www.fhwa.dot.gov/construction/econstruction/ and at https://www.fhwa.dot.gov/construction/partnering/, respectively.

12.22 Resources and References

ATSSA. *Guidelines on Rolling Roadblocks for Work Zone Applications*, FHWA, U.S. DOT, July 2013. https://www.workzonesafety.org/training-resources/fhwa_wz_grant/atssa_rolling_roadblocks/.

Brown, H., C. C. Sun, P. Edara, and R. Rahmani. Safety Assessment Tool for Construction Zone Work Phasing Plans, InTrans Project Report 203, 2016.

Brown, H., C. Sun, P. Edara, S. Zhang, and Z. Qing. Evaluation of Green Lights on TMAs, Missouri Department of Transportation, MoDOT project #TR201722, May 2018.

FHWA. Safely Implementing Rolling Roadblocks for Short-Term Highway Construction, Maintenance, and Utility Work Zones, Work Zone Management Program, FHWA-HOP-19-031, FHWA, U.S. DOT, n.d., https://ops.fhwa.dot.gov/publications/fhwahop19031/index.htm, accessed September 5, 2019.

Highway Safety Manual, AASHTO, Washington, D.C., 2010. [HSM]

Shaw, J. W., M. V. Chitturi, and D. A. Noyce. Special-Color Pavement Marking for Highway Work Zones: Literature Review of International Practices. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2617, 2017, pp. 78–86.

Shaw, J. W., M. V. Chitturi, K. R. Santiago-Chaparro, L. Qin, A. Bill, and D. A. Noyce. Orange Work Zone Pavement Marking Midwest Field Test, Smart Work Zone Deployment Initiative, April 2018.

Ullman, G., J. Schroeder, and D. Gopalakrishna. *Use of Technology and Data for Effective Work Zone Management: Work Zone ITS Implementation Guide*, FHWA-HOP-14-008, FHWA, U.S. DOT, January 2014.

Ullman, G. L., M. Pratt, M. D. Fontaine, R. J. Porter, and J. Medina. *NCHRP Research Report 869: Estimating the Safety Effects of Work Zone Characteristics and Countermeasures—A Guidebook*. Transportation Research Board, Washington, D.C., 2018. http://dx.doi.org/10.17226/25007.

CHAPTER 13

Framework for Evaluation of Work Zone Strategies

This section describes various methods by which work zone strategies are evaluated.

13.1 Typical Work Zone Crash Characteristics

Increased crash risks at a given work zone are a combination of temporary changes in geometrics and influences related to work activity. Drivers can be distracted by ongoing construction activities behind barriers, moving equipment, construction access and egress, and lane closures that require drivers to maneuver around the closure or shift laterally. When work activity is occurring and travel lanes are temporarily closed, the risk of a crash for an individual motorist traveling through the work zone can increase by as much as about 66 percent during the day and 61 percent at night, compared with the crash risk expected to exist at a particular location (Ullman et al. 2008). The actual change in crash risk will vary substantially between projects, even when stratified on the basis of time period (daytime or nighttime) and work condition (no work activity, active work without lane closures, or active work with lane closures).

Crashes that occur in nighttime work zones are not necessarily more severe than those that occur in similar daytime work zones, although differences do exist in the types of crashes. Generally, the increase in crash risk is higher for property-damage-only crashes than for injury and fatal crashes, regardless of whether the work is performed during the day or at night. The only exception is for intrusion crashes during nighttime, which have a greater percentage of injury and fatal crashes (Ullman et al. 2008). Crashes involving rear-end collisions are one of the most common crash types in work zones and typically increase as a function of AADT in both daytime and nighttime periods; the percentages are substantially lower in the nighttime periods. However, the percentage of rear-end collisions increases noticeably during daytime work activity on low- to moderate-volume roadways, but not on higher-volume roadways. Nevertheless, the benefit of working at night, compared with doing the work during the day, extends across all AADTs, but it is much greater at higher AADTs.

Several strategies have the potential to substantially lower the increased crash risk resulting from work zones (Appendix A). Strategies that appear to offer the greatest potential for crash-risk reduction include the following:

- Practices to reduce the number and duration of work zones (i.e., within a specific project limit).
- Project coordination with adjacent projects on the same or nearby corridors to avoid conflicts (i.e., rerouted traffic to closed or reduced capacity routes or conflicting signs or messages).
- Use of full directional roadway closures with median crossovers or detours.
- Use of time-related contract provisions to reduce construction duration.
- Appropriate work activities on high AADT roads (i.e., those that require temporary lane closures) being moved to nighttime hours.

- Use of demand-management strategies to reduce volumes through work zones during the day.
- Use of enhanced or automated traffic law enforcement (or both).

13.2 Expected Effects of Work Zones on Crashes

It would be beneficial for work zone designers and others to be able to predict the safety consequences of their proposed work zone designs and management decisions before implementing them in the field. The following are examples of ways to use work zone crash estimates:

- Quantify the safety-related benefits of completing the work faster (i.e., accelerated contract incentives).
- Estimate the expected effects of safety countermeasures contemplated for use in the work zone as part of the TMP.
- Predict the differences in safety effects of alternative work zone design options (i.e., narrowed or closed lanes, closed shoulders, ramp closures, and complete closures).

13.3 Work Zone Safety-Related Data Analysis

Depending on the actions being considered, methods are needed to estimate the number of crashes expected to occur in a work zone and the incremental change in crashes resulting from different work zone features. These methods vary in the amount of data and level of effort required, as well as in the level of accuracy to be achieved.

Because of the relatively short duration of most construction projects (versus 3–5 years of after data in a typical before/after study at a permanent location) and relatively few crashes, there may not be sufficient work zone crash data to make statistically significant conclusions.

Poor-quality data in the data set can result in misleading or incorrect conclusions. The number of variables that can affect the analysis of crashes within work zones can make isolating a single variable difficult. Factors related to analyzing safety-related data in work zones include the following:

- Frequent changes to the configuration of a work zone make it difficult to track or assign an exact work zone setup to a particular crash.
- The number of work zone crashes per project is relatively small and typically does not follow a normal distribution.
- Work zone strategies that encourage trip diversion may have significantly different pre- and post-traffic volume, and the analysis may provide misleading conclusions.
- Some crashes within the work zone limits may have been caused by non–work zone characteristics (e.g., driver impaired or speeding), meaning the work zone may not have been a contributing factor or an indirect cause.

13.3.1 Before and After Crash Data Analysis

Several considerations when conducting a before and after study of crash data within the work zone may affect the validity of the evaluation. These considerations include the following:

- **Regression-to-mean bias.** A project corridor may have a high number of crashes immediately before the work zone period. This may be an abnormal condition in which the site may experience fewer crashes during construction, regardless of the deployment. A simple before and after comparison is likely to result in an overestimation of the work zone strategy effect. Analysts can use more robust statistical analysis methods such as a Bayesian approach to minimize the problem.

- **Other explanatory factors after the work zone strategy deployment.** Increased law enforcement may cause drivers to reduce speed or be less aggressive, which potentially reduces crashes. If the before and after study does not take this relationship between increased law enforcement presence and reduced crashes into account, then the benefits of the work zone deployment can be overestimated.
- **Trends in the value of MOEs over time.** If the decrease in crashes in the *after* data is a result of a long-term trend and not a result of the work zone deployment, then the evaluation will suffer from what is known as a maturation threat to validity.
- **Random data fluctuations.** According to FHWA, "Crashes are random events that naturally fluctuate over time at any given site. If you consider a short-term average crash frequency, it may be significantly higher or lower than the long-term average crash frequency. The crash fluctuation over time can make it difficult to determine whether changes in observed crash frequency are due to changes in site conditions or natural fluctuations" (Herbel, Laing, and McGovern 2010). This threat to evaluation validity is known as instability.

13.3.2 Crash Rate Calculation

Crash rate is a measure that can be applied to work zones to monitor trends in crashes using either real-time or lagging data. Crash rate analysis typically uses exposure data in the form of traffic volumes or roadway mileage. As Table 13.1 shows, crash rates are calculated by dividing the number of crashes by a normalizing factor. Such rates can be compared with preconstruction values to determine whether safety hazards exist and whether analysts need to consider modifications to the work zone.

The benefit of crash rate analysis is that it provides a more effective comparison of similar locations with safety issues than analyzing crash frequency alone. In a situation when traffic volumes have changed significantly during the work zone, the crash rate calculation allows practitioners to take this into account.

One way to calculate the crash rate for road segments is

Equation 1. Crash rate for road segment.

$$R = \frac{100{,}000{,}000 \times C}{365 \times N \times V \times L}$$

where

R = Crash rate for the road segment expressed as crashes per 100 million VMT;
C = Total number of crashes in the study period;
N = Number of years of data (or fraction of a year);
V = Number of vpd (both directions); and
L = Length of the roadway segment in miles.

