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State Transportation Agencies' utilization of work zone congestion mitigation strategies

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by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

Through the compliance of the Federal Highway Administration's work zone policy, State Transportation Agencies (STAs) are required to address safety and mobility issues of vehicles through and around work zones. Work zone congestion mitigation strategies are utilized by agencies to reduce or eliminate congestion through a work zone as part of the project's Transportation Management Plan (TMP). Generally, five strategy groups, each consisting of several strategies, are considered to address mobility and safety impacts.

- Traffic Management Strategies
- Demand Management Strategies
- Alternative Project Scheduling and Phasing Strategies
- Design Alternatives to Minimize Life Cycle Congestion Cost Strategies
- Alternative Contracting and Delivery Strategies to Accelerate Project Completion

The objective of this research is to identify strategies used by STAs nationwide and their experiences to assist agencies' strategy selection during the work zone planning phase to reduce work zone congestion. A survey was developed to focus on STAs' current strategy implementation, past experiences (both positive and negative), and future strategy research and objectives. STA respondents were asked questions concerning strategy implementation for projects similar to four developed scenarios: rural reconstruction, rural resurfacing, urban reconstruction and urban resurfacing projects. Other areas investigated include the identification of traffic analysis tools used in the work zone planning process and work zone lane capacity values. The culmination of the survey analysis consists of recommendations for future research and strategy selection tables displaying the results of the analysis to assist agencies in building strategy combinations for TMPs.

The survey received 42 responses, encompassing at least 28 states. The most commonly identified strategies include dynamic message signs, nighttime construction schedules and incentives/disincentives to reduce project duration. Several differences in strategy selection were identified based on project location and work activity through an analysis of current strategy implementation responses. The analysis compared strategy selection individually, both between and within strategy groups, within each scenario. It was determined that many agencies are encompassing strategies from several strategy groups in their TMPs. The analysis also compared strategy selection between scenarios, both individually and through strategy pairs.

Two other issues identified and discussed include the variety and inconsistent use of traffic simulation and analysis tools by agencies and work zone lane capacity values used by different agencies. The survey also identified strategies that STAs are researching or planning to utilize in the future that may benefit from further research. These strategies include Intelligent Transportation System strategies and, to a lesser extent, alternative contracting strategies. Another question asked respondents was to identify unsuccessful strategy implementation. While few responses were provided, with narrowed lanes being identified by the most respondents, it was found that many agencies lacked a process and tool to measure the performance of strategies during and after project implementation.

CHAPTER 1 – INTRODUCTION

The number of work zones motorists encounter is a common concern and cause of frustration among the traveling public. This is due to two issues: an aging infrastructure and the need for increased capacity causing recurring congestion. The Dwight D. Eisenhower National System of Interstate and Defense Highways is more than 50 years old, thus different segments throughout the system are continuously needing to be either reconstruction or rehabilitated (1). In 2001, nearly 13 percent of the National Highway System was under construction, resulting in approximately 3110 work zones. Of these work zones, 85 percent of the work zone miles were for preservation projects, 12 percent for capacity additions and three percent for new routes (2). In 2001, motorists encountered an active work zone one out of every 100 miles driven on the National Highway System (3).

Highway work zones are a prominent cause of nonrecurring congestion that can cripple mobility on a transportation facility and throughout a surrounding network if motorist mobility is not considered in construction scheduling and work zone planning. Many facilities already experience recurring congested during normal operation conditions, thus, the congestion conditions worsen during a lane closure. The current number of roadways that are considered congested during normal operating conditions is nearly 58 percent (4). This can be attributed to the significant increase in vehicle miles traveled, which was 79 percent between 1982 and 2002, and only a three percent increase in highway lane miles during the same period (2). This makes it even harder to maintain adequate mobility for motorists because facility capacity is reduced while demand stays the same when lanes are closed.

When work is required on facilities that have a traffic demand either approaching or exceeding capacity, mobility aspects through the work zone needs to be addressed. Today, motorists have increased expectations of mobility on the road network. This means that road construction and the necessary work zones should not inconvenience motorists to a level higher than usually occurs. Maintaining an acceptable level of mobility through a work zone poses a significant issue to State Transportation Agencies (STAs): balancing roadwork costs while providing acceptable mobility to the public. STAs apply strategies to manage and reduce congestion created, exceeding current conditions (as applicable), from a lane closure or other activities in a work zone.

1.1 Research Overview

Because motorists commonly expect little or no disruption to their normal driving habits, even when roadways need to be maintained or reconstructed, measures need to be taken to minimize the increased congestion work zones can create on a facility. Congestion created or amplified by lane closures in work zones can create unacceptable delays to motorists if not adequately addressed. To manage or reduce this congestion, State Transportation Agencies (STAs) can use various congestion mitigation strategies. These strategies fall into the following five strategy groups:

- Traffic Management Strategies
- Demand Management Strategies
- Alternative Project Scheduling and Phasing Strategies
- Design Alternatives to Minimize Life Cycle Congestion Cost Strategies
- Alternative Contracting and Delivery Strategies to Accelerate Project Completion

Within these strategy groups, various strategies are available for implementation, singularly or in combination with other techniques. Traffic simulation and analysis tools is a strategy that is not categorized in the above five groups. The analysis of work zone induced impacts is considered a planning strategy and important to maintaining mobility through a work zone.

This research analyzes the strategies used by various STAs and identifies what strategies STAs use for various road reconstruction and resurfacing projects for both urban and rural scenarios. The strategies discussed in the literature review and listed in the research are geared to the specific scenarios developed in the survey portion of the project. Table 1 outlines these strategies organized by strategy group.

Table 1. Work Zone Congestion Mitigation Strategies Included in Research

Traffic Management Strategies
• Increased Incident Management Capabilities
• Increased Speed Enforcement
• Use of ITS Technologies
o Smart Work Zones
o Dynamic Message Signs
o Travel Time and Delay Estimation System
o Advanced Speed Information System
o Real Time Traffic Conditions on the Internet
• Narrowed Lanes
Demand Management Strategies
• Demand Side Traffic Management Strategies
• Alternative Route Improvements
• Improved Pre-Construction Traveler Information
• Mass Transit Improvements
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies
• Temporary Pavement
Alternative Project Scheduling Strategies
• Nighttime Construction Schedules
• Full Road Closures and Detour Routes
Alternative Contracting and Delivery Strategies to Accelerate Project Completion
• Design/Build
• Lane Rental
• A+B and A+B+C Contracting
• Incentives/Disincentives to Reduce Construction Duration and Impacts
• Interim Completion Dates and Liquidated Damages
Planning Applications
• Traffic Simulation and Analysis Tools

1.2 Contribution to the State of the Art

Chapter 2 reviews the literature on congestion mitigation strategies for work zones. It was found that congestion mitigation in work zones is becoming an important part in the construction process. The selection of strategies by STAs for Transportation Management Plans (TMPs) varies widely between agency, work activity (reconstruction, resurfacing, maintenance, etc.), and location (urban or rural), and facility type (expressways, freeways, two-lane highways, etc.).

STAs are currently working towards meeting the requirements of the Federal Highway Administration Work Zone Safety and Mobility Rule (23 CFR Part 630) (5). This Rule requires STAs to systematically consider management of work zone impacts on Federal-aide highways and other projects that have “significant” impact on road users. One of the objectives of the rule is to address the development of TMPs for projects to maintain acceptable levels of mobility and safety through a work zone by using transportation management strategies. Potential strategies that may be included in TMPs are those that an STA feels would benefit the project and could include those identified in this research. This research can assist STAs when they are identifying strategies for TMPs and provide information on what other agencies are using in similar situations.

In current practice, several strategies used by STAs were developed within the respective agency. The agencies discover what works through a trial and error experimentation process and are sometimes reluctant to try new strategies developed at other STAs and through research institutions. While the current strategies may work to an extent, new or different strategies may provide a greater benefit and reduce congestion further than the currently used strategies. However, failure to reduce congestion can cause gridlock and impose very high costs on the road users. The trial of a new method imposes a certain amount of risk on the STA beyond what that agency may be comfortable in taking. This research will provide more information on strategies for their first implementation, encouraging agencies to try new strategies and improve their Transportation Management Plans.

Through a review of the literature, it was found that case studies have been performed on certain strategies, such as full road closures, innovative contracting techniques and enroute traveler information. The case studies provide valuable information about work zone congestion mitigation strategies, but other information that would be valuable to reducing congestion is absent. Most of the case studies only document successful application of strategies, but do not address any unsuccessful applications. Similarly, many of the case studies highlight only one strategy, while the reduction of congestion in work zones was likely due to the combination of strategies. The beneficial strategy combinations are minimally documented in the literature and often quite limited in explanation and discussion. The case studies often deal with reconstruction efforts but fail to highlight shorter duration projects such as resurfacing and maintenance work. This research provides scenarios in which agency staff will indicate what strategies their agency would use in a similar situation.

Another gap in the literature is the discussion of rural freeway work zone congestion mitigation. Most case studies dealt with projects on urban facilities. In the Midwest, the traffic demand is approaching capacity on many four lane rural freeway segments and these facilities will need to be reconstructed into six lane, or more, facilities to accommodate future traffic volume projections. An example of this is the current six lane facility, Interstate 80, reconstruction between Lincoln and Omaha, Nebraska. In the Nebraska Department of Roads' 2013 and Beyond plans (6), roughly 160 miles of Interstate 80 is planned to be reconstructed to six lanes from the current reconstruction near Omaha to central Nebraska. Similarly, the Iowa DOT is discussing possible reconstruction of Interstate 80 in the future.

The strategies beneficial in reducing congestion on urban facilities may not provide the same benefits to a rural facility. Traffic characteristics, such as drivers' trip purpose and peak volume periods, are generally different on rural freeways than they are on urban freeways. Most motorists on rural Interstates are making longer trips and may not adjust their trip due to work zones. Many may not be aware of work zone locations prior to the trip. Trips on rural facilities are generally longer in length. This contributes to peak periods occurring more gradually on rural facilities than urban facilities, where peak commute periods spike quickly. Traffic volumes on urban facilities increase very rapidly during the morning commute period because many people begin work at similar times. The peak in the evening is more gradual as people ending their workday are more spread out from late afternoon to early evening. This research will identify those strategies that provide greater benefits to either an urban facility project or a rural facility project.

1.3 Thesis Organization

This thesis is presented in six chapters. Chapter 1, Introduction, identifies the issues posed to STAs to maintain acceptable mobility on road facilities. Chapter 2, Literature Review, first identifies and defines common terms used when describing work zone congestion in the Definitions section. The literature review also provides descriptions to the strategies that were selected for the research. The descriptions may include, in conjunction with a strategy overview, case studies and implementation examples. Chapter 3, Problem Statement, presents what information is lacking when discussing congestion mitigation strategies and narrows the scope of this research. Chapter 4, Methodology, describes the survey process, including the scenarios used for the survey questions, the survey questions and the survey recipients. Chapter 5 consists of the analysis of the survey results. The includes the analysis of STA responses for the four scenarios concerning current strategy utilization, prior experiences, future considerations, work zone lane capacities, and traffic analysis tools. Chapter 6 includes the conclusions and recommendations based on the survey responses, where several recommendations are presented for future consideration and research.

CHAPTER 2 – LITERATURE REVIEW

The purpose of this research is to determine what strategies State Transportation Agencies (STAs) are using to reduce congestion through work zones on high-speed facilities. A wide variety of strategies are available for implementation, but their benefits towards maintaining acceptable levels of safety and mobility through a work zone differs by work zone characteristics. This chapter reviews the work zone congestion mitigation strategies previously identified and reviews the literature on these strategies and their potential congestion mitigation benefits. The literature review contains a definitions section followed by a review of the Federal Highway Administration (FHWA) and STA policies regarding work zone mobility and safety and STA lane capacity threshold values. The remainder of this chapter reviews the work zone congestion mitigation strategies being used in the survey. STA and FHWA documents, research, and case studies, as available in the literature, provides the basis of the strategy descriptions and review of the literature. The review will identify the technical concepts, implementation possibilities, and potential congestion reduction benefits of each strategy.