Table 13.1. Examples of crash rate normalizing factors.

Normalizing Factors	Example Measures
Time	• Crashes per month
Exposure	• Crashes per 1,000 vehicles traveling through the work zone • Crashes per vehicle hours of travel time through the work zone • Crashes per 100 million VMT through the work zone
Distance	• Crashes per mile

Note: VMT = vehicle miles traveled.

For example, a particular work zone is being assessed with the following values:

$C = 90$ crashes over the past 1 year within this work zone,
$N = 1$ year of data,
$V = 35{,}000$ vpd, and
$L = 8$ miles.

The resulting segment crash rate (equation 2) would be 88.1 crashes per 100 million VMT.

Equation 2. Example crash rate calculation for road segment.

$$R = \frac{100{,}000{,}000 \times 90}{365 \times 1 \times 35{,}000 \times 8} = 88.1\ crashes\ \ per\ 100\ million\ VMT$$

Depending on the details of crash-reporting methods and crash history along the project corridor, a value of 88.1 crashes per 100 million VMT may or may not be cause for additional study. The most appropriate use of this crash rate is to determine the relative safety of the work zone in comparison with the pre–work zone condition and with other work zones that have similar characteristics. If a DOT has access to real-time crash reports, it can improve safety in its work zones even further by modifying active work zones based on reported work zone crashes.

13.3.3 Crash Modification Factors

CMFs can be employed to estimate the incremental change in crashes related to alternative work zone features being considered, similar to procedures found in the HSM. A CMF is a multiplicative factor used to indicate how a particular condition or feature increases or decreases the number of crashes expected from base conditions. A CMF of 1.0 indicates that the feature has no incremental effect on crash risk. A CMF less than 1.0 indicates that the feature reduces crash risk, and a CMF above 1.0 indicates that the feature increases crash risk relative to base conditions. When multiple features are present, several CMFs are multiplied to arrive at the estimate of the expected change in crashes. Although many CMFs have been developed for many different permanent roadway features in recent years, only a few work zone-specific CMFs are currently available. In the absence of CMFs developed specifically for work zone features, the only available option is to use those that exist for permanent roadway features. In these cases, practitioners apply engineering judgment when interpreting the results of the analysis.

The HSM provides limited information on CMFs for practitioners to use in work zones. The work zone elements addressed in the HSM include the duration (number of days) and length (miles) of freeway work zones. Equations 3 and 4 are based on research that considered work zone durations from 16 to 714 days, work zone lengths from 0.5 to 12.2 miles, and freeway AADTs from 4,000 to 237,000 vpd (Khattak, Khattak, and Council 2002).

The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is a work duration of 16 days and 0.51 miles. The standard errors of the CMFs are unknown.

Duration. Equation 3 provides expected average crash frequency for increasing work zone duration above the base condition (CMF = 1.0) of 16 days.

Equation 3. Average crash frequency for increasing work zone duration (days).

$$CMF_{all} = 1.0 + \frac{(\%\ increase\ in\ duration \times 1.11)}{100}$$

where

CMF_{all} = crash modification factor for all crash types and all severities in the work zone; and

% increase in duration = the percentage change in the duration (days) of the work zone.

Length. Equation 4 provides expected average crash frequency for increasing the work zone length above the base condition (CMF = 1.0) of 0.51 mi.

Equation 4. Average crash frequency for increasing work zone length (mi).

$$CMF_{all} = 1.0 + \frac{(\%\ increase\ in\ length \times 0.67)}{100}$$

where

CMF_{all} = crash modification factor for all crash types and all severities in the work zone; and

% increase in length = the percentage change in the length (mi) of the work zone.

13.4 Work Zone Crash Estimation and Crash Cost Analysis

NCHRP Research Report 869 (Ullman et al. 2018) describes the following two methods for estimating work zone crashes and crash costs:

1. Applying an overall WZCMF to a pre–work zone baseline estimate of crashes expected on the roadway segment where the work zone will occur.
2. Using a general safety performance function (SPF) that has been created using work zone-specific data.

A brief description of both methods follows.

13.4.1 Method 1. Using Pre–Work Zone Crash Estimates and an Overall WZCMF

The preferred approach for developing planning-level work zone crash estimates is to apply an overall generic WZCMF to the pre–work zone baseline crash estimate for the roadway segment. Pre–work zone crash estimates would generally come from an SPF calibrated to the particular roadway segment using methods contained in the HSM or in state-calibrated crash-prediction models. However, if those data are not available, other estimation methods may be used. For example, work zone analysts could use the last 3–5 years of crashes occurring along the roadway segment along with yearly AADT values to determine a weighted yearly average of crashes. An overall WZCMF for freeways and Interstate facilities from a multistate data set of four- and six-lane freeway and Interstate work zones was developed as part of *NCHRP Research Report 869* (Ullman et al. 2018). The CMF is based on a ratio of pre– and during–work zone SPFs developed for those roadway segments. Equation 5 gives the ratios of those SPFs:

Equation 5. WZCMFs for four- and six-lane freeway and Interstate work zones.

4-lane Facility

$$WZCMF_{4\text{-lanes}} = \frac{e^{-10.036+1.164\ln(AADT)}}{e^{-11.231+1.248\ln(AADT)}}$$

6-lane Facility

$$WZCMF_{6\text{-lanes}} = \frac{e^{-9.987+1.164\ln(AADT)}}{e^{-12.318+1.344\ln(AADT)}}$$

To compute the total number of crashes expected during a work zone, multiply the per mile number of crashes normally occurring on the roadway segment each year by the duration of the work zone and calculate the overall WZCMF for the AADT of the roadway segment. As Equation 6 shows, if a crash rate is used, then the rate is first multiplied by the length of the project.

Equation 6. Total number of crashes expected during a work zone.

$$Expected\ WZ\ Crashes = \left(\frac{Non\text{-}WZ\ Crashes}{Mile/Year}\right)(Project\ Length)\left(\frac{WZ\ Duration(Mo.)}{12}\right)(WZCMF)$$

13.4.2 Method 2. Work Zone-Based SPFs

If no good data exist for the normal crash frequency on the section of freeway or Interstate where a work zone will be placed, a work zone engineer can use an SPF to develop a planning-level estimate of crashes expected during the work zone. *NCHRP Research Report 869* (Ullman et al. 2018) used the multistate database of work zones performed on four- and six-lane Interstates and freeways to develop the following two predictive functions of the total number of work zone crashes expected to occur based on work zone length, work zone duration, and overall roadway AADT (equations 7 and 8).

Equation 7. Crashes expected to occur on four-lane freeway and Interstate work zones.

$$Number\ of\ work\ zone\ crashes\ expected = L \times n \times e^{-10.036+1.164\ln(AADT)}$$

Equation 8. Crashes expected to occur on six-lane freeway and Interstate work zones.

$$Number\ of\ work\ zone\ crashes\ expected = L \times n \times e^{-9.987+1.164\ln(AADT)}$$

where

L = length of work zone in miles and
n = number of years the work zone will require (or number of months/12).

The functions were developed with the following work zone conditions:

- Pavement width of 40 ft in each direction for four-lane segments and 52 ft in each direction for six-lane segments (equal to 12-ft lanes, a 6-ft inside shoulder, and a 10-ft outer shoulder).
- No lane shifts present.
- No lane closures present.
- Median width of 60 ft, inclusive of inside shoulder width of 6 ft in both directions.
- No longitudinal barriers present.
- AADTs ranging between 5,000 and 70,000 vpd on the four-lane segments.
- AADTs ranging between 50,000 and 150,000 vpd on the six-lane segments.

Examples 1 and 2 in the following sections are based on the work zone condition described above.

NCHRP Web-Only Document 240: Analysis of Work Zone Crash Characteristics and Countermeasures (Ullman et al. 2018) provides additional details regarding the development of these models.

13.4.3 Example 1. Computing an Expected Crash Rate per Month during Construction

A work zone engineer plans to monitor crashes occurring during a 2-year, 5-mi Interstate-widening construction project. The engineer will compare monthly crashes to determine if they are increasing beyond what should be expected for the work zone setup. The roadway has the following characteristics:

- Rural four-lane Interstate facility (12-ft lanes, 6-ft inside shoulder, 10-ft outside shoulder, wide median).
- Traffic volume on the facility is 45,000 vpd during Year 1 of the project and 50,000 vpd during Year 2.
- Based on a calibrated SPF developed by the DOT, the normal non–work zone crash rate on this facility is estimated to be 7.4 crashes per mile in Year 1 and 7.9 crashes per mile in Year 2.

Step 1. Calculate the WZCMF (Years 1 and 2), assuming that good pre–work zone crash data exist.
Step 2. Use the WZCMF to calculate the work zone expected crashes, work zone crash rate, and project length (Years 1 and 2, equation 9).
Step 3. Sum Year 1- and Year 2-expected crashes to determine total crashes (equation 10).

Equation 9. Crashes expected to occur during the project duration.

$$\text{WZCMF}_{\text{4-lanes, year 1}} = \left(\frac{e^{-10.036+1.164 ln(45{,}000)}}{e^{-11.231+1.248 ln(45{,}000)}} \right) = 1.34$$

$$\text{WZCMF}_{\text{4-lanes, year 2}} = \left(\frac{e^{-10.036+1.164 ln(50{,}000)}}{e^{-11.231+1.248 ln(50{,}000)}} \right) = 1.33$$

In this example, the expected crash rate each year follows:

Equation 10. Expected crash rate per year.

$$\text{Expected Work Zone Crashes}_{\text{year 1}} = \left(\frac{7.4\ crashes}{mi/yr} \right)(5\text{ mi})(1\ year)(1.34) = 49.58\text{ crashes}$$

$$\text{Expected Work Zone Crashes}_{\text{year 2}} = \left(\frac{7.9\ crashes}{mi/yr} \right)(5\text{ mi})(1\ year)(1.33) = 52.54\text{ crashes}$$

$$\text{Expected Work Zone Crashes}_{\text{year 1 and 2 (Total)}} = 49.58 + 52.54 = 102.12\text{ crashes}$$

The work zone engineer can divide by 12 (number of months in year) to get a month-by-month crash estimate per year. If a more finite-period analysis is needed, the engineer can apply seasonal factors to the AADT factors and develop and apply WZCMFs to determine the crashes expected each month of each year. Monthly crashes can be compared directly as well as cumulatively. Significant variations between actual and expected crashes per time period might indicate that a safety issue exists at the site and additional investigation is needed.

As Figure 13.1 shows, an increase in the number of crashes is observed starting in month 7. If it is determined that the increase in crashes is significant enough, then the work zone engineer can initiate a more in-depth review to determine potential reasons for the increase. The potential reasons may be that the project has had a major traffic switch, work activities have involved more frequent deliveries, or poor weather conditions occurred during this time.

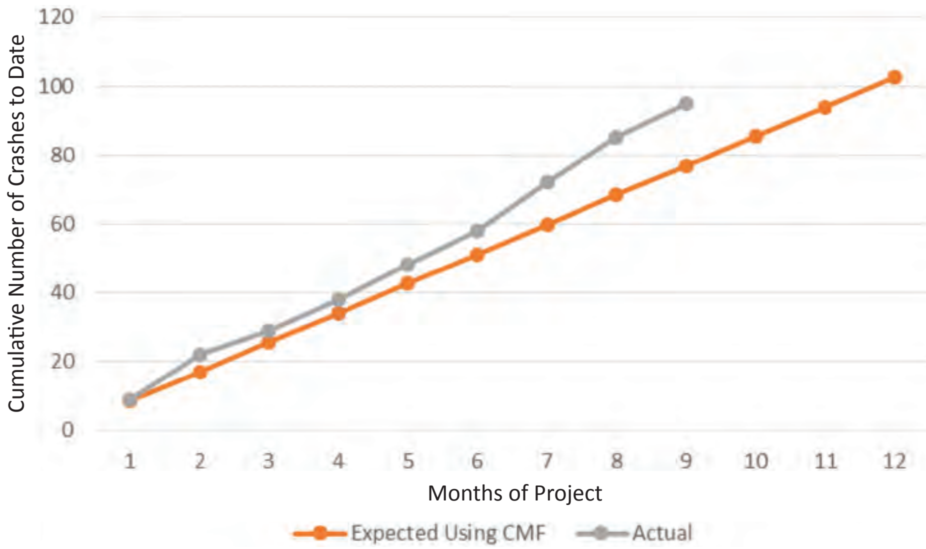


Figure 13.1. Expected versus actual crashes using Equation 9 WZCMF.

If good non–work zone crash data are not available for the segment, then the work zone engineer can apply a previous work zone SPF for four-lane facilities (equation 11). The computations would be as follows:

Equation 11. Expected crash rate using SPF.

$$\text{Expected Work Zone Crashes}_{\text{year 1}} = (5\text{ mi})(1\ \mathit{year})\left(e^{-10.036+1.164\,ln(45{,}000)}\right) = 57.11 \text{ crashes}$$

$$\text{Expected Work Zone Crashes}_{\text{year 2}} = (5\text{ mi})(1\ \mathit{year})\left(e^{-10.036+1.164\,ln(50{,}000)}\right) = 64.56 \text{ crashes}$$

$$\text{Work Zone Crashes Expected}_{\text{year 1 and 2 (Total)}} = 57.11 + 64.56 = 121.67 \text{ crashes}$$

The work zone SPF estimate of 121.67 crashes over the 2-year project (5.07 crashes per month) is approximately 19.1 percent higher than what was computed using the calibrated pre–work zone crash rates and the overall WZCMF. As Figure 13.2 shows, in using the work zone SPF,

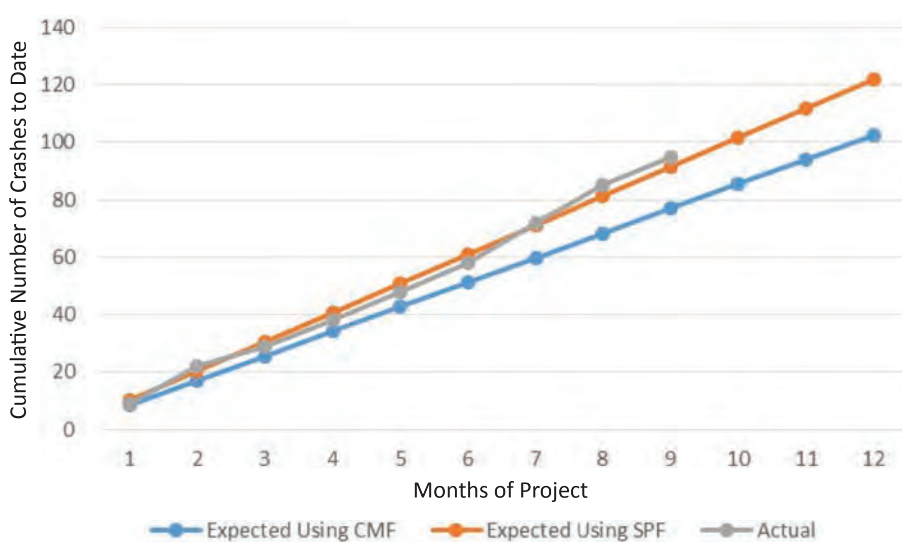


Figure 13.2. Expected versus actual crashes using the work zone SPF and CMF.

the work zone engineer may conclude that crashes were not excessive relative to expectations. The difference in results shown in Figure 13.2 using both methods is another reminder of the importance of engineering judgment when interpreting and using planning-level estimates.

13.4.4 Example 2. Estimating the Effect of Accelerated Construction on the Expected Number of Work Zone Crashes and Savings

A DOT is contemplating including contract incentives in a bid package to reduce the project duration and is trying to determine the savings, if any. By using traditional methods, the project would take 2 years to complete; however, if the duration is reduced to 18 months (i.e., accelerated construction) what would be the project savings?

The DOT will first calculate the non–work zone CMF to serve as a baseline for comparison (equation 12). The roadway has the following characteristics:

- Project is 6 mi long.
- It is an urban six-lane freeway facility.
- The traffic volume on the facility is expected to be approximately 120,000 vpd for Year 1 of the project and 140,000 vpd for Year 2 of the project.
- The freeway has 12-ft lanes, 6-ft inside shoulders, and 10-ft outside shoulders.
- The total crash density on this section of freeway is 34.8 crashes per mile per year before construction based on 3 years of historical data. Traffic volumes during those years averaged 115,000 vpd (similar to what is expected for Year 1 of the project).

Equation 12. Year 1 and 2 work zone crash rate.

$$\text{Non-Work Zone Crash Rate}_{\text{year 1}} = \left(\frac{34.8\ crashes}{mi/yr}\right)\left(\frac{120{,}000}{115{,}000}\right) = 36.31 \text{ crashes per mile per year}$$

$$\text{Non-Work Zone Crash Rate}_{\text{year 2}} = \left(\frac{34.8\ crashes}{mi/yr}\right)\left(\frac{140{,}000}{115{,}000}\right) = 42.36 \text{ crashes per mile per year}$$

The DOT does not have a normal non–work zone expected crash frequency for the roadway for each year of the project. Consequently, it will be necessary to estimate the normal pre–work zone crash frequency for each of the 2 years of the project based on the data available (equation 13). Because the only data available for use are the historical crash rate for the roadway segment associated with a lower AADT than that anticipated during the project, the DOT would first factor the crash rate for the 2 years of the project using the following ratio of AADT numbers:

Equation 13. Work zone CMFs.

$$\text{WZCMF}_{\text{6-lanes, year 1}} = \left(\frac{e^{-9.987+1.164\,ln(120{,}000)}}{e^{-12.318+1.344\,ln(120{,}000)}}\right) = 1.253$$

$$\text{WZCMF}_{\text{6-lanes, year 2}} = \left(\frac{e^{-9.987+1.164\,ln(140{,}000)}}{e^{-12.318+1.344\,ln(140{,}000)}}\right) = 1.219$$

This factoring process assumed a linear relationship between crashes and AADT, which is often not true. However, in the absence of local SPFs, it is considered to be a plausible planning-level assumption. Once the DOT has a predicted non–work zone crash rate for each year, WZCMFs are then computed for each of the 2 years of the project based on the expected traffic volumes (equation 14).