2.1 Definitions

Congestion: Congestion is caused by a downstream bottleneck where demand exceeds capacity. Motorist delay is incurred which creates a longer travel time than would be experienced during free flow condition.

Congestion can be divided into two categories: recurring and nonrecurring. Recurring congestion is congested conditions that occur day after day; nonrecurring congestion is only temporary and will not be encountered on a "typical" day. Causes of recurring congestion include insufficient capacity, unrestrained demand and ineffective management of capacity, such as poor signal timing. Causes of nonrecurring congestion, of interest to this research, include work zones, incidents, weather events, special events and emergencies (7).

Capacity: Capacity is the maximum flow rate that can be accommodated by a given traffic facility under prevailing conditions (8, p.8-17). The value of lane capacity is not constant throughout all facilities and locations. The capacity at a work zone lane closure is dependent on a number of location specific variables, some can be controlled, such as merge point location, while others cannot, such as weather. Work zone lane capacity values are described in Section 2.3. Capacity is also partially dependent on driver behavior, which has a certain amount of uncontrollable randomness. The following list of variables influencing capacity is further described by Maze, et al. (9):

- Work zone lane closure configuration
- Intensity and location of work
- Percentage of heavy vehicles

- Driver characteristics
- Entrance ramp locations and volumes
- Grade of lane closure
- Duration of work
- Weather conditions
- Work time
- Location of merge point and enforcement

Delay: Delay can be characterized in two ways: a) by speed and distance change where delays occur due to speed changes and/or increased travel distances, and b) capacity restriction where delays occur due to insufficient capacity, causing vehicle queuing (10).

Road User Costs: When evaluating project alternatives and issues created by these alternatives, it is important to analyze the impacts on motorists, also known as the road user costs. Work zones create increased road user costs in terms of increased travel time costs, crash (safety) costs and vehicle operating costs due to congestion, and delays from deviations of normal travel and capacity reductions. The objective of congestion mitigation strategies is to reduce the impact and magnitude of increased road user costs due to work zones.

2.2 Federal Highway Administration and State Transportation Agency Work Zone Safety and Mobility Policies

State Transportation Agencies are currently working towards meeting the requirements of the Federal Highway Administration Work Zone Safety and Mobility Rule (23 CFR Part 630) (5). The deadline for compliance by all STAs is October 12, 2007. The updated Rule establishes requirements and guidelines that for STAs to systematically assess impacts to safety and mobility early in the project development process and develop strategies to address these impacts. This is required on all Federal-aid highway projects and other projects that will have a "significant" impact on road users. The three major components of the rule consist of the policy, process and project level components and provides for flexibility to individual agencies to create a policy specific to their needs. Part of the project level component is to address the development of Transportation Management Plans for projects that will maintain acceptable levels of mobility and safety through a work zone by using transportation management strategies. At this stage, work zone congestion mitigation strategies are selected to provide and maintain adequate safety and mobility through the work zone.

After reviewing the STAs that have working or completed policies, it was found that the amount of discussion of work zone congestion mitigation strategies varies widely between STAs. Some STAs provide a list of congestion mitigation strategies, others provide more detailed strategy information in their document, while others do not discuss or identify any strategies. As an example, the Ohio Department of Transportation has one of the more extensive work zone policies which contains a matrix of construction strategies and work zone traffic control options (11). For each strategy, this matrix lists the objectives, pros and cons, restrictions, suggestions for use, and costs incurred by implementation. The Center for Transportation Research and

Education completed a report that surveyed 30 STAs regarding their procedures to forecast and monitor work zone safety and mobility impacts (9). It also provides detailed case studies of Virginia Department of Transportation, Ohio Department of Transportation, and Oregon Department of Transportation, which further discusses what the states were currently using to maintain safety and mobility through a work zone.

The Federal Highway Administration maintains a webpage dealing with work zone operations, through their Work Zone Mobility and Safety Program (12). The website is continually updated with additional research reports and case studies of STA strategy implementation and work zone related topics. It also provides guidance for STAs in implementation of the Work Zone Safety and Mobility Rule. While several strategies have extensive literature on the website, others are not mentioned beyond inclusion in a strategy list or matrix.

The Federal Highway Administration includes many strategies in their *Developing and Implementing Transportation Management Plans for Work Zones* document, but the descriptions are minimal and the included matrix identifies general characteristics of each strategy (13). The matrix indicates whether the strategy is a mobility improvement, motorist safety improvement, or worker safety improvement. Further, it provides lists of characteristics including triggers for consideration, potential pros, potential challenges, and other considerations. Another document that provides strategies to mitigate work zone impacts is NCHRP Synthesis 293, Reducing and Mitigating Impacts of Lane Occupancy during Construction and Maintenance (14). This document reviews strategies available to reduce lane occupancy during construction and maintenance activities and conducts a survey of STAs to assess the levels of lane occupancy reduction some strategies have. The document also provides case studies for several of the techniques identified. Maze and Wiegand, 2007, developed a synthesis of 23 work zone congestion mitigation strategies. The synthesis provides a description and any research and case studies that have been completed of each strategy.

2.3 Work Zone Lane Capacity Values

A work zone lane capacity threshold is often the point where an STA will decide if a lane closure is allowed or if strategies are needed because a work zone would likely create congestion. Interestingly, it was found in the literature that threshold values vary widely between STAs. When comparing what strategies an STA utilizes, it is necessary to account for their respective work zone lane capacity threshold value. For example, using two values for a lane capacity threshold, one higher and one lower, and a facility has a volume near the higher threshold value; the STA that has a lower threshold (lane capacity) value would need to utilize more extensive strategies to reduce the demand further than that of the STA with a higher threshold value. Several studies have been performed to identify a consistent value; however, this value is hard to identify because drivers behave differently throughout the United States. An example of this is where drivers living in location A feel more comfortable driving at higher speeds and reduced headways than similar drivers at location B, thus facility capacity is greater in location A because of a greater flow discharge rate.

The *Highway Capacity Manual* (HCM) *2000* version (8) provides theory and calculations for short and long term work zone lane closures. However, the HCM does not account for localized driving behavior for short term construction zones. The HCM equations only account for heavy vehicles, intensity and location of work zone activity, location of ramps and the number of open lanes. The adjustment factors are applied to a base capacity of 1600pc/h/ln, as suggested by Krammes and Lopez and cited in the *HCM*, to determine the work zone facility in veh/h (15). For long-term construction zones, the capacity values are generally higher. Table 2 displays the average values for lane closures based on previous studies, provided by Dudek (16), which is also displayed in the *HCM*. Past studies have shown that a lane that crosses over to use a lane usually occupied by opposite direction traffic has a capacity closer to 1550 vphpl (17), while a single lane that does not have a cross over, only a merge point, will average about 1750 vphpl (18).

Table 2. Summary of Capacity Values for Long-Term Construction Zones (16)

Number of Lanes	**Number of Lanes Open**	**Range of Capacity Values** (veh/h/ln)	**Average Capacity per Lane** (veh/h/ln)
3	2	1780 - 2060	1860
2	1	-	1550

The literature also provides work zone lane capacities for various STAs. These values are the lane capacity at which work zones are not allowed to occur without congestion mitigation strategy implementation. Two recent surveys were administered to determine what values STAs were currently using for work zone lane capacity values. One was performed by Sarasua et al. (19), and the other was completed by Maze and Wiegand at the Center for Transportation Research and Education (20). The values, in either vehicles per hour per lane or passenger car equivalents per hour per lane, are presented in Table 3.

Table 3. State Transportation Agency Work Zone Lane Capacity Threshold Values

State Transportation Agency	**Work Zone Lane Capacity Threshold Value(s)** *Vehicles per hour per lane (vphpl)* ** Passenger ca equivalents per hour per lane (pcphpl)*
CDOT Region 1	1600 minus factors 1100 for select mountainous regions
Connecticut DOT	1500 to 1800*
Mn/DOT Metro District	1800
MoDOT	1240 for one of two lanes open 1430 for two of three lanes open
Nevada DOT	1375 to 1400
Oregon DOT	1400 to 1600*
ODOT	Varies between 1000 and 1490
South Carolina DOT	800 vphpl (or 1230*)
Washington DOT	1350
WisDOT	Generally ranges between 1500 and 1600 1200 to 1300 in select regions

2.4 Increased Incident Management and Removal Capabilities during Construction

Incidents within the work zone cause unacceptable delays and congestion, especially when they obstruct an open lane. However, incidents are difficult to anticipate because they can occur anywhere within and around work zone and they vary greatly in magnitude. Because of this unpredictability, it is necessary to plan for a wide range of possible incidents and be able to quickly and efficiently clear the incident area and reopen the lanes to travel. The definition of traffic incident management, according to the Federal Highway Administration (FHWA) is

> The systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of incidents, and improve the safety of motorists, crash victims, and incident responders. Effectively using these resources can also increase the operating efficiency, safety, and mobility of the highway. This results from reducing the time to detect and verify an incident occurrence; implementing the appropriate response; safely clearing the incident; and managing the affected flow until full capacity is restored. (21, p. 1-1)

The tasks required for incident management within work zones is similar to that of incident management on facilities during normal operations, which are outlined in the *Traffic Incident Management Handbook 2000* (21). Further research has been performed to build upon this document and apply the incident management techniques to work zone management, which will be identified later in this section. The sequential activities of an incident management plan are categorized into six phases (21):

- Incident detection
- Incident verification
- Incident response
- Incident site management
- Traffic management and information dissemination
- Incident clearance

Each phase allows the incident management plan to identify the necessary activities performed in each phase with the required personnel, equipment and traffic related response for various incident levels. Figure 1 shows the typical phases of incident management, from incident occurrence, detection, and response, to clearance.

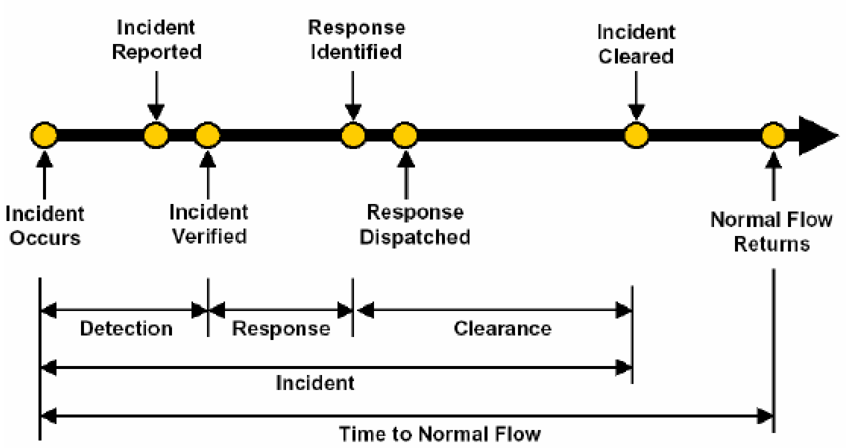

Figure 1. Tasks Required for an Incident (22)

As previously mentioned, the traffic incident management guidelines have been used to develop work zone specific guidelines and checklists for work zone traffic incident management plans. Horowitz and Jin, 2005, created the *Guidebook on Incident Management Planning in Work Zones* as a resource for developing incident management plans for work zones (23). Because of the varying and unpredictable nature of incident occurrence, the guidebook emphasizes flexibility in the planning approach and application of principles. The document builds upon existing literature of incident management techniques, work zone incident management, and combines it with traffic engineers' experiences to create the guidebook. Hofener, 2003, created a checklist for work zone incident management plans based on the key aspects, of incident management (24).

The Colorado Department of Transportation has a comprehensive work zone traffic incident management plans guidebook, entitled *Guidelines for Developing Traffic Incident Management Plans for Work Zones*, 2003 (25).The guidebook describes considerations for developing work zone traffic incident management programs and describes the planning process. It also lists the key components of a traffic incident management programs. The planning process addresses the key components of incident management, listed previously and shown in Figure 1. A unique and beneficial component of this document is the use of previous examples in the state of Colorado when explaining an aspect of incident management process.

Many examples are available in the literature of projects that utilized extensive incident management programs to minimize the lane occupancy times of incidents in work zones. The Transportation Reconstruction and Expansion Project (T-REX) was a five year urban interstate reconstruction and light rail construction project in Denver. The Colorado Department of Transportation developed a comprehensive incident management plan prior to project start, which is further described by Noyes (26). Another notable example of an extensive and efficient incident management plan is the Woodrow Wilson Bridge Project within the Washington DC region (27). Cyra discusses the initial process of the planning stage of an incident management plan for The Marquette Interchange reconstruction project in downtown Milwaukee (28). This document provides a very comprehensive list of impacts and needs to consider when developing an incident management plan.

The *Work Zone Operations Best Practices Guidebook*, 2000, listed several best practices for incident management from various states (29). The best practices can be broken into four topics: towing services, service patrols, emergency response coordination and contractor relations and responsibilities. The following are examples, taken from the guidebook, of what STA work zone incident management.

- Towing Services
  - California uses a designated towing service responsible for keeping a work zone free of disabled vehicles.
  - Pennsylvania uses a tow truck through motorist services on long-term freeway work zones.
- Service Patrols
  - Illinois and Indiana report using an emergency traffic patrol to assist motorists with vehicle problems, such as flat tires, out of gas, overheating, etc., and facilitate incident clearance.

    - Indiana also advises motorists of crash-related congestion through Highway Advisory Radio, Variable Message Signs, and pagers from the scene of the incident through its Hoosier Helper.
- Emergency Response Coordination
    - North Carolina and Pennsylvania require meetings between representatives from emergency response agencies, other involved agencies, and STAs prior to or during a project.
    - Utah uses a cooperative effort of all emergency response agencies, private sector companies such as a Trucking Association involved in the design and evaluation of the traffic control plan, and the media.
- Contractor Relations and Responsibilities
    - Iowa requires the contractor to traverse the work zones and provide assistance.
    - Mississippi writes special provisions within the contract to encourage the contractor to be more active in the incident management process.
    - Utah has the contractor provide the service courtesy vehicles to implement proper measures to clear the lane.

2.5 Increased Enforcement during Construction

A common cause of crashes within or around work zones is excessive motorist speed. In order to maintain a reasonable traffic flow through the work zone in high volume areas, motorists should maintain safe speeds with minimal speed differential. The effects of enforcement activities within and around a work zone provide congestion mitigation benefits. This congestion mitigation strategy is a preventive measure with the objective of reducing the number and extent of the incidents that could occur within the work zone by reducing motorist speeds through the work zone and increasing motorist awareness.

A travel survey performed by Griffith and Lynde, 2002, noted that surveyed drivers expressed that many other drivers traveled aggressively at excessive speeds and the lanes were too narrow for the posted speeds (30). Often in work zones, especially in urban areas, open travel lanes may not have shoulders for vehicles to use because of space limitations and concrete barriers may be placed near the inner and outer lanes' edge lines. Therefore, an incident in this area will effectively close a lane and further reduce the limited capacity until the vehicle(s) is moved from the travel lane.

The congestion mitigation aspect of this strategy is realized in the reduction of incidents within a work zone. The most effective way to decrease the number of incidents is through speed enforcement. The Center for Transportation Research and Education (CTRE) has conducted studies on the use of added enforcement in work zones and found that added enforcement always ranks as the most effective strategy for reducing speeds in the work zones and controlling errant, reckless, and aggressive driving behavior (31). The FHWA published a report, *A Study on the Use of Uniformed Police Officers on Federal-Aid Highway Construction Projects*, which also determined that uniformed officers was best operation because their presence resulted in the greatest speed reduction (32). However, the *Work Zone Safety Toolbox* states that speeds are decreased upstream and at the location of the officer, while the speeds often again increase downstream (33). While being the most costly speed enforcement strategy, there are other benefits to having a police enforcement presence in work zones. These include increased motorist alertness to surroundings and traffic control and an improvement of incident detection and verification times within the incident management process (33).

Three forms of a police presence are often used in work zones. One form is a stationary police vehicle, which may utilize a combination of flashing lights and/or radar. A second form is the use of a cruising vehicle. This, however, only encourages compliance in the area of the vehicle and the vehicle is not always near the location where compliance is most desired. A third form is a police traffic controller, where a uniformed officer stands at the side of the road near a speed limit sign motioning for traffic to slow down. Of the three forms, this may be the least effective method because it does not indicate a chance of a motorist disregarding speed or lane merge location being caught (33).

Another form of enforcement used, not necessarily as a way to ticket motorists but to inform the motorist of speeding, is through speed detection devices. A speed sign or trailer displaying the motorist's speed may encourage the driver to slow down, as shown in Figure 2. This is used as an awareness tool, since some drivers are not always aware of their speed, and helps in two ways. One, drivers will slow down when they are shown both their speed and the speed limit, causing them to become aware of the difference. Second, drivers with radar detectors may slow down because their detector will be activated by the trailer's radar (33).

Figure 2. Speed Display Trailer (38)

Several studies have been performed through the Midwest Smart Work Zone Deployment Initiative on the effectiveness of speed displays and other speed reduction measures. The studies all agree that the use of speed display systems reduce the mean speed at the onset of implementation, however, some of the studies vary on the magnitude and duration of this reduction. A study by Meyer, 2000, noted that speeds were reduced by a mean speed of 2.8 mph at the display location and 0.8 mph reduction 0.5 miles downstream (34). However, there was a notable decrease in the percent of motorists traveling above the posted speed limit, decreasing from

67 percent to 36 percent after implementation. McCoy and Pesti, 2000, recorded similar mean speed reductions and substantial reduction in percent of motorists exceeding the speed limit (35). Maze, et al, 2000, noted a small decrease in mean speeds, but the decrease was not statistically significant (36). Fontaine, et al, 2000, states that on average, speed displays decrease traffic speeds around five miles per hour, while other speed reduction measures decreased speeds between 1-4 mph: rumble strips 1.5 to 4 mph (Figure 3)and drone radar about 1 mph (37).

Figure 3. Traversable Rumble Strips (38)

A common opinion in the literature is that a speed display trailer conveys a novelty effect in that it reduces motorist speeds the first time they approach the display, but as the motorist traverses the location more often they become familiar with the display and ignore it. The duration of the previously mentioned studies did not occur for longer than one week. McCoy and Pesti, 2001, performed another study that lasted five weeks to test the validity of a novelty effect (39). The study showed a three mph reduction in speed during the first week and this remained constant throughout the duration of the five-week study.

Variable speed limits through work zones is a method to decrease speeds where workers are located but allows motorists to increase to higher speeds through other areas of the work zone. Instead of having a constant speed limit throughout the work zone, an STA can vary the speed limit based on conditions such as traffic flow, traffic speed, weather, and the nature and location of roadwork, shown in Figure 4. This encourages drivers to slow to a safe speed to avoid having to abruptly hit the brakes or make an evasive maneuver into the work zone or shoulder. Variable speed limits also increase the credibility of speed limits by instructing vehicles to slow down when needed and return to a normal speed when conditions improve (1).

A similar technique to a variable speed limit is Michigan Department of Transportation's "Where Workers Present 45" work zone speed limit policy, implemented in 2006. The Michigan Department of Transportation's Guidelines to Establish Speed Limits in Work Zones describes the policy and outlines the work zone speed limit procedures for six conditions for typical applications and location of work (40). The policy states that there is a 10 mile per hour maximum speed limit reduction through a work zone and the utilization of a 45 mph speed limit where workers are present. This is identified on the facility through a "Where Workers Present 45" sign.

Mark Bush of the Michigan Department of Transportation indicated that one year speed studies, since implementation, show greatly reduced speed differentials (41). The crash rates have decreased in total crashes, injury crashes and fatal crashes from 2005 to 2006. The reductions of each crash type are shown below (41):

- Work Zone Crashes: 20.3 percent
- Work Zone Injuries: 19.9 percent
- Work Zone Fatalities: 10 percent

Figure 4. Variable Speed Limit (42)

2.6 Use of ITS Technologies to Divert Traffic or Differ Trips to Less Congested Times

The objectives of Intelligent Transportation Systems (ITS) are to improve the safety and mobility of vehicles through or around a work zone using technology to provide motorists accurate and timely information (33). ITS encompasses the entire process of collecting traffic data, dissemination of information, and all included components. Another term for this system when used in work zones is a “Smart Work Zone.” Traffic data is collected through various methods, such as closed circuit television, inductive loops, radar, microwave or other vehicle detectors. A computer then processes the traffic data to determine delay and alternative route information to be disseminated to motorists. The potential benefits of using ITS in work zones include better informed motorists, improved mobility, improved safety, reduced speeding violations, and better coordination with other agencies (43).

Many different ITS tools are available to enhance safety and mobility through and around a work zone. ITS is typically used in the following applications: traffic monitoring and management, traveler information, incident management, tracking and evaluation of contract incentives, worker protection and speed management and enforcement (44). Examples of ITS tools to disseminate information include dynamic message signs (DMS), the Internet, pager alerts, cell-phone text messages, e-mail alerts, highway advisory radio, and the 511 traveler information service. As an example, the Michigan Department of Transportation realized several benefits after utilizing a mobile traffic monitoring system with a full road closure on I-496. The benefits included a reduced construction time from two seasons to one, a quick identification and response to incidents, real-time information dissemination to problem areas and many local agencies were able to observe conditions so communication was improved (43).

Several traveler surveys have been conducted to determine the percent of motorists that changed their route because of the ITS information they received. At a work zone on I-75 near Dayton, Ohio, Zwahlen and Russ reported that nearly 52 percent of the motorists changed their route "a few times", while only about 20 percent changed their route "quite often" (45). Bushman and Berthelot reported a higher percentage of motorists altering their routes, 85 percent "at least once" and 73 percent "sometimes" or "often" (46). Other surveys indicated that 78 percent of the motorists changed their route in a Santa Clarita, California, work zone (47) and 51 percent changed their route due to a work zone on I-94 near Minneapolis, Minnesota (48). The results of these surveys are examples that many motorists pay attention to the DMSs and make a route decision based on the provided information.

2.6.1 Dynamic Message Signs

Dynamic message signs (DMS) are used to display real-time traffic conditions and other information to enroute motorists. The messages may inform motorists of upstream traffic conditions and suggest the use of alternative routes or a specific alternate route. Usually, the signs are placed at or prior to locations that provide access to an alternative route so the motorist can make an informed decision on which route to travel. One of the benefits of dynamic message signs is that the messages may be changed as needed to reflect variable traffic conditions and changes within the work zone. The signs are linked wirelessly to a variety of possible locations, such as a traffic management center, computers used on site, or other agencies that dictate the messages used. Signs that will display more of a static message, one that will not change often through the duration, can be programmed on-site through the sign's keypad, if applicable. This could be used when announcing an upcoming lane closure or construction zone, allowing a motorist to plan ahead and determine possible alternate routes or travel times. Another benefit is the ability for the signs to provide multiple phases of text. This allows for longer and more descriptive messages than that of a static sign.