The total number of crashes expected for each alternative is calculated using the results of equation 13 as follows, assuming 24 months (Years 1 and 2 summed) for Alternative 1:

Equation 14. Number of crashes expected for Alternative 1.

$$\text{Expected Work Zone Crashes}_{\text{ALT 1 year 1}} = \left(\frac{36.31\ crashes}{mi/\ yr}\right)(6\text{ mi})(1\ year)(1.253) = 272.97\text{ crashes}$$

$$\text{Expected Work Zone Crashes}_{\text{ALT 1 year 2}} = \left(\frac{42.36\ crashes}{mi/\ yr}\right)(6\text{ mi})(1\ year)(1.219) = 309.82\text{ crashes}$$

$$\text{Expected Work Zone Crashes}_{\text{ALT 1 (year 1 and 2 Total)}} = 272.97 + 309.82 = 582.79\text{ crashes}$$

For Alternative 2, the expected number of crashes for Year 1 of the project would remain the same as Alternative 1. For the second year, the first 6 months would be at the expected work zone crash rate and the second 6 months would be at the non–work zone crash rate (required to complete Year 2), as shown in equations 15 and 16:

Equation 15. Number of crashes expected for Alternative 2.

$$\text{Expected Work Zone Crashes}_{\text{ALT 2 year 2}} = \left(\frac{42.36\ crashes}{mi/\ yr}\right)\left(\frac{6\ mo}{12\ mo/\ yr}\right)(6\text{ mi})(1.219)$$

$$+\left(\frac{42.36\ crashes}{mi/\ yr}\right)\left(\frac{6\ mo}{12\ mo/\ yr}\right)(6\text{ mi}) = 281.99\text{ crashes}$$

$$\text{Expected Work Zone Crashes}_{\text{ALT 2 year 1 and 2 (Total)}} = 272.97 + 281.99 = 554.96\text{ crashes}$$

Equation 16. Difference between Alternatives 1 and 2.

$$\text{Expected Work Zone Crashes}_{\text{ALT 1–ALT 2}} = 582.79 - 554.96 = 27.83\text{ crashes}$$

Reducing the duration of the project by 6 months would be expected to result in 27.83 fewer crashes over the non-accelerated project schedule.

The DOT can now apply comprehensive crash cost numbers to estimate the road-user safety cost savings that could be attributed to this reduction. Assuming a crash severity distribution on the facility similar, as Table 13.2 shows, to typical crash cost values recommended in the HSM, reducing the project duration would be estimated to yield nearly $1,332,592 in crash cost savings. This would be in addition to any other savings that might also be achieved (i.e., travel time, freight, and emissions).

Table 13.2. Estimated crash cost savings if project duration can be reduced, Example 2.

Crash Severity Level	Proportional Distribution of Crash Severities	Proportion of the 27.83 Crashes Reduced	Average Crash Cost[a]	Crash Costs Saved If Project Is Accelerated
Fatality (K)	0.005	0.13915	$4.509,991	$627,565.25
Disabling injury (A)	0.018	0.50094	$242,999	$121,727.92
Evident injury (B)	0.088	2.44904	$88,875	$217,658.43
Possible injury (C)	0.136	3.78488	$50,512	$191,181.86
Property damage only (PDO)	0.753	20.95599	$8,325	$174,458.62
Total	**1.000**	**27.83**	**n.a.**	**$1,332,592.08**

NOTE:
[a]Crash costs in the *Highway Safety Manual*, 1st ed., updated to 2016 dollars.
n.a. not applicable.

13.5 Evaluation of Alternative Work Zone Design Using Alternative CMFs

Work zone designers developing construction plans have options for accommodating traffic through the various phases or stages of the project. These alternatives can include factors such as whether to close lanes or shoulders, use narrower lanes, close ramps, reduce acceleration or deceleration lane lengths, and deploy together with various technologies (e.g., EQWSs, DLMs). When designers must make decisions, it is useful for them to know the differences in expected crashes among these alternatives. The steps are as follows:

Step 1. Define the work zone alternatives for which the expected safety effects are to be compared.
Step 2. Determine the availability and suitability of CMFs.
Step 3. Obtain baseline crash estimates that will be used to evaluate each alternative.
Step 4. Multiply the selected CMFs for each work zone alternative with their appropriate baseline crash estimates.
Step 5. Compute crash estimate differences among the alternatives.

For example, to alert drivers of downstream queues, a DOT is contemplating using the EQWS during an 8-month bridge repair project over an Interstate facility. The contractor will institute nighttime lane closures (7:00 p.m. to 6:00 a.m.) on the Interstate to perform the work and will work 5 nights per week. The Interstate serves 70,000 vpd in this area, and queues are expected to develop each night of work and can grow to up to 7 mi. Normally, this section of Interstate records 20.4 crashes per mile per year, 50 percent of which occur during the hours when the work is scheduled. The DOT wishes to estimate how many crashes might be prevented if the EQWS is incorporated into the project. The DOT performs the following analysis.

Step 1. Define work zone alternatives to be compared.

Alternative 1. Perform the nighttime lane closures over the 6-month project without EQWS.

Alternative 2. Install EQWS at the beginning of the project to warn of queued traffic conditions downstream.

Step 2. Determine availability and suitability of CMFs for alternatives.

A CMF for working at night with one or more lanes closed is 1.61 (Table 13.3). For Alternative 2, a CMF describing the effect of the EQWS is 0.56 with traffic queues (Table 13.4).

Table 13.3. Freeway WZCMFs.

Crash Severity Level	CMF	
	Nighttime	Daytime
Work Zone Active with Temporary Lane Closures		
PDO Crashes	1.748	1.808
Injury and Fatal Crashes	1.423	1.455
All Crashes Combined	1.609	1.663
Work Zone Active without Temporary Lane Closures		
PDO Crashes	1.666	1.398
Injury and Fatal Crashes	1.414	1.174
All Crashes Combined	1.577	1.314
Work Zone Inactive without Temporary Lane Closures		
PDO Crashes	1.330	1.196
Injury and Fatal Crashes	1.114	1.020
All Crashes Combined	1.237	1.127

NOTE: CMF = crash modification factor; PDO = property damage only; WZCMF = work zone crash modification factor.
SOURCE: Ullman et al. (2008).

Table 13.4. Available WZCMFs.

Work Zone Condition	Work Zone Application	CMF	Volume Range	Quality	Crash Severity
Stationary Police Enforcement	DA	0.585	<125,000	M	A
Automated Speed Enforcement	P	0.83	NS	H	F/I
Speed Feedback Display	P	0.54	NS	H	A
Transverse Rumble Strips (Nighttime) (Queues Not Present/Queues Present)	DA	0.89/0.397	55,000–110,000	H	A
End Queue Warning System (Nighttime) (Queues Expected/Queues Present)	DA	0.559/0.468	55,000–110,000	M	A
Increase Shoulder Width (Inside/Outside) by 1 ft	DA	0.97/0.948	NS	M	A
Change Median Width 20 to 10 ft. Conversion (Rural/Urban Freeway)	P	1.16/1.12	<120,000/<131,000	H	NS
Reduce Lane Width 12 to 11 ft. (Divided Rural Multilane Roadway)	P	1.03	>2,000	H	A
Reduce Lane Width 12 to 10 ft. (Divided Rural Multilane Roadway)	P	1.15	>2,000	H	A
Reduce Lane Width 12 to 9 ft. (Divided Rural Multilane Roadway)	P	1.25	>2,000	H	A
Reduce Shoulder Width 6 to 4 ft. (Rural Two-Lane Roadway, Undivided Multilane Roadway)	P	1.15	>2,000	H	A
Reduce Shoulder Width 6 to 2 ft. (Rural Two-Lane Roadway, Undivided Multilane Roadway)	P	1.3	>2,000	H	A
Reduce Shoulder Width 6 to 0 ft. (Rural Two-Lane Roadway, Undivided Multilane Roadway)	P	1.5	>2,000	H	A
Variable Speed Limit	P	0.92	NS	H	A
Crossover Work Zone Left-Hand Merge and Downstream Shift	DA	1	NS	M	A
	DA	0.54	20,000–35,000	L	A
Reduce Speed Limit (10 mph/15–20mph)	Q	0.96/0.94	NS	M–H	A
Safety Edge on Temporary Roadway	P	0.94	<19,000	H	A

NOTE: WZCMF = work zone crash modification factor; CMF = crash modification factor; DA = direct application; P = possible; Q = questionable; H = high quality of CMF; M = medium quality of CMF; L = low quality of CMF; A = all; F/I = fatal/injury; NS = not specified.
SOURCE: *NCHRP Research Report 869* (Ullman et al. 2018).