In the United States, most DMSs are located on trailers on the roadway shoulder or on permanent overhead fixtures, both shown in Figure 5. Portable DMSs can be placed every few miles, as necessary, to provide continuous, updated information through the work zone. The fixed signs are usually placed before an interchange with another high-speed facility, thus can be utilized when informing motorists that an alternate route may be desired. The Netherlands uses portable sign gantries to inform motorists of upstream work zone traffic conditions. Figure 5 also displays an example of this type of sign. The signs are on trailers, with an attached attenuator, and set up on the side of the road or shoulder and the gantry is swung into place over the lanes. The sign sits about five meters above the roadway. The benefit of these portable signs is that they are easy to install, taking about 15 minutes, traffic does not need to be shifted or stopped during installation, and they are visible at a distance of over one half mile (49).

Figure 5. Dynamic Message Signs: Portable, Fixed Overhead (50) and Portable Sign Gantry (49)

2.6.2 Travel Time and Delay Estimation Systems

A travel time and delay estimation system uses real-time traffic data and computer software to predict the current travel time on a section of roadway. In addition to informing motorists of downstream travel times, STAs can use the collected data to understand volume trends and peak periods through and around the work zone. This can be used to better schedule lane closures during periods where the likelihood of delays is reduced. As an example, the systems used by the Maryland State Highway Administration are either microwave traffic sensors or video image recognition along the section of roadway being monitored to collect traffic data (33). The microwave sensor data is sent to the computer that calculates the current travel times, based on the speed and volume data. The video image system tracks individual vehicles between two points.

Utilizing an Internet website that provides pre-trip traffic information is a technique used to provide motorists with current information to make informed decisions on route selection and time to begin a trip. An example of an Internet based travel time estimation system is from the Georgia Department of Transportation, Navigator, shown in Figure 6. Travelers are able to pick two points and the system gives the distance, estimated travel time and travel speed. Because the travel times are based on monitored traffic conditions, the estimated travel times reflect traffic congestion created by a work zone. If travel times are deemed unacceptable to a motorist, the person may choose an alternate route, which also reduces the demand on the congested route. The public can also look on an agency’s website to find a historical database of typical travel times during certain times of the day (33).

Travel times may also be disseminated to motorists using or approaching a facility where the driver can decide if the delay is tolerable or if an alternate route should be used. DMSs display the travel times, similar those shown in the previous section. The nature of the message may vary. Two examples of DMS messages include the travel time through a work zone or the typical delay a motorist could expect when traversing a work zone, both shown in Figure 7. Through a European scanning tour sponsored by the FHWA, it was found that Scotland and France typically use DMSs to display the duration of the delay (49).

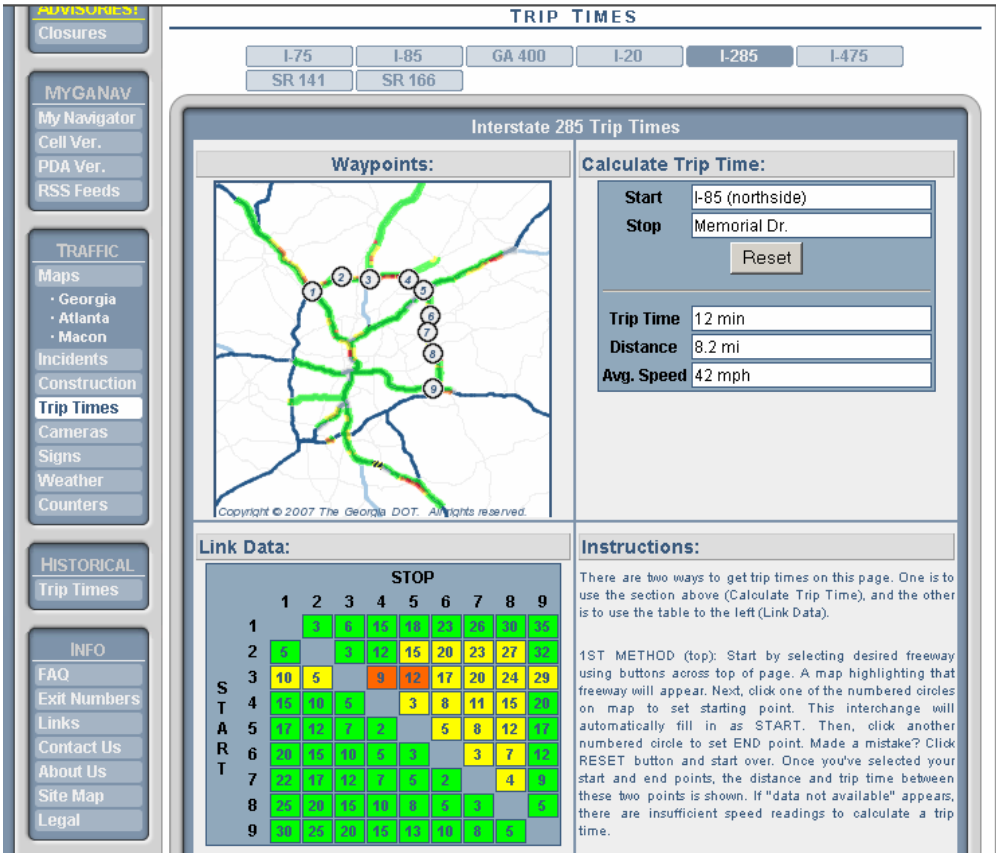

Figure 6. Navigator: Georgia DOT Trip Time Estimation System (51)

Figure 7. Travel Time and Delay Estimation Displays (52)

An example of an extensive travel time estimation system is a Real Time Traffic Control System used to help reduce congestion during the reconstruction of the I-55 Lake Springfield Bridge in Illinois (53). The system consisted of DMSs, portable traffic sensors, and portable closed-circuit television cameras linked to a central workstation. The sensors collected information on a traffic queue, if present, and the system server calculates the volume and traffic speeds. The information was then placed within preset threshold limits and the necessary messages were displayed on the DMSs, as shown in Figure 8. The automated system rarely needed human intervention. The Illinois Department of Transportation reported no significant traffic backups for the duration of the project. This may have been due to the 17 DMSs placed upstream, up to 40 miles, of the bridge in both directions.

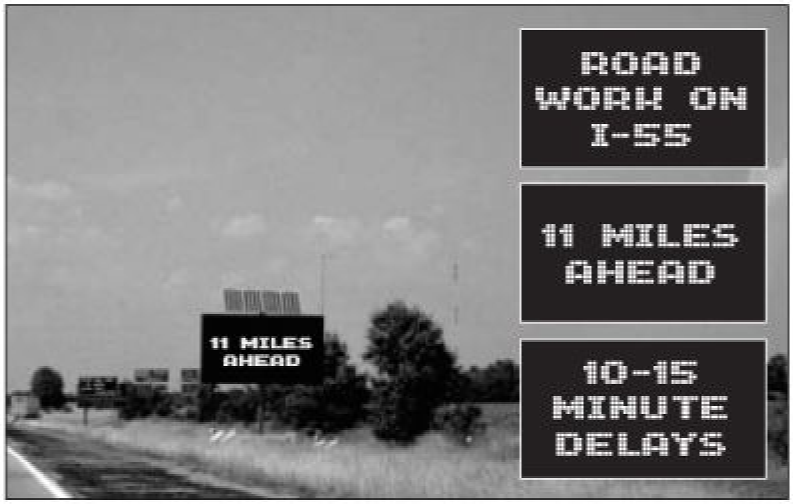

Figure 8. Example of a Three-Phase Message on I-55 Lake Springfield Bridge (53)

2.6.3 Advanced Speed Information System

Another application of Intelligent Transportation Systems is an advanced speed information system. The objective of displaying an advanced speed condition of downstream traffic is to alert the motorists of possible reduced speeds, which can potentially help reduce vehicle speed differentials and the probability of rear-end collisions. A motorist can change their trip route based on speed information, thus reducing demand at the congested location. Multiple DMSs can be placed throughout and upstream of the work zone. The Maryland Stat Highway Association provides examples of messages displayed on the DMSs for varying downstream speeds (33).

- Free Flow Speed:
  - "Speed Limit 65 mph";
- Congested conditions with speeds ranging from 30 to 50 mph:
  - "Reduce Speed" and "Speed Ahead XX MPH";
- Heavy congestion with speeds ranging from 0 to 30 mph:
  - "Traffic Backup Ahead" and "Stay Alert"

Pesti, et al., evaluated the effectiveness of a work zone speed advisory system on Interstate 680 in Omaha, Nebraska, in 2002 (54). The authors concluded that the peak period volumes did not significantly decrease and vehicle diversion did not significantly increase from an advanced speed information system. However, the authors noted that the system may be more effective during higher traffic demand and congested conditions. Another component of the evaluation was a motorist survey. The survey respondents indicated that they felt the speed advisory was useful and the messages were accurate. However, when asked what type of information they would like in order to decide if they should take an alternate route, 51 percent indicated downstream traffic speed while 69 percent indicated they would like to know the downstream travel time.

Intellizone is a commercial product provided by Highway Information Systems that uses microwave detectors to record traffic speed, volume and occupancy across all lanes and computes a “decision speed” that is a volume-weighted average of speeds over three minute spans (55). This information is displayed on DMSs as 10 mph ranges when speeds are between 20 and 50 mph. When observed speeds are below 20 mph, the DMS displays “stopped traffic” warning and when speeds are greater than 50 mph, the sign is blank. Horowitz and Notbohm found through a study of the system on US 41 near Green Bay, Wisconsin, that the calculated “decision speed” was often an inaccurate estimation of the speeds when there was appreciable queuing ahead of the work zone or where adjacent lanes had significantly different speeds. The speed did not correlate with the actual delay experienced by the motorists. Overall, though, the drivers felt that signs were accurate of work zone speeds and the authors thought this system was an acceptable alternative to Travel Time Prediction Systems.

Figure 9. Two Phase Message Display from Intellizone System (55)

2.6.4 Traffic Conditions on the Internet

The data collected by traffic surveillance technologies can also be used to provide real-time traffic conditions on a project specific or agency web site. Traffic conditions on the Internet is an effective strategy to inform motorists planning to make a trip of current traffic conditions. Project web sites can also identify alternate routes on the map to help plan a trip from one location to another to avoid the congested work zone. Many STAs have real-time updates concerning incidents, work zones, traffic conditions, and road conditions. Figure 14 displays an example of the system in place for Des Moines, Iowa. The left screenshot is Iowa Department of Transportation’s 511 Traveler Information website featuring the Des Moines metro area. Each icon will display embedded information on the type of alert when the mouse is passed over it. The right screenshot is of the traffic cameras that allow the public and traffic management personnel to view facility conditions. By utilizing the current technology in place, a motorist would be able to view the current work zones and traffic conditions in and around the work zone to better plan a trip.

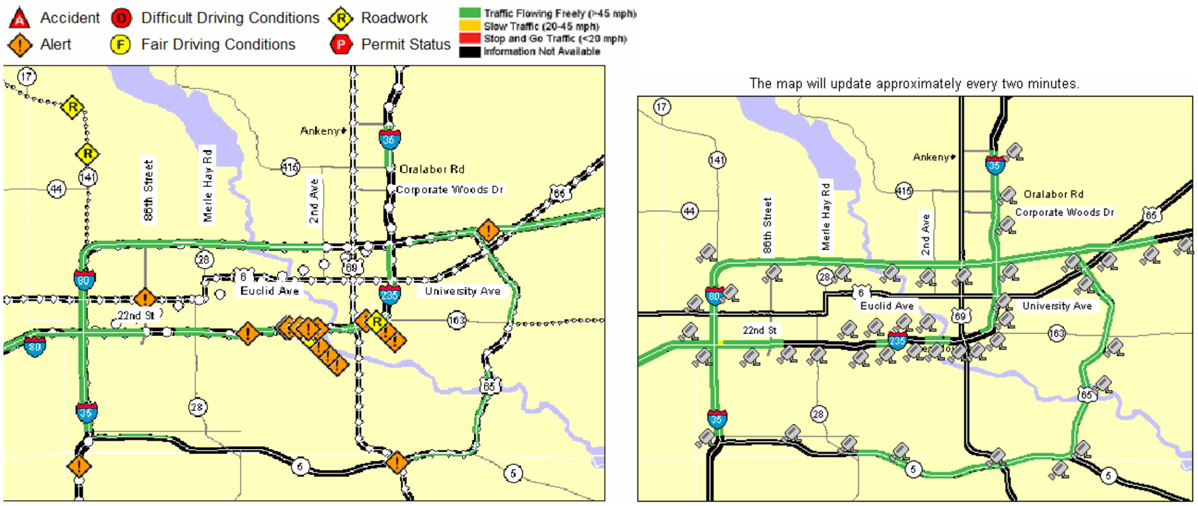

Figure 10. Des Moines Metro Area Travel Information and Camera Locations, Iowa DOT (56)

2.7 Narrowed Lanes through Work Zones to Maintain Same Number of Lanes

State Transportation Agencies may choose to maintain a certain level of mobility through a work zone by using narrower travel lanes to maintain the same number of lanes during construction as there were before. STAs utilize this strategy to maintain the same number of lanes through a work zone and/or as a speed reduction measure. A narrower lane encourages drivers to slow down and pay attention. A study performed by the Texas Transportation Institute in 1984 evaluated two lane widths, 12.5 ft. and 11.5 ft. as a speed reduction measure (57). Cones were selected as the narrowing devices on the freeway and urban arterial sites. Speed reductions were observed between 0 and 8 mph with the greater reductions on the 11.5 ft. wide lanes. However, the speed reductions were not significant when trying to reduce speeds and the speed variance increased. Decreased speeds reduce lane capacity and increased speed variance can be a safety issue.

Several agencies currently utilize narrowed lanes through work zones in order to maintain the same number of lanes. Caltrans is one the STAs that suggests the use of narrower lane widths to maintain the same number of lanes through a work zone as available during normal conditions (58). Several examples are available in Europe, specifically from Scotland, Belgium and France, where narrowing of lanes is the norm in work zones. In Scotland, lanes are reduced from 12 ft wide to about 9.8 ft or 8.2 ft in work zones. In Belgium, work zones usually consist of 9.8 ft wide lanes that are open to all vehicles and possibly 8.2 ft lanes that are restricted to automobiles only. The French Highway Agency reduces its lanes from 11.5 ft wide to 8.2 ft in work zones (49). Truck travel can be maintained through work zones with narrower lanes by keeping one lane at a wider dimension and restricting trucks to that lane.

While the number of open lanes remains the same, the reduction in lane width causes a reduction in lane capacity. Drivers will reduce their speed in response to the reduction of lateral clearance and having to drive closer to other vehicles or objects than they normally desire. The capacity reduction is especially noticeable when the narrowed lanes have concrete barriers or traffic control devices (barriers, cones, etc.) near the travel lane. Through this narrowed section, the driver will slow down and shy away from the barrier and towards the centerline of a lane. Ressel, 1991, found that for traffic with passenger cars only, lane reductions from 11-ft widths to 10.5 or 10-ft lanes increased headways by about 10 percent. A reduction to 9-ft travel lanes showed increased headways by an additional six percent. The additional headway percentages represent a nine and 14 percent drops in capacity (59). Figure 11 illustrates a capacity reduction due to decreased lane widths and lateral clearance between the vehicle and concrete barrier. Because vehicles are traveling near the centerline of the two lanes, it is difficult for two vehicles to travel alongside each other.

Figure 11. Effects of Narrowed Lane Widths and Lateral Clearance Reductions (8)

2.8 Traffic Simulation and Analysis Tools

Traffic simulation and analysis tools are a valuable part of the project planning process. The tools allow agencies to measure traffic impacts from lane closures and analyze work safety and mobility aspects of various work zone configuration alternatives to identify the best possible configuration. This includes analysis of the work zone and traffic impacts on the surrounding network, especially if alternative routes and modes of travel are utilized. Common output data that facilitates the analysis includes expected work zone induced delays, queue lengths, and road user costs. From this data, STAs can compare several alternatives in work zone configuration and project staging to minimize road user costs

The methods of analyzing and simulating work zone impacts vary significantly by the extent and means of simulation. Generally, simulation modeling techniques can be categorized into three dimensions (9):

1. Type of queuing model used
2. Traffic treatment
    - Microscopic: vehicles are individual entities
    - Macroscopic: traffic is treated as an individual flow
3. Network capabilities

- o Model distributes trips along paths inside network based on internal algorithms
- o Modeler distributes trips inside network by hand

Several programs are available to analyze the impact of the work zone to assist in the development of alternative routes, project staging, and work limitations. Table 4 displays examples of simulation and analysis tools used by state agencies and consulting firms (list includes those that may be more common).

Table 4. Examples of Microscopic Simulation and Deterministic Queuing Tools

Microscopic Simulation Tools		Macroscopic Models
With Network Trip Distribution Capabilities	**Without Network Trip Distribution Capabilities**	**Deterministic Queuing Tools**
• INTEGRATION • SMARTEST • AIMSUN • DRACULA • HUTSIM • Paramics • MITSIM • VISSIM	• CORSIM • FRESIM • SimTraffic/Synchro	• Highway Capacity Manual • QuickZone • QUEWZ

Edara performed a survey in December 2005 and January 2006 to identify what tools STAs are currently utilizing to assess work zone traffic impacts (60). Table 5 summarizes the survey results from 19 respondents combined with the results of a simulation and analysis tool literature of search of 10 STAs by Edara (60). Each STA respondent in the survey and from the literature review may have indicated more than one tool in the survey. The table shows the variety of tools STAs use and that there is not one standard tool.

Table 5. Summary of STA Responses about Work Zone Traffic Impacts Assessment Tools

Tools	Totals
Highway Capacity Spreadsheets	17
CORSIM	6
SimTraffic/Synchro	6
QUEWZ	6
QuickZone	8
MINUTP	1
DELAY	1
TRIPS	1
TRANPLAN	1
Do not use	2
In development	2

2.8.1 Deterministic Queuing Models

The Highway Capacity Manual defines a deterministic model as “a mathematical model that is not subject to randomness. The result of one analysis can be repeated with certainty” (8, p. 5-5). This model assumes that when the vehicle arrival rate exceeds the available capacity, the excess vehicles are stored in a queue upstream of the lane closure or capacity reduction location. One issue with a deterministic queuing model is that it does not account for the behavior of queued traffic upstream of the lane closure. The model estimates the queue at a single point and in essence stacks vehicles vertically instead of horizontally across the roadway (61).

Highway Capacity Manual analysis is a deterministic queuing tool. The Definition of Capacity, section 2.1, describes the components and procedures for work zone capacity determination (8). Using this type of analysis, computer programs have been developed to simulate traffic impacts created by a work zone. A spreadsheet-based tool often utilizes Highway Capacity Manual equations in queue and delay calculations. This tool only requires minimal input and is used to estimate delay and queue lengths, often agency specific to account for localized factors. The simplicity of the spreadsheets is attractive when only estimates of the potential queues, however, the analysis is limited to that location and network level impacts is beyond the spreadsheets capabilities.

QuickZone is a traffic analysis tool developed by the Federal Highway Administration to estimate work zone delays. The software is a Microsoft based application suitable for urban and interurban corridor analysis. QuickZone can quantify corridor delay resulting from capacity decreases in the work zone, identify delay impacts of alternative project phasing plans, do a tradeoff analysis between construction costs and delay costs and examine the impacts of construction staging by location along mainline, time-of-day, and season (62). One benefit of this program is that it is a network model, allowing the analysis of network level scenarios where traffic is diverted to alternative routes. However, traffic distribution across a network is done by hand which requires high data input. The software can also perform an assessment of travel demand measures and other delay mitigation strategies, which allows the establishment of work completion incentives (63). The program utilizes a spreadsheet format where STAs input the traffic data and customize the simulation to represent conditions in the respective state. Through the queue and delay estimation analysis, QuickZone accounts for traveler response to prevailing traffic conditions, such as: route changes, peak spreading, mode shifts, and trip losses.

On a resurfacing project on I-80 in Pennsylvania, the Pennsylvania Department of Transportation (PENNDOT) used QuickZone to model different work zone configurations before implementation. PENNDOT was able to select work zone configurations and construction schedules that met the traffic mobility and construction needs for the project. Based on previous, similar projects, PENNDOT received fewer complaints for this project and the length of time motorists experience delays in the work zone (62).

Another product that applies a deterministic queuing model is the Queue and User Cost Evaluation of Work Zones (QUEWZ) and its derivative models QUEWZ3, QUEWZ-85, QUEWZ-92, and QUEWZ-98. The Texas Transportation Instituted developed these models for estimating traffic impacts of work zone lane closures. Work zone capacity is determined through the HCM calculations and uses a diversion algorithm to adjust traffic demand based on motorists that may use an alternate route. However, this algorithm is based on observations in Texas where the freeways have parallel frontage roads, so it is not necessarily applicable to all freeway locations (60).

2.8.2 Microscopic Simulation Programs

Another method to measure network impacts of a work zone is the use of microscopic simulation tools. One issue with these simulation programs is that they need to be calibrated and validated to produce realistic results. Microscopic simulation programs can be either with or without network trip distribution capabilities. Those with network trip distribution capabilities have dynamic assignment capabilities. These models are ideal when analyzing network impacts of a work zone closure. Numerous microscopic simulation programs are available. As an example, in 1997 researchers for SMARTEST identified 56 microscopic traffic simulation packages and evaluated 32 of these (64).

The other microscopic simulation programs do not have network trip distribution capabilities. This type of simulation is based on the car-following and lane-change algorithms utilized by individual vehicles that are assigned properties to move through the traffic stream. Common microscopic simulation programs without network trip distribution capabilities include CORSIM and SimTraffic. CORSIM is part of the Federal Highway Administration's Synchro software package and includes FRESIM, which is the freeway simulator in CORSIM. While these programs are less user-intensive, as fewer user inputs are required and require less expertise to use, they do not have the capabilities to distribute trips throughout the network independently of the user's input. Therefore, to create the network impacts of a work zone, the facility characteristics need to be manually inputted into the program and do not model dynamic impacts of a complex network. In an attempt to overcome these issues, Anderson and Souleyrette integrated CORSIM and Tranplan (65). Tranplan is a regional travel demand model and includes a macroscopic model (a gravity model) that distributes trips throughout the network based on linked travel times. CORSIM and Tranplan interact with each other to converge travel times to a constant volume. Initially, travel times are estimated using CORSIM and fed into Tranplan where the trips are redistributed on the network, based on the CORSIM travel times. Then, new travel times are calculated in CORSIM based on this new trip distribution.

2.8.3 Traffic Analysis and Simulation Tool Analyses

A couple studies have been performed to try to determine traffic flow analysis tools that most accurately estimate actual field conditions. Schnell et al. evaluated Highway Capacity Software (HCS), Synchro, CORSIM, NetSim, QUEWZ 92 and a spreadsheet developed by the Ohio Department of Transportation on four work zones on multilane freeways in Ohio (66). QUEWZ 92 was the found to estimate the work zone capacity most accurately and the Ohio DOT spreadsheet provided the most realistic queue length estimates. However, the queue length estimates of the spreadsheet were most accurate only when an adequate work zone capacity value is used. The microscopic simulation programs could not be calibrated to show oversaturated conditions created by the work zone; thus under predicting queue lengths.