Table 13.5. Estimated crash cost savings, Alternative 2 example.

Crash Severity Level	Proportional Distribution of Crash Severities	Proportion of the 24.08 Crashes Reduced	Average Crash Cost[a]	Crash Costs Saved in Alternative 2
Fatality (K)	0.005	0.1204	$4.509,991	$543,002.92
Disabling injury (A)	0.018	0.43344	$242,999	$105,325.49
Evident injury (B)	0.088	2.11904	$88,875	$188,329.68
Possible injury (C)	0.136	3.27488	$50,512	$165,420.74
Property damage only (PDO)	0.753	18.13224	$8,325	$150,950.90
Total	**1**	**24.08**	n.a.	**$1,153,030**

NOTE: [a]Average crash costs are derived from the *Highway Safety Manual,* 1st edition, updated to 2016 dollars.
n.a. = not applicable.

Step 3. Obtain appropriate baseline crash estimate for applying CMFs.
The work zone baseline crash estimate Alternative 1 is computed as in equation 17:

Equation 17. Baseline crash estimate for applying CMFs.

$$\text{Baseline Crashes} = \left(\frac{20.4\text{ crashes}}{(\text{mi/yr})}\right)(7.0\text{ mi})\left(\frac{8\text{ mo}}{12\text{ mo/yr}}\right)\left(\frac{5\text{ days/wk}}{7\text{ days/wk}}\right)\left(\frac{0.5\text{ night crashes}}{\text{all crashes}}\right)(1.61)$$

$$= 54.74\text{ crashes}$$

Step 4. Apply CMFs for each alternative to baseline crash estimate.
For Alternative 2 (with EQWS), the baseline crash estimate (Alternative 1) must be multiplied by the work zone queue warning CMF, as in equation 18, to compute the expected number of crashes:

Equation 18. Computation of expected number of crashes.

$$\text{Crashes}_{\text{ALT 1}} = 54.74\text{ crashes}$$

$$\text{Crashes}_{\text{ALT 2}} = 54.74 \times 0.56 = 30.65\text{ crashes}$$

Step 5. Compute differences in crash estimates between alternatives.
As shown in equation 19, the difference between Alternative 1 and 2 yields the number of crashes that installing the work zone QWS is expected to prevent:

Equation 19. Differences in crash estimates between alternatives.

$$\text{Expected Crash Difference}_{\text{ALT 1–ALT 2}} = 54.74 - 30.65 = 24.09\text{ crashes}$$

The use of an EQWS at this location was computed to result in 24.08 fewer crashes. If, for example, the DOT had found crash severities at previous work zones to be distributed, as Table 13.5 shows, the crash cost benefits of the QWS would be computed to be nearly $1,153,050. The crash cost savings estimate in this analysis assumes that the severity of crashes remains the same in either alternative and is equivalent to the overall average crash severity distribution that the DOT had in previous work zones. Some evidence shows that the severity of crashes that occur when a QWS is implemented is also reduced relative to a no-system condition, which would further increase the crash cost savings that might be achieved.

13.6 General Freeway WZCMFs

Table 13.3 presents WZCMFs based on *NCHRP Report 627* (Ullman et al. 2008) for injury and fatal crashes, for property-damage-only crashes, and for all crash severity types combined. Generally speaking, the CMFs are higher for property-damage-only crashes than for injury and fatal crashes. Multiplying the appropriate CMF by the SPF provides an estimate of the crash frequencies expected on a given type of roadway for a given work zone condition. These computations yield the expected number of severe and property-damage-only crashes under each of the three work zone conditions.

The crash frequencies estimated using the appropriate SPF and WZCMF can then be multiplied by a per crash cost value to assess exposure under each work zone condition as a function of roadway AADT.

As noted, work zone–specific CMFs often lack many features of interest. All that can be done is to apply CMFs developed for permanent roadway features (Section 13.7) to what is expected, understanding that the results obtained are only a rough approximation of how an alternative may affect crashes during the time that the work zone is in place. These approximations may provide useful insights into the potential value of the different alternatives being considered; agencies are asked to use engineering judgment in applying the data.

13.7 Available CMFs

Table 13.4 presents the available CMFs extracted from *NCHRP Research Report 869* (Ullman et al. 2018). More detailed information on these and other non–work zone CMFs can be found in the report.

13.8 Measurable Goals and Performance Measures

A successful performance-monitoring and evaluation work zone program generally comprises six steps:

- Set goals and objectives that are consistent with DOT work zone priorities.
- Identify appropriate performance measures to accurately evaluate and monitor goals and objectives.
- Identify required data and sources to support calculation of performance measures.
- Define appropriate evaluation methods within the constraints of data availability and staff.
- Define an appropriate schedule for ongoing, periodic monitoring of the work zone.
- Report results in a usable and easily understood format.

Successful performance-monitoring and evaluation activities ensure that the project is designed and constructed efficiently. In any assessment of what strategies to include and design into the work zone, agencies need to think through safety considerations along with mobility and other considerations. It takes only one serious crash that can be attributed to the work zone to halt all operations and for the DOT to launch a comprehensive review of all work zone procedures and other activities.

The performance measures in Table 13.6 are more specific to evaluation of work zone strategies. Having cursory knowledge of typical performance measures currently in use and those emerging as consistent practice among local, state, and federal transportation agencies helps ensure consistency in work zone performance-monitoring and evaluation practices. Each goal area is discussed in the following subsections.

Because the various TMP strategies mitigate effects differently, different approaches are needed for evaluating them. It is generally easier to evaluate capacity-enhancing influences and changes that reduce activity duration than it is to evaluate strategies that influence trip-making behaviors. This is because a relationship exists between changes in motorists' trip-making decisions and behaviors that occur because operating conditions change when a

Table 13.6. Recommended performance measures.

Goal Area	Performance Measure
Safety	Reduction in overall crash rate
	Reduction in rate of crashes resulting in fatalities and serious injuries
	Improvement in surrogate measures (i.e., speeding and reckless driving citations)
Mobility	Reduction in average speed or percentage above PSL
	Reduction in 85th percentile of percentage above
	Reduction in travel time
	Reduction in percent time above predetermined speed
	Reduction in queue length and duration per time period
	Increase in throughput (vph)
	Reduction in change in volume/capacity ratio
Environmental Impact	Reduction in emissions such as hydrocarbons (HCs), carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxide (NOx)
Customer Satisfaction	Change in work zone quality ratings
	Reduction in the ratings of condition of travel through the work zone
	Complaint frequency
Productivity	Reduction in incident or severity rate
	Reduction in average duration between road repairs
	Reduction in user cost

NOTE: PSL = posted speed limit; vph = vehicles per hour.

work zone is introduced. Therefore, agencies might not measure strategies that attempt to affect trip-making decisions and behaviors against what was happening before the work zone implementation, but instead measure relative to what would have occurred had the particular strategy not been implemented.

Work zone practitioners may identify one or more metrics that can be measured and that are known or expected to correlate to work zone impacts of concern (i.e., safety, mobility, customer satisfaction, and construction productivity and efficiency), and perform analyses to determine whether the implementation of a strategy affects that metric.

13.8.1 Safety

The purpose of a safety evaluation and related MOEs is to assess the effects of a given work zone strategy on the project network safety. Safety is expressed quantitatively through MOEs such as the number of crashes, crash rate, and crash severity. The total number of crashes is an important consideration because of the potential for diversion of traffic with any lane or road closures.

The crash rate is an important MOE as it *normalizes* the number of crashes based on exposure (i.e., the amount of travel on a section of roadway or through an intersection). The crash rate is normally expressed in number of crashes per one million VMT on a section of roadway or in number of crashes per one million vehicles traveling through an intersection.

Crash severity is an important consideration because it deals with the cost of crashes in terms of fatalities, injuries, and property damage. Changes in roadway geometry or operations can affect the types of crashes that occur. It is possible to observe an increase in the number of crashes or the crash rate along a particular section of roadway, but the types of crashes occurring might be less severe.

With respect to safety surrogate measures, these are highly site specific and best suited to evaluating strategies when a without-with comparison at each site can be made. For example, the presence of paid law enforcement can be assessed at each project by comparing speeds and erratic maneuvers during times when enforcement is not present to times when it is.