Another study compared QUEWZ 92, FRESIM and QuickZone and their ability to predict work zone traffic conditions on 11 freeway work zone locations in Illinois (67). Chitturi and Benekohal found that none of the models accurately estimated actual field conditions. In the analysis, QUEWZ 92 overestimated the capacity and underestimated queue lengths, with an average queue length error of 78 percent. FRESIM was found to overestimate speeds under queuing conditions and then either overestimating or underestimating queue lengths, with an average queue length error of 74 percent. QuickZone often under predicted queue lengths, but had the least average queue length with 32 percent.

Currently, the Smart Work Zone Deployment Initiative has a project being conducted by Eric Meyer on the *Comparison of Software Packages for Traffic Congestion and Delay Estimation* (68).

2.9 Demand Side Traffic Management Strategies

An effective way to reduce delays and queue lengths created by a work zone is to reduce peaking traffic volumes on a facility through travel demand management. Travel demand management strategies are a blend of individuals and organizations cooperating to reduce facility volumes during the peak periods (69). Together, the individuals and organizations promote a shift in typical travel behavior by providing alternatives through day-to-day choices about travel mode, departure time, and travel route, as well as trip reduction choices, and business and residence choices (70). Typical demand management strategies are currently applied in cities that have recurring congestion issues. Many of these strategies are also applicable to reduce volumes during lane closures on freeway facilities. Maze et al. (69) provided a list of demand management strategies, for illustrative purposes only:

- Incentives for changing time of travel
    - Encourage employer to permit flextime
    - Coordinate work zone activities with shift changes
    - Time of day reduced parking prices or prefer location
- Modal strategies
    - Guaranteed ride home when work demands make it impossible to leave work to meet transit service schedule
    - Reduced cost transit pass programs
    - Financing for shared vehicles
    - Parking price and location incentives for vehicles shared by employees
- Trip reduction strategies
    - Employers adoption of telecommuting program and policies
    - Compressed work week programs

A Transportation Management Association (TMA) is an organization common to metropolitan areas that assist in implementation of demand management strategies. TMAs are non-profit associations that collaborate with employees, employers, developers, political entities, chambers of commerce, state highway departments, planning commissions, and other transportation related agencies with the objective of reducing congestion and increasing system-wide mobility (69). A TMA assists in determining what strategies should be used based on current traffic trends and levels of funding in order to maximize the benefit. A TMA may also increase efforts or target a facility to help reduce volumes during construction activities that require a lane closure through the unique partnership of private and public entities.

As an example, the Iowa DOT and regional government partners (Des Moines Downtown Community Alliance, the Des Moines Area Metropolitan Planning Organization, and Metropolitan Transit Authority) created a TMA in Des Moines, Iowa, to help with demand management issues during reconstruction of I-235. The organization, "Avoidtherush" was created to reduce the demand on I-235 during peak commute times to and from downtown Des Moines (71). The program promotes car and van pooling programs, works with employers to reduce peak hour demands, provides information on roadway restrictions (closed off-ramps or on-ramps, lane closures, etc.), provides assistance with commuter tax benefit program information, and other programs aimed to reduce congestion on the I-235 corridor.

2.10 Improved Alternative Routes and Modes of Travel on Existing Facilities

Alternative routes are used to alleviate congested conditions on a roadway that has lost capacity due to lane closures. The traffic is detoured onto pre-determined routes to facilitate transportation around a work zone by a similar, parallel route. However, the available alternate routes may not have sufficient capacity to handle these new volumes and capacity improvements may be necessary to help reduce the anticipated congestion. Signalized intersections are a common cause of congestion, especially when large traffic volumes are diverted to the intersection. One of the methods to improve mobility through the intersection is to adjust the signal. If needed, STAs may place left-turn restrictions at critical intersections, especially when there is a shared left turn lane or storage capacity is not adequate to handle the queue in the left turn lane. Intersection widening and channelization may be desired to help separate turning and through vehicles.

If it is not feasible to add lanes to an alternate route, but increased capacity is necessary, techniques are available that utilize the existing infrastructure. Parking restrictions are an option during peak periods to gain an extra lane in the direction needed. Reversible lanes are a way to respond to directional peak volumes and alternating, one-way street pairs can help increase roadway capacity. Other improvements or implementations include police control at critical locations or intersections, resurfacing and other pavement repairs, signing and lighting improvements and public notification and information so the drivers know to allow for extra travel time or choose another alternate or destination (72,73).

Sometimes it is neither feasible nor cost-effective to improve an alternative route, but utilizing demand management strategies that shift motorists to public transportation may effectively remove vehicles from the facility. As an example, the Delaware Department of Transportation advertised during the reconstruction of I-95 in Wilmington that one full bus is equivalent to removing 45 vehicles from the road (74). However, when demand management strategies are used to shift large numbers of motorists from their vehicles to public transit, the current transit infrastructure may not be capable of efficiently transporting the proposed influx of riders in a timely manner. Therefore, infrastructure improvements may be needed to handle an increase in transit ridership, such as larger park and ride lots, passenger terminals, bus stop enclosures and new or expanded commuter rail lines.

Increased route service and alterations of route characteristics are strategies to adjust transit service to meet demands and increase capacity. This could include more direct routes downtown (or other large employment centers) with fewer stops or an increase in bus or train arrival frequency. Reduced transit fares and reduced fares for parking at transit stations may promote and encourage increased ridership (14). With increased ridership to a location, such as downtown, it may be necessary to create or improve mobility in these locations, such as a shuttle service for people that are now downtown without a vehicle. Again, during the I-95 reconstruction project, two new bus routes, called "Expresso," were added acting as express routes from the perimeter of the project into downtown with only two stops along the route (74). Ridership was 1648 commuters per month on average. The opening of a commuter rail station along the Amtrak northeast corridor was also coordinated with the beginning of the project. Rail ridership was encouraged by eliminating parking fees at this station.

2.11 Improved Pre-Construction Traveler Information

Providing project information to the public prior to the start of a roadway project is a proactive measure to reduce congestion through a work zone by increasing project awareness and assist travelers in making informed decisions about future trips and routes. Examples of traveler information mediums include direct mailings, door-to-door flyers, internet information, project information booths at events or high traffic locations, informational meetings with businesses, personal telephone calls, radio and newspaper ads, media coverage, and e-mails. The information provided may include general project details such as a timeline, current or planned work activities, and alternate routes or modes of transportation. Often, agencies begin providing this information a few months ahead of construction commencing to allow ample time for alternative route decisions by motorists.

Another approach to create project awareness and include public input is through neighborhood or town meetings. This also helps the neighborhoods and those with an interest in the project become a part of the project because they are able to provide input on such things as staging, alternative routes, lane closure times, etc. These can begin many months or years before project initiation, in the project development and planning process, to gather public input about expectations of traffic control. Meetings closer to the project beginning can focus on education and answering the public's questions concerning project scheduling, detour routes, access, etc. During the project, updates can be provided by the same means of pre-project awareness techniques as deemed necessary and community meetings allow the public to provide input on traffic issues.

Previous research has evaluated work zone traveler information methods by measuring the effectiveness of the information medium and the likelihood a motorist would use this information for alternative route selection. Motorist or household surveys performed by the Massachusetts Highway Department (75), Minnesota DOT (76) and the Pennsylvania DOT (77) found that the most effective way to inform motorists of work zone issues is through three media communications: radio, television and newspaper. The surveys also indicated that advisory signs along the roadways prior to work commencing and newsletters were effective means of informing motorists. Saag, 1999, found evidence that supported the importance of project information and the ability of the public to change travel patterns when faced with a major work zone closure when they are given and understand the closure's impact (78). Saag found that "[e]ven when lane closures during construction are required, experience has shown that many predictions of dire adverse traffic conditions resulting from the closures did not materialize."

An example of extensive pre-construction traveler information is the Transportation Expansion (T-REX) Project in metro Denver, which includes building a light rail and reconstructing and adding capacity to freeway segments. Project information is available on the project website, www.trexproject.com (79). A 36-page T-REX Fact Book educates travelers on the components of the project in order to help them understand what is going to occur during construction. The project includes a T-REX Public Information team that travels to special events throughout metro Denver to inform and educate people in the area. People are able to request project update presentations from the information team. Another notable tool used to disseminate project update information is a bi-weekly e-mail that businesses and travelers can sign up to receive.

Public outreach began two years prior to project implementation for the I-95 rehabilitation project in Wilmington, Delaware. Similar methods used in the T-REX Project were used by the Delaware DOT (DelDOT) to increase awareness of the project, including: placing advertisements in local newspapers, holding outreach events and public informational meetings, and creating a "Survival Guide" which explained the project, when the project would occur and how a motorist should plan ahead (74). DelDOT also purchased a radio station prior to the project to provide traffic and travel information on a 24-hour basis for this and future projects. Another method used to institute awareness of the project to the public was the creation of a character named "Creep" that made public appearances. The public could also go online and play a game where they could try to "beat the creep" by taking alternate ramps or routes, allowing for extra travel time and using carpool or transit options.

2.12 Use of Nighttime Construction to Alleviate Congestion

Many freeway facilities have long, sustained periods of high traffic volumes during the daylight hours that prevent closing a lane without causing unacceptable congestion. Therefore, many STAs have chosen to utilize nighttime construction as an alternative scheduling technique. Generally, the two main reasons for conducting nighttime construction and maintenance operations are to (10):

- Allow work over a longer period of light traffic than is possible during the off peak daylight hours, and
- Decrease or eliminate the excessive traffic delays and congestion associated with a lane closure during daylight hours.

Through the review of literature, several STAs have guidelines for nighttime work zones. The relevant research also consisted of several documents discussing various aspects of nighttime work zones. Three NCHRP reports specifically address nighttime work zones:

- NCHRP Report 475: *A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance* (80)
- NCHRP Report 476: *Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction* (81)
- NCHRP Report 498: *Illumination Guidelines for Nighttime Highway Work* (82)

2.12.1 Advantages

The most significant benefit to utilizing nighttime construction schedules is the reduction in work zone induced road user costs. Instead of closing a lane during the daylight hours and creating traffic congestion, the peak periods can be avoided by implementing lane closures during the night. The placement of lane closures is typically allowed as soon as facility capacity, with the lane closures, can handle the demand.

Another benefit of nighttime construction is the longer continuous work periods between peak periods when compared to continuous work periods during daylight hours. When all lanes need to be open on a facility during the peak periods, a nighttime construction schedule provides a longer continuous work period than that of the allowable time between the morning peak and afternoon/evening peak. A longer continuous work period promotes improved productivity because more time is devoted to work activities between setup and removal of lane closure activities. The type of work needs to be conducive to allowing quick lane closure installation and removal to maximize work time and not hinder peak commute periods. A work zone requiring an extensive traffic control plan, with long setup and removal times may not be feasible for nighttime work. The decreases in road user costs and increased construction productivity may more than offset the possible increases in construction costs.

2.12.2 Safety Concerns

Worker and motorist safety are two concerns with nighttime work zones. The National Institute for Occupational Safety and Health (83,84) reports that of the 910 worker fatalities between 1992 and 2000, 95 occurred during twilight and darkness hours. Of those 95 worker fatalities, 37 were from a motorist's vehicle entering the work area and nine of those had an impaired driver. In 2000, there were 966 fatal crashes in work zones. Of the 966 fatal crashes, 458 occurred during the night, which represents 47 percent of the total fatal crashes in work zones (85). Sullivan examined seven sections of urban freeways in California in 1989 (86). The study concluded that the presence of nighttime construction activities was associated with an 87 percent increase in the crash rate. A 1978 study of seven states by the FHWA found that the percentage of total night crashes to total crashes remained constant for before and during work zone implementation (87).