Estimating the safety effects of any work zone strategy is difficult because many factors can contribute to the causes and prevention of a crash. These factors include driver skill, driver aggressiveness, driver attention, driver fatigue, speed and speed differential between lanes, level of congestion, type and difficulty of driving maneuver (e.g., changing lanes, making a permissive left turn), lighting, weather, level of law enforcement presence, and roadway geometry and operations. A given strategy might affect one or more of these factors, while other measures being taken (e.g., increase in law enforcement presence) might affect some of these factors as well. In estimating the safety effects, the work zone engineer must consider and control all other potential explanatory factors involved in a crash.

13.8.2 Mobility

The purpose of any mobility goal is to estimate the effects of a work zone strategy on project network efficiency. Mobility is expressed quantitatively through MOEs such as travel time delay and travel time variability. Day-to-day variability in overall travel time from a particular origin to a destination is undesirable in a transportation network. Reduction of travel time variability improves the ability of individual citizens and the freight industry to plan and schedule their tasks.

Efficiency is expressed by MOEs such as throughput or effective capacity. Effective capacity is the maximum potential rate at which persons or vehicles may traverse a link, node, or network under a representative composite of roadway conditions. *Capacity* (as defined by the *Highway Capacity Manual*) is “the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a given point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions.” The HCM defines the major difference between effective capacity and capacity; capacity is assumed to be measured under good weather and pavement conditions and without incidents, whereas effective capacity can vary depending on the work zone strategy or strategies deployed.

Throughput is defined as the number of persons, vehicles, or units of freight actually traversing a roadway section or network per unit time. Under certain conditions, measured throughput may reflect the maximum number of vehicles that can be processed by a transportation system. Capacity (and effective capacity) is calculated given the design and operation of the network segment and does not change unless the physical construction or operations of that network segment are changed. In contrast, throughput is an observable measure and, thus, is an MOE for the efficiency of the work zone. Care must be given to interpreting results, however, because throughput changes may be the result of factors besides effective capacity changes (e.g., changes in demand). Thus, not all throughput changes indicate improvements (or lack thereof) in the efficiency of a given situation.

These measures can then be further subdivided to reflect certain subsets of time (e.g., peak periods, when lane closures are present) or different dimensions (e.g., duration of queue presence or average or maximum queue length, average delay per vehicle or total vehicle hours of delay per day). For some strategies, detailed project activity data would be needed to focus the assessment on the conditions that the strategy attempts to target. Examples of data would be the dates of implementation of night or weekend work or the dates of a major phase change when a particular ramp was closed to traffic.

13.8.3 Environmental Impact

The purpose of an emissions assessment is to estimate the effects of the work zone strategy on vehicle emissions. From a systemwide perspective, fuel consumption is important because of its potential effect on the emissions of various gases, including hydrocarbons (HC), carbon monoxide (CO), CO_2, and nitrogen oxide (NO_x). The primary measure of an emission is its concentration in the atmosphere, usually expressed as grams per cubic centimeter (g/cm^3). In addition, the total volume (expressed in tons) of an emission type present in the atmosphere is a useful MOE.

For light duty vehicles, the highest emission rates of HC, CO, and NO_x generally occurred during the transitional period when traffic changed from free-flow to congested conditions and vice versa; the lowest rates occurred during low-speed work zone congestion periods. However, the highest fuel consumption rates and the highest CO_2 emissions occurred under work zone congestion, while the lowest fuel consumption and CO_2 emissions occurred with peak hour congestion. Results for heavy duty vehicles were different in that work zone congestion was associated with the highest emissions of HC, CO, and CO_2 and the highest fuel consumption, while NO_x emission rates under the different traffic conditions were similar.

For the freeway scenarios, fuel consumption and greenhouse gas emissions increased by 85 percent and 86 percent, respectively, under heavily congested work zones compared with free-flow conditions without congested work zones. For the multilane (four- or six-lane) road scenarios, fuel consumption and greenhouse gas emissions increased by 83 percent and 84 percent, respectively, under heavily congested work zones, compared with uncongested traffic conditions. Mitigating congested work zones from heavy (average speeds of 5 mph) to medium congestion (average speeds of 25 mph for a freeway and 15 mph for a multilane road) would reduce fuel consumption and greenhouse gas emissions by 40 percent on a freeway and 32 percent on a multilane road (Zhang, Batterman, and Dion 2011).

13.8.4 Customer Satisfaction

One of the key goals of a TMP strategy is to satisfy motorists' desire for a good driving experience. To improve customer satisfaction, agencies rely heavily on public complaints as an information source for work zone problems that need attention. Some agencies are conducting or commissioning customer surveys to gain feedback regarding work zone safety and mobility performance. These surveys can help agencies plan projects, adjust construction and traffic management strategies, and improve success on future projects. By establishing simple methods of contact, the agencies can enable customer feedback through a project website or another method through which customers' concerns can be reviewed and addressed. Properly designed survey instruments can help agencies assess the overall effectiveness of TMP strategies and differentiate between individual strategies within a set.

Good two-way communication with the public can lessen congestion, since road users can make more informed choices as they plan trips. In addition, keeping the public informed can improve safety if drivers are more aware of prevailing road conditions (Hallmark, Turner, and Albrecht 2013). On the part of a roadway agency, communicating work-zone performance to the public can inspire confidence in the system and show good stewardship. For design and construction teams, communication can lead to improved design specifications and field training.

13.8.5 Productivity

The productivity of work zone construction operations has definitions that range from how effective and safe workers are on the job to exact metrics of how many units of a construction product are accomplished in a certain span of time. The most widely accepted definition focuses on units produced over a defined time duration, or, conversely, on the labor hours needed to produce a unit.

The purpose of productivity assessment is to estimate the effects of the work zone strategy on the efficiency of production. Performing the work safely and efficiently, such as implementing the full closure of a roadway, reduces the potential for crashes in a work zone, especially crashes involving both vehicles and workers. Completely closing the roadway to traffic can reduce the duration of the construction, since the contractor does not need to interact with traffic and will likely have access to a larger work space. Both avoiding interaction with the traffic and having access to larger work space will very likely increase the productivity of the contractor and reduce the duration of construction. Other strategies such as night work, extended hours in the off-peak direction of traffic, and multiple lane closures can also improve productivity.

The measures pertaining to work productivity are expected to be the most applicable for evaluation of the TMP strategies implemented to reduce the frequency of traffic-affecting events and the total duration of work zone features that affect safety. In general, contractors will benefit from reduced injury costs, reduced construction costs, and, possibly, faster project completion. Road users will also benefit through less traffic congestion and shorter project construction time.

13.8.6 Partnering and Leadership Evaluation

Although an important measure, client/contractor satisfaction (i.e., the DOT/contractor) is not discussed in this paper. This measure reflects the clients' experiences with and confidence in the contractors' abilities and cooperation. Client satisfaction does not guarantee loyalty (future work with that customer) but generally builds a level of trust and a partnership that can only work positively for the project. A dissatisfied client will tend to review all contractor submissions in detail, partner less, and not work with the contractor in the future. Conversely, a satisfied client still cannot necessarily guarantee future projects to any contractor. Therefore, the main benefit of high client satisfaction for a contractor is the opportunity to remain a client's potential partner in the future. Client satisfaction measures are generally obtained through periodic partnership workshops and resulting surveys of project staff, both the contractor and client. This activity is carried out by a third party hired by the contractor.

Items for evaluation are generally safety, quality, schedule, environmental compliance, issue resolution, responsiveness, communication, and command climate. Each area is evaluated quarterly if both the client and the contractor agree that the executive leadership and partnering is going well. If, however, any one party believes that a breakdown in communication is leading to project-related issues, then these evaluations can be held monthly. An example survey output is shown in Figure 13.3.

13.8.7 Use of Data and Results

When agencies measure performance, they may end up with large amounts of data and results. The challenge is to use these results to make good decisions or to take timely and effective action. Project-level results may require immediate action by the responsible party (for example, a maximum queue length in the work zone is exceeded or a high frequency of crashes indicates a traffic control plan may not be working well).

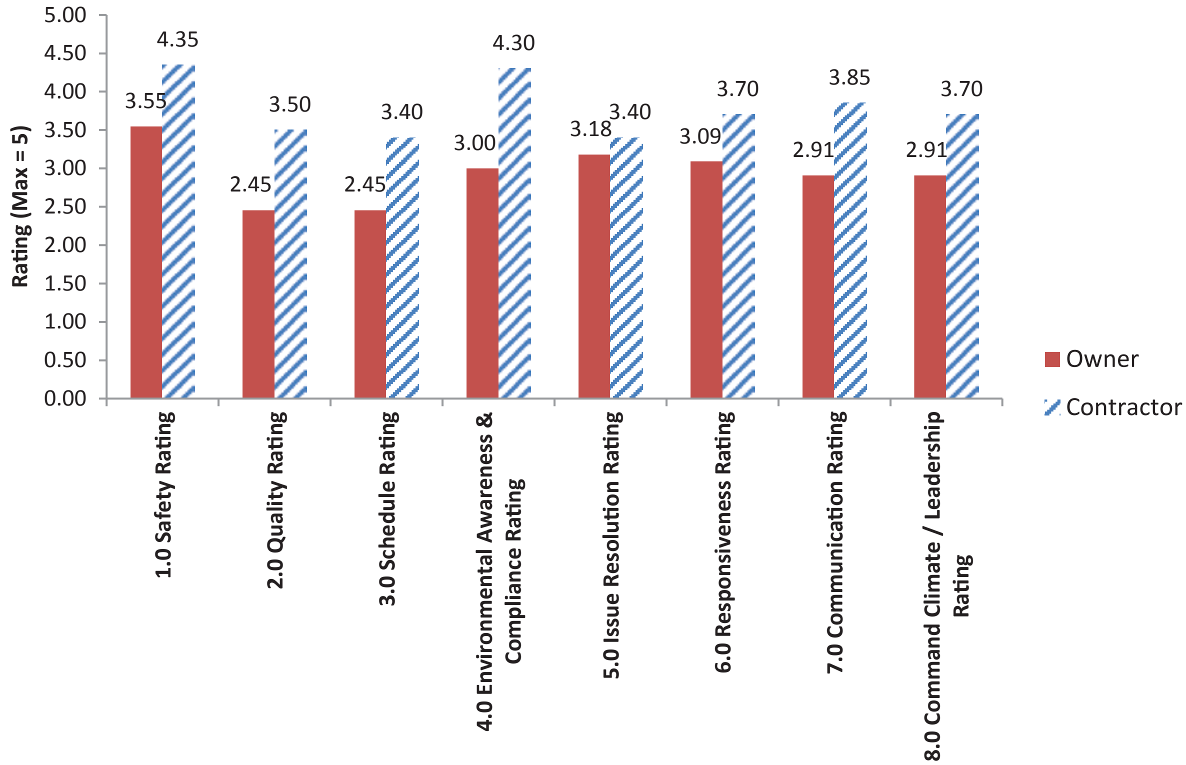


Figure 13.3. A typical client/contractor monthly evaluation result.

Audiences for data and results can vary from project-level personnel, to district-level management, to central-office management, to elected or appointed officials, to the traveling public. These different audiences will be interested in different levels of information. For example, project-level personnel will need detailed results for each performance measure with potential solutions to mitigate negative impacts, whereas upper-level management may only require a quick briefing (if positive) on how things are going. The project contract documents need to carefully outline a scope—what data are to be collected and what expectations or goals the contractor is expected to meet—but allow the contractor to develop the approach (i.e., the public information plan). It is also important to be fair by recognizing and examining the successes as well as the problems and failures. Failure does not have to be recognized by the DOT as non-compliance, but rather as an opportunity to work with the contractor to mitigate potential issues. Performance data and results will provide a valuable baseline for impact assessment and future project planning.

13.9 Resources and References

Hallmark, S., J. Turner, and C. Albrecht. *Synthesis of Work-Zone Performance Measures*, Smart Work Zone Deployment Initiative and Iowa Department of Transportation, September 2013.

Herbel, S., L. Laing, and C. McGovern. *Highway Safety Improvement Program (HSIP) Manual*, FHWA-SA-09-029, FHWA, U.S. DOT, January 2010.

Highway Capacity Manual: A Guide for Multimodal Mobility Analysis, 6th ed. Transportation Research Board, Washington, D.C., 2016.

Highway Safety Manual. AASHTO, Washington, D.C., 2010. [HSM]

Khattak, A. J., A. J. Khattak, and F. M. Council. Effects of Work Zone Presence on Injury and Non-Injury Crashes, *Accident Analysis and Prevention*, Vol. 34, 2002.

Ullman, G. L., M. D. Finley, J. E. Bryden, R. Srinivasan, and F. M. Council. *NCHRP Report 627: Traffic Safety Evaluation of Nighttime and Daytime Work Zones.* Transportation Research Board of the National Academies, Washington, D.C., 2008.

Ullman, G. L., M. Pratt, M. D. Fontaine, R. J. Porter, and J. Medina. *NCHRP Research Report 869: Estimating the Safety Effects of Work Zone Characteristics and Countermeasures—A Guidebook*. Transportation Research Board, Washington, D.C., 2018. http://dx.doi.org/10.17226/25007.

Ullman, G. L., M. Pratt, S. Geedipally, B. Dadashova, R. J. Porter, J. Medina, and M. D. Fontaine. *NCHRP Web-Only Document 240: Analysis of Work Zone Crash Characteristics and Countermeasures*. Transportation Research Board, Washington, D.C., 2018. https://doi.org/10.17226/25006.

Zhang, K., S. Batterman, and F. Dion. Vehicle Emissions in Congestion: Comparison of Work Zone, Rush Hour and Free-Flow Conditions. *Atmospheric Environment* 45 (2011) 1929–1939. National Science Foundation Materials Use: Science, Engineering, and Society Biocomplexity Program Grant and the University of Michigan Risk Science Center, January 2011.

CHAPTER 14

Additional Transportation Management Plan Strategy Resources

The information provided in this guidebook reflects the current work zone strategy state of practice based on available published literature, FHWA programs, surveys of state DOT work zone engineers, follow-up interviews with select survey respondents, and reviews of state design and engineering manuals, special provisions, and standard drawings.

However, almost all state DOTs are continually looking at ways to expand or enhance their practices within work zones. This is especially true for SWZs, which more and more states are adopting, and for integration with motorist information systems (e.g., 511, websites), highway condition reporting systems, TMC, and soon to be tested dedicated short-range communications/vehicle-to-infrastructure.

It is also necessary to understand that evaluation of work zone strategies, refinement of these strategies for optimum effectiveness and efficiency, and development of guidelines and specifications are continuously evolving.

As such, readers seeking additional information about work zone management may find the following additional resources to be of interest.

14.1 Transportation Management Plans

A TMP lays out strategies for managing the work zone impacts of a project. Section 630.1012 of the FHWA Work Zone Safety and Mobility Rule states that for significant projects, the state shall develop a TMP that consists of a TTC plan and addresses both transportation operation and public information components. For individual projects or classes of projects that the state determines to have less than significant work zone impacts, the TMP may consist only of a TTC plan. However, states are encouraged to also consider transportation operations and public information issues for these projects. Additional information on TMPs, TMP development resources, examples, checklists, and so on can be found at https://ops.fhwa.dot.gov/wz/resources/final_rule/tmp_examples.htm and https://www.workzonesafety.org/topics-of-interest/transportation-management-plans/.

14.2 National Work Zone Safety Information Clearinghouse

The National Work Zone Safety Information Clearinghouse website, now in its 21st year, provides users with a plethora of information about work zone safety, including news articles, fact sheets, emerging technologies, best practices, key safety experts, laws and regulations, safety standards, research publications, training videos and programs, and more. The information is updated daily, so the user receives the most recent information first.

The website can be accessed at https://www.workzonesafety.org/.

14.3 FHWA Smart Work Zones

SWZs are among a few select initiatives being promoted during Round 3 of the FHWA EDC initiative. SWZs are work zones that use innovative strategies to minimize work zone safety and mobility impacts. In EDC-3, focus is on coordination of construction projects and use of technology applications to dynamically manage work zone impacts. These strategies include coordination of roadway construction projects to reduce work zone impacts and use of technology applications to dynamically manage traffic in the work zone environment.

Additional information can be accessed at https://www.workzonesafety.org/swz/.

14.4 FHWA Peer-to-Peer Program for Work Zones

The FHWA has established the Work Zone Safety and Mobility Peer-to-Peer Program to facilitate the exchange of information among practitioners to help stimulate improvements toward making work zones function better.

The program provides state and local transportation agencies, at no cost, easy access to peers knowledgeable about a range of work zone issues. Assistance is available from practitioners who have expertise in work zone topic areas and can share lessons learned and success stories from their own experiences. This assistance will in turn help agencies and the traveling public realize the benefits of improved safety and mobility in and around work zones.

Additional information can be accessed at https://ops.fhwa.dot.gov/wz/p2p/index.htm.

14.5 Work Zone Management Capability Maturity Framework Tool

The Work Zone Management Capability Maturity Framework tool is intended for agencies or regions to assess current capabilities with respect to work zone management. Modeled after the AASHTO Systems Operations and Maintenance Guidance, this tool assesses work zone management capability in six dimensions: business processes, systems and technology, culture, organization and workforce, performance measurement, and collaboration. When the current capabilities are determined, the tool provides a list of concrete actions for agencies to raise their capabilities to the desired levels.

Additional information can be accessed at https://ops.fhwa.dot.gov/tsmoframeworktool/tool/wzm/index.htm.