There are many safety concerns with nighttime work zones. Bryden and Mace identify many nighttime construction safety concerns, such as higher motorist speeds, poor visibility, impaired drivers, greater speed differentials between vehicles, irresponsible worker and driver behavior, driver confusion and workspace intrusions, and traffic control that may not be suited for nighttime operations (80). Driver attentiveness is more likely to be less at night than during the daylight because drivers are more likely to be impaired by alcohol and fatigue. Poor visibility of a work zone also leads to safety concerns because it may violate a driver's expectation of what he/she will encounter. A survey conducted by Cottrell found that STA respondents felt that poor visibility was the most common safety problem within work zones (88). Many of these issues can be addressed through proper traffic control that reduces speeds and safely directs vehicles into the through lanes a safe distance from the work area. Proper visibility of the work zone, equipment within the work zone, and workers also provides safety benefits.

2.12.3 Other Issues

Various other issues arise that are unique to nighttime work. The productivity and quality of work should be accounted for when deciding if nighttime work will be implemented. NCHRP Report 475 states that reduced visibility and greater difficulty communicating with supervisors or technical support staff are two common problems with night work (80). Hancher and Taylor note the effects of night construction have on people that are not using the road, but near the work area (89). Noise and lighting may be a problem, especially in a residential area. Loud noises and light can disrupt household and community activity.

Another issue is the possible increase in agency costs for nighttime construction. Agency costs include the overtime and night-premium pay, possible longer construction duration, lighting expenses, added traffic control costs due to added reflective devices and warning lighting, and sometimes increased material and traffic maintenance costs (80). The cost differential between daytime and nighttime construction has been debated in the literature. Hinze and Carlisle, 1990, state that there is about a 10 percent average contract cost increase for nighttime work when compared to the same operation during daylight hours (90). However, Ellis and Kumar, 1993, state that in a study of Florida DOT projects, the mean construction costs were slightly lower for nighttime operations (91). Longer project durations would likely extend agency personnel costs, traffic control costs and lighting costs (90).

Lighting is an important component of night work. Not only does it provide light for the construction operation, but it is a major factor for overall work zone safety. The lighting should be intense enough to provide adequate lighting for work, yet angled correctly and dim enough to minimize glare for motorists and light pollution on the surrounding neighborhood (92). Glare can be discomforting and distracting to passing motorists and is often caused by improper height of light poles or lights that are angled into the driving lanes. NCHRP Report 498 provides a glare control checklist to help minimize glare imposed on motorists. This acts as a guideline for installation of lighting equipment; however, each project should be reviewed to determine the necessary requirements (82).

2.13 Use of Full Road Closures and Detour Routes to Reduce Total Construction Time

The objective of a full road closure is to reduce the overall road user costs by expediting the project duration (7). The project duration is reduced by allowing the contractor full access to the roadway and rerouting traffic to nearby facilities. Figure 12 is an example of a full closure and the maximized work area.

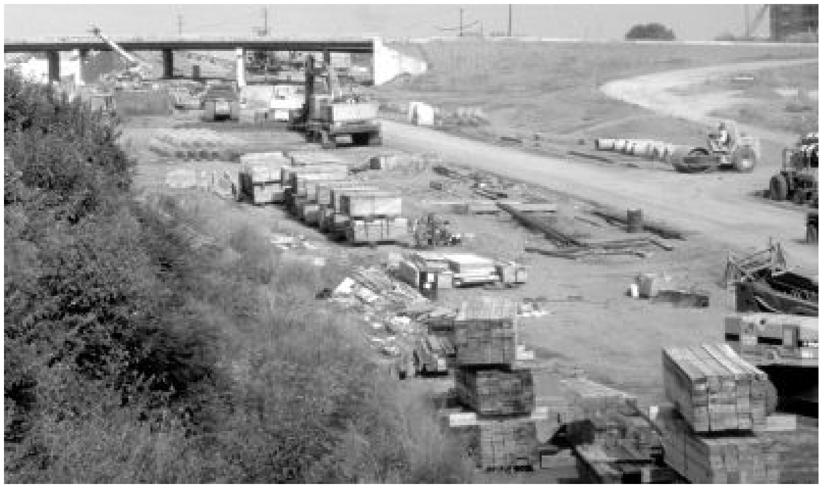

Figure 12. Example of Increased Available Workspace of a Full Road Closure (93)

Generally, an STA may use one of two closure types, a complete closure of all directions (shown in Figure 12) or a directional closure (shown in Figure 13). Full road closures are commonly used over three time durations: 1) exclusive weekend closures, 2) nighttime closures where the work is completed in one night or staged over multiple nights where all lanes are reopened during the day, and 3) closures that are continuous until project or task is complete (continuous week or weekend closures). Utilizing full closures at night and on weekends avoids peak weekday traffic, however, will lead to a longer project duration than a continuous road closure.

Figure 13. Caltrans I-710 Full Closure (94)

A variation of a full road closure is a limited capacity closure, which may be used in conjunction with one of the three full-closure durations. A limited capacity closure maintains a certain number of lanes in either direction but restricts a certain type of vehicle and/or access to these lanes. An example of this application is the I-75 rehabilitation in Detroit, Michigan (93). This highway carries a significant number of commercial vehicles to and from Detroit to the Canadian Border. Realizing this, it was determined that commercial vehicle traffic needed to use this facility during construction. Therefore, the Michigan DOT implemented a limited capacity closure, which included a directional closure with two lanes in contra flow on the other side. The two lanes of traffic was specifically left open for commercial vehicles and served as an express route because entry and exit ramps on the route were closed. This method reduced congestion on alternate routes by allowing for commercial traffic on I-75 and the speed and quality of work was improved because the contractor had exclusive use of one side of the highway.

Utilization of a full road closure requires sufficient alternate routes to allow motorists to reach their destinations when the facility they would have traversed is closed. Successful implementation of detour routes requires assistance from other strategies, such as alternative route improvements, pre-construction traveler information, demand management, and enroute motorist information disseminated via ITS. Effective designs of a detour route require that it should run parallel or near the closed road to avoid unreasonable travel distances. The designated detour route must have excess capacity to be able to handle the increased traffic without creating significant delays. If capacity is not sufficient, improvements to the alternative route may need to be considered. Another issue when selecting alternate routes is the pavement condition and design strength. It can be quite costly to repair the pavement on the alternative route if it was not designed for the increased volumes or certain types of vehicles, especially trucks (11).

Agencies may realize other benefits from the use of full road closures, especially productivity. Trucks delivering material will be unimpeded within the work zone by traffic and open lanes of traffic will not restrict equipment movement. There is the potential for a smoother roadway, because of the reduction in the number of joints and seams, as paving can be continuous on the project without needing to stop and open the lane up to traffic each morning or at the end of a weekend. All operations can be continuous, with 24-hour workdays, which eliminate stopping and starting measures.

The literature provides extensive documentation of full road closures and alternative route utilization. These projects utilized a variety of closures and detours to mitigate congestion. While all provided time reduction benefits, among others, the maximization of these benefits is dependent on the type of reconstruction/maintenance utilized for a particular project. To highlight successful practice of this method, the following documented case study summaries are presented.

M-10 Lodge Freeway, Detroit, Michigan, Fix Detroit 6 Program (95)

- <u>Full-Closure Information</u>: During the M-10 rehabilitation project the Michigan DOT used a bi-directional 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 that took place during the 2002 and 2003 construction seasons. The traffic in the direction of the closure was detoured off the freeway.

- Detour Information: Prior to determining the detour route, Michigan DOT (MDOT) personnel collected samples of actual travel times on alternate routes during peak hours and all alternative routes experienced acceptable delays on the weekends before the weekend closures of the Lodge Freeway. During the full-closures, the detour routes experienced minimal increased in travel delays, except for an exit ramp where people were attempting to avoid the prescribed detour. A final assessment of the project, after completion, indicated that even though MDOT recommended alternate routes on state roads, motorists would still divert to local roads and alternative within the dense urban roadway network. Even motorist seem quite able to navigate to their destination on surface streets, it was deem important to identify and provide specific alternate routes to accommodate diverted traffic volumes
- Estimated Duration Without Full-Closure: 6 months
- Actual Duration With Full Closure: 53 days

Figure 14. M-10 Lodge Freeway, Detroit, Michigan (95)

I-84 Banfield Freeway, Portland, Oregon (96)

- Full-Closure Information: The Oregon DOT used directional road closures over two consecutive weekends instead of using the traditional part-width night construction. Detours were used to divert the traffic in the direction of the full closure.
- Detour Information: A traffic model was used to estimate the impact of new traffic volumes on the detours and the actual traffic volumes were less than expected.
- Estimated Duration Without Full-Closure: 320 hours, or 32 nights for nighttime only work
- Actual Duration With Full Closure: 112 hours

I-95, Wilmington, Delaware (74)

- Full-Closure Information: The Delaware DOT chose a full closure for the 6.1 mile rehabilitation project because of an alternate route with sufficient capacity, I-495, and to expedite the construction time.

- Detour Route Information: The primary alternate route used was I-485, which is a six lane highway with existing traffic volumes only equaling 25 percent of and operating a level of service (LOS) of A or B, so I-495 had sufficient reserve capacity to absorb traffic diverted from I-95. During the project, the LOS on I-495 only dropped to C and majority of the delay occurred at interchanges.
- Estimated Duration Without Full-Closure: 2 years
- Actual Duration With Full Closure: 185 calendar days

I-285, between I-675 and I-20, Atlanta, Georgia (94)

- Full-Closure Information: The Georgia DOT (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 including media campaigns, mass mailings, community meetings, and dynamic signing. The contractors paved an average of eight miles 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 work site
- Detour Route Information: Detours were placed on I-75 and I-20 to bypass I-285 during closures
- Estimated Duration Without Full-Closure: 2 years
- Actual Duration With Full Closure: 12 weekends, six for each direction

2.14 Use of Temporary Pavements and Structures

The objective of the strategies temporary pavements and temporary structures is to maintain mobility through a work zone. STAs utilize temporary pavements to maintain the same number of lanes through a work zone and/or to maintain mobility through the existing right-of-way instead of using a detour route. The traffic is removed from the existing travel way to shoulders or temporary pavement adjacent to the existing surface. This mitigates the likely congestion from a lane closure and allows the contractor to have exclusive use to the work area. However, temporary pavements and structures have a few issues, including additional construction costs, time consuming to construct the pavements, additional right-of-way may need to be purchased, and can be an inefficient use of materials since the pavement will be removed after work is completed.

Utilizing existing shoulders as a travel lane is another option to maintain traffic on a facility through a work zone. While this can be a less costly alternative to using temporary pavement, there are a couple of issues regarding the use of shoulders. Utilizing a shoulder limits the area for vehicles to remove themselves out of the travel lane when involved in an incident. Shoulders are often close to guardrail, embankment or piers, which will cause traffic to shy away from the structures and reduce capacity. Also, existing shoulders may not be constructed to handle truck traffic. In order to accommodate the excess loads, the shoulders need to be rebuilt before being used as a travel lane (97). As an example, the Nebraska Department of Roads utilizes, depending on the phase of the project, either construction of a temporary lane in the median or the use of shoulders as a travel lane in order to maintain two lanes of traffic in each direction on the Interstate 80 six-lane reconstruction project (98).

Bridge reconstruction projects are good candidates for the use of temporary structures. A temporary structure may be utilized to maintain traffic in the same location while the original structure is closed to traffic. However, this is often expensive, an inefficient use of materials, requires additional time for design and construction and may require additional right-of-way. Prefabricated components can dramatically reduce the construction time and many agencies have standard designs for temporary structures (97). The Ohio Department of Transportation widens bridges and adds temporary pavement prior to construction to maintain at least two lanes open in each direction during construction (20).

2.15 Design/Build Construction

Design/build contracting is a project delivery method where one contract is let to a construction and design team that performs both the final design and building of the project. The design/build team generally receives the project when around 30 percent of the design is completed (69). However, design/build projects have been awarded to the design/build team anywhere from just after conceptual design to the 90 percent completion of design. The design/build team can then design the project to the best of their constructional capabilities.