14.6 FHWA Work Zone Data Initiative

"Work zone activity data" is information regarding when, where, and how work zones are deployed. The FHWA launched the Work Zone Data Initiative in 2017 to develop a recommended practice for managing work zone activity data and to create a consistent language, through the development of a data dictionary and supporting implementation documents, for communicating information on work zone activity across jurisdictional and organizational boundaries. The effort promotes a stakeholder-driven and systems-driven perspective for data that allows practitioners a better understanding of users' needs and, ultimately, a better approach to collecting national work zone activity data.

FHWA reference documents relating to planning and deploying standardized work zone activity data can be accessed at FHWA's Work Zone Management Program Collaboration Site, https://collaboration.fhwa.dot.gov/wzmp/.

Abbreviations

A+B	cost-plus-time
AADT	annual average daily traffic
ABC	accelerated bridge construction
ACM	alternative contracting method
ABCUTC	ABC University Transportation Center
ADOT	Arizona Department of Transportation
ADT	average daily traffic
AFAD	automated flagger assistance device
ARAMPS	MDSHA real-time Travel Time Prediction System
ASE	automated speed enforcement
ATMA	autonomous truck-mounted attenuator
ATMS	advanced traffic management system
ATSSA	American Traffic Safety Service Association
AVL	automatic vehicle location
AWARE	advanced warning and risk evasion
CA4PRS	Construction Analysis for Pavement Rehabilitation Strategies
Caltrans	California Department of Transportation
CALM	Construction Area Late Merge
CARS	Condition Acquisition and Reporting System (MnDOT)
CCTV	closed circuit television
CDOT	Colorado Department of Transportation
CHART	coordinated highway action response team
CM	construction manager
CMAR	construction manager at risk
CM/GC	construction manager/general contractor
CMF	crash modification factor
CMS	changeable message sign
CO	carbon monoxide
CO_2	carbon dioxide
COTS	commercial off-the-shelf
CTR	Commute Trip Reduction
D–B	design–build
DBB	design–bid–build
DDOT	District of Columbia Department of Transportation
DelDOT	Delaware Department of Transportation
DLMS	dynamic lane-merging system
DOT	department of transportation
DSDS	dynamic speed display signs

DWZTM	district work zone traffic manager (Ohio DOT)
EDC	Every Day Counts (FHWA)
EQWS	end of queue warning system
FDM	Facilities Development Manual
FDOT	Florida Department of Transportation
FSP	freeway service patrol
FST	Freeway Service Team
GDOT	Georgia Department of Transportation
GMP	guaranteed maximum price
GRS-IBS	geosynthetic reinforced soil-integrated bridge systems
HC	hydrocarbon
HERO	highway emergency response operators
I/D	incentive/disincentive
IDOT	Illinois Department of Transportation
IMP	incident management plan
InTrans	Iowa State University Institute of Transportation
IRIS	Intelligent Roadway Information System (MnDOT)
ITE	Institute of Transportation Engineers
ITS	intelligent transportation system
KSDOT	Kansas Department of Transportation
LCM	Lane-Closure Manual
LCS	lane closure system
LCSY	Lane Closure Strategy
LID	Locked Incentive Date
LUCS	lane-use control signals
MAP	Motorist Assistance Program
MassDOT	Massachusetts Department of Transportation
MBT-1	Mobile Barrier Trailer
MCDOT	Maricopa County Department of Transportation
MDOT	Michigan Department of Transportation
MDSHA	Maryland State Highway Administration
MnDOT	Minnesota Department of Transportation
MoDOT	Missouri Department of Transportation
MOE	measure of effectiveness
MOU	memorandum of understanding
MUTCD	Manual on Uniform Traffic Control Devices
NCDOT	North Carolina Department of Transportation
NEI	no-excuse incentive
NHTSA	National Highway Traffic Safety Administration
NJDOT	New Jersey Department of Transportation
NOx	nitrogen oxide
NTCIP	National Transportation Communications for ITS Protocol
NWZAW	National Work Zone Awareness Week
NYSDOT	New York State Department of Transportation
ODOT	Ohio Department of Transportation
OKDOT	Oklahoma Department of Transportation
PA	public awareness
PBES	prefabricated bridge elements and systems
PC	project coordination
PCMR	portable changeable message sign with radar
PCMS	portable changeable message sign
PDM	project-delivery method
PDMSG	Project Delivery Method Selection Guidance

PDSM	Project Delivery Selection Matrix
PennDOT	Pennsylvania Department of Transportation
PLCS	permitted lane-closure schedule
PPSM	Procurement Procedure Selection Matrix
PSA	public service announcement
PSL	posted speed limit
PVSLS	portable variable speed limit system
QWS	queue warning system
RFB	request for bids
RFP	request for proposal
RFQ	request for qualifications
RITA	Research and Innovative Technology Administration
ROW	right-of-way
RRB	rolling road block
RTTS	real-time travel system
RUC	road-user cost
SCDOT	South Carolina Department of Transportation
SDDOT	South Dakota Department of Transportation
SEQ	sequential flashing warning lights
SEP-14	FHWA Special Experimental Project No. 14, Alternative Contracting
SPF	safety performance function
SPMT	self-propelled modular transport
SWZ	smart work zone
TCD	traffic control device
TIPS	Traffic Information and Prediction System
TMA	truck-mounted attenuator
TMC	transportation management center
TMP	transportation management plan
TO	transportation operation
TOC	traffic operations center
TRS	temporary rumble strips
TTC	temporary traffic control
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
UW-TOPS	University of Wisconsin Traffic Operations and Safety Laboratory
VDOT	Virginia Department of Transportation
VE	value engineering
VMT	vehicle miles traveled
vpd	vehicles per day
vph	vehicles per hour
vphpl	vehicles per hour per lane
VSL	variable speed limits
WAS	Worker Alert System
WisDOT	Wisconsin Department of Transportation
WISE	Work Zone Impact and Strategy Estimator
WisTMP	Wisconsin TMP
WSDOT	Washington State Department of Transportation
WZARD	Work Zone Accident Reduction Deployment system
WZCMF	work zone crash modification factor
WZIA	work zone intrusion alarm
WZPM	Work Zone Performance Monitoring tool
WZSAP	Work Zone Safety Awareness Program

Appendices A Through N

Appendices A through N to *NCHRP Research Report 945* are not provided herein but can be found on the TRB website by searching on "NCHRP Research Report 945".

Appendix titles are listed below.

Appendix A—TMP Strategy Cross-Reference Matrix
Appendix B—UDOT Portable Variable Speed Limit Standard Drawing
Appendix C1—MDOT Special Provision for Temporary Rumble Strips, March 2018
Appendix C2—MDOT Special Provision for Temporary Rumble Strips (Orange) in Advance of a Stop Condition, February 2012
Appendix C3—MDOT Special Provision for Temporary Rumble Strips (Orange) in Advance of a Work Zone, February 2012
Appendix C4—UDOT Standard Drawings for Use of Temporary Rumble strips for Freeway/Divided Highway Lane and Shoulder Closures, June 1018
Appendix C5—CDOT Temporary Portable Rumble Strips: Typical Applications for Use with One-Lane, Two-Way Operation Using Flaggers and for Lane Closures on Multilane Divided Highway, Revised May 2018
Appendix D1—MnDOT Dynamic Lane Merge Layout
Appendix D2—KSDOT Dynamic Lane Merge Layout
Appendix D3—WisDOT Dynamic Lane Merge Outreach
Appendix D4—CDOT Dynamic Lane Merge Layout
Appendix E1—WisDOT Incident Management Plan (IMP) Example 1
Appendix E2—WisDOT Incident Management Plan (IMP) Example 2
Appendix F—PennDOT Automated Work Zone Speed Enforcement Program Operation Process Flowchart
Appendix G—CDOT Full Road Closure Worksheets
Appendix H—NCDOT Presence Lighting Standard Typical
Appendix I1—Illinois DOT Special Provisions for Speed Display Trailers
Appendix I2—Iowa DOT Special Provisions for Speed Feedback Trailers
Appendix J1—CDOT Project Delivery Selection Matrix (PDSM)
Appendix J2—CDOT Procurement Procedure Selection Matrix (PPSM)
Appendix K1—WSDOT Project Delivery Method Selection Guidance (PDMSG) Checklist
Appendix K2—WSDOT Project Delivery Method Selection Guidance (PDMSG) Matrix
Appendix L—Wisconsin Work Zone Cell Phone Restrictions Bill (2015 Assembly Bill 198)
Appendix M—TxDOT Go-No-Go Tool
Appendix N—MnDOT Work Zone ITS Scoping Decision Tree

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

TRANSPORTATION RESEARCH BOARD
500 Fifth Street, NW
Washington, DC 20001

ADDRESS SERVICE REQUESTED

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people's lives worldwide.
www.nationalacademies.org

ISBN 978-0-309-48178-6

NON-PROFIT ORG.
U.S. POSTAGE
PAID
COLUMBIA, MD
PERMIT NO. 88