The most beneficial aspect of this technique is the time savings it has on the total project duration. By allowing the design/build firm to utilize their resources to an optimal level, activities can be designed and performed to what the firm is capable of doing (99). Certain activities within the construction process can begin while other aspects are still in design, because much of the design phase and construction phase can overlap. Instead of having to wait for an activity to be completed that is not a predecessor for a separate activity, the crew can work on the independent activity. The use of lump-sum payment can eliminate many change orders and time extension requests due to design errors or project phasing from a separate design firm and traditional contracting techniques (100). Design/build also allows for fast track construction and efficient phasing which can reduce construction time. Having both the design and construction teams within the same agency, there is a streamlined path of communication between office and the field.

The California Department of Transportation (Caltrans) chooses to conduct most of their highway design in-house, by Caltrans staff. In order to utilize the design/build concept and its benefits, the concept is slightly modified to work within the constraint posed by the design being done predominantly in-house. The design process for Caltrans design/build projects does not involve a design consultant and is known as “design sequencing.” Design sequencing is similar to design/build in that when the design work is partially completed, 30 percent for Caltrans, a contractor is selected to begin construction. The design is continued and completed while construction is also taking place, thus reducing total work durations due to design and construction occurring simultaneously (69). Design sequencing allows the designer and contractor work together as a more cost effective means to conduct construction.

U.S. Highway 52 through Rochester, Minnesota is an urban freeway with complete access control. In the 1990s, the Minnesota DOT (Mn/DOT) completed the environmental documents for reconstruction of

Highway 52 and started the preliminary engineering and construction phasing concepts. The initial plan was to reconstruct the roadway over 11 years through a series of individual contracts, but was deemed unacceptable by the community. Having successfully experimented with design/build on an interchange and several miles of a rural highway, Mn/DOT officials decided to employ design/build on Highway 52 (the “Roc 52” project). After selecting a design/build team in 2002, the roadway was reconstructed and fully open for use in 2005 (three years in duration). The project was completed after only three years, instead of the originally planned 11 years of construction.

2.16 Lane Rental

Lane rental is a contracting technique in which the contractor is charged a fee to occupy lanes or shoulders during construction operations. The objective of this technique is to encourage the contractor, through a monetary incentive, to minimize the impacts on traffic flow by limiting the time that travel lanes and shoulders are closed. This encourages the contractor to use innovative construction techniques and project phasing (100). The technique can also reduce the number of detours for the traveling public.

Lane rental fees are based on the estimated cost of delay or inconvenience imposed on the motorists, derived from road user costs added to the costs incurred by the agency. Fee assessment can be based on work schedule (weekdays or weekends), work duration (hourly periods during the day), and lane location (left lane, center lane) (14). Lane rental fee amounts can vary depending on the time of day, location and extent to encourage lane closures during off-peak hours by providing a less expensive fee during this time. Typically, any lane obstruction that lasts more than 15 minutes is considered for fee assessment (100).

Another application of lane rental is in the A+B contracting technique. In this technique, lane rental can be applied through A+B*LRC, where A is the cost of the project and B is the total number of days subject to lane closures required to complete contract work and LRC is the lane rental cost (101). Therefore, during the bid process, the contractor determines the number of lane closures needed and includes it in the bid proposal.

2.17 A+B and A+B+C Contracting

A + B bidding is often referred to as cost plus time bidding, or bi-parameter bidding. The bid package incorporates a dollar amount (A) of the project work and a time amount (B), usually in calendar days that will be required to complete the project. The time portion of the bid can be multiplied by the calculated daily road user cost (RUC), thus described by the formula: Bid Price = A + B * RUC. The RUC term represents the worth of a road to motorists and is calculated for an individual location or segment (100). The winning bid has the lowest combined project cost and project time cost. The primary benefit of this technique is the potential time savings. Since part of the bid accounts for project duration, which affects traffic, the contractor wants to minimize this aspect to reduce the total bid amount. This type of bidding encourages contractors to actively manage their work schedule and to adopt innovative and aggressive scheduling and construction management processes in order to shorten the project duration and reduce public user costs.

A+B contracting is not appropriate for all projects. Generally, this technique is most beneficial on facilities that will exhibit unacceptable delay and congestion due to lane closures. This typically includes projects on high traffic urban facilities where there will be a disruption of traffic movement due to a lane reduction or work being done near the open travel lane. Projects with lengthy or extended detours will benefit by reducing the duration of the needed detour. This method encourages efficient staging techniques that could either reduce overall project duration, thus reducing the B portion of the bid. While total lane occupancy may not be shortened through this method, often the work is performed over longer periods during a day, thus utilizing nighttime and weekend work periods. Having lane closures at this time typically reduces the impact on road users when compared to lane closures during peak periods (14). Strong, et al. confirmed previous research that A+B contracts leads to shorter project durations and outside sources of conflict within the project should be minimized (102). However, it was also concluded that A+B contracts have the greatest value, compared to other contract types, when all relevant performance values factors are considered.

Another form of cost plus time bidding is adding a third component (C) that accounts for future rehabilitation, reconstruction and user-delay costs, therefore Bid Price = A + B + C (103). This method looks to the frequency and quickest time the road will need maintenance or rehabilitation based on materials and methods used in the project. Building a product that will need maintenance that is more frequent or quicker rehabilitation will increase the life-cycle costs and life-cycle user costs due to an increased number or duration of a lane closure(s) in the future. As an example, the Louisiana DOT used an A+B+C contract for a project on I-10 from U.S. 51 to the Reserve Relieve Canal, which was approximately four miles. To help distinguish what material was to be used, it was determined to use a C term in the bid. Of the five bids received, four were from hot-mix asphalt and one for PCC. The winning bid used hot mix asphalt and the life-cycle cost of the asphalt over a 30-year life was approximately $4.6 million (103). This component in the bid package allowed the DOT distinguish between the life cycle costs of hot mix asphalt and Portland cement concrete over a 30 year period, thus providing the greatest potential benefit for this facility during the analysis period.

2.18 Incentives/Disincentives to Reduce Construction Duration and Impacts

Incentives/disincentives may be included in a contract to help reduce project duration and traffic impacts, often in conjunction with other contracting techniques. An incentive/disincentive (I/D) clause encourages timely completion in which the contractor can receive a monetary incentive for completing the project or predetermined milestone on time without sacrificing quality and safety. Longer hours, multiple shifts during each day, increased number of workers on project, equipment, and separate schedules in different areas are examples of methods to facilitate timely project completion. If the project was completed after the deadline, the contractor has to pay a monetary penalty, which is part of the disincentive or liquidated damages portion of the contract. Road user costs of lane occupancy are usually the basis for incentive and disincentive amount determination. Often, an A+B contract includes an I/D provision which shifts the appropriate risk to the contractor while maximizing agency resources. In relation to reducing congestion, the advantages of using an

A+B with I/D bidding are the reduction of project time. The project will be bid with aggressive and innovative schedules to maximize the incentive potential for the contractor (100).

One form of an incentive clause is a no-excuse incentive. This gives the contractor a final date for completion of a phase or the entire project. The contractor receives an incentive if completed by this date and no incentive for completion after the set date. The no-excuse term means that the final date will not be changed regardless of interim issues, identified in the contract, which may delay construction. The no-excuse terms vary between agencies, but examples include inclement weather, change orders, overruns of quantities, utility delays or other delays not being valid reasons for late completion.

Numerous examples of the use of incentive/disincentive contracting methods to reduce total construction time are documented in the literature. Most, if not all, STAs use this sort of clause to promote efficient construction to reduce total duration, ranging from only a couple projects to many of the STA projects.

In 1998, a $120 million project to reconstruct the Route 4 and Route 17 interchange in New Jersey used incentives to expedite construction (104). The project duration was reduced from an estimated 30 months to 13 through the help of $7 million in time incentives. The original incentive included a $3.5 million incentive for completing the project by November 25, 2000. After six months, the project was considerably ahead of schedule and the contractor renegotiated the incentives with NJDOT. The renegotiated incentive included an additional $3.5 million if the interchange was complete, except for the final flyover, by the 1999 Christmas holiday. According to the New Jersey Department of Transportation, the contractor was working 80 to 100 people 12 hours per day, six or seven days a week.

STAs may also implement alternative incentives instead of monetary incentives. As an example, the Big I, I-25 and I-40 interchange, project in Albuquerque, New Mexico, the New Mexico DOT (NMDOT) had little money available for cash incentives. The NMDOT instead offered innovative incentives such as access to excess right-of-way. For the project, NMDOT purchased 21 acres, 4 acres of required right-of-way, for the project. The excess ROW was used as staging areas during construction. Because the contractor finished ahead of schedule, the contractor received the deed for the excess 17 acres along the project and several other tracts of land that was determined as excess to future highway needs from the NMDOT (94).

While many projects offer incentives based on total project duration, or until all lanes are reopened, some provide incentives for increments within the total project duration. In the I-95 rehabilitation project in Wilmington, Delaware, 24.4 lane miles of roadway was reconstructed. The Delaware DOT estimated that the user delay cost was approximately $88,000 per day for the maintenance of traffic plan they were using. The project was divided into four phases lasting about 30 to 50 days each. Each phase contained a $25,000 per day bonus or penalty for up to 10 days early or late completion. Therefore, for the entire project, the contractor had the possibility of earning a $1 million bonus or penalty depending on completion dates (105).

2.19 Interim Completion Dates and Liquidated Damages

Interim completion dates addresses concerns of local agencies, businesses, and motorists with regard to duration of certain segments of the project. Specific functional elements, such as a ramp, bridge, or intersection that has been taken out of service, can be specified for completion within a shorter period of time within the overall contract duration to be put into service sooner than other elements. This method provides the contractor with incentives or disincentives to expedite the completion of a specific portion of the contract, within a realistic timeframe. Two drawbacks to this method are possible increased costs and increased overall contract duration. Projects where the damages clearly outweigh the cost of added duration should be considered for interim completion dates to restore traffic on critical segments. Segments that have been identified as successful applications for this technique include: segments critical to commuters, segments to be completed by the beginning of a school year, and segments to be completed before peak shopping periods (106).

2.20 Literature Review Summary and Conclusions

The Federal Highway Administration, through their updated rule on work zone safety and mobility, has emphasized on maintaining adequate levels of mobility and safety through a work zone. Congestion mitigation strategies are effective methods to maintain the levels of safety and mobility expected by motorists by mitigating the impacts created by work zones. The common methods used by STAs to reduce congestion through a work zone include traffic management strategies, demand management strategies, design alternatives, alternative scheduling strategies, and alternative contracting and project delivery strategies. This chapter provides a description and review of the literature on many strategies that are widely used by STAs.

A review of the literature indicates that some congestion mitigation strategies have a great deal of literature consisting of case studies, technical research and evaluation, and documented examples of successful implementation. However, the literature for some strategies is not much more than a few sentences in a STA manual or other documents dealing with congestion mitigation. A few areas that the literature lacked information was the combinations of strategies that provide the greatest benefit for a specific type of project and strategies that failed to provide the expected benefits on projects. Furthermore, much of the literature dealt with work zones on urban Interstates and not rural Interstates. The gaps in the literature and research objectives are further discussed in Chapter 3.

CHAPTER 3 – PROBLEM STATEMENT

The focus of this research is to identify congestion mitigation strategies that state transportation agencies are currently using. As projects become more costly and funding is not sufficient to perform all desired projects, efficient STA management and good financial foresight is needed. The implementation of certain congestion mitigation strategies is often quite extensive and costly, depending on project characteristics and need to reduce congestion. Because many facilities are already congested, the risk to try a new strategy may not be worth the potential benefit. Similarly, the expense of trying a new strategy that may not provide the necessary benefits may also not be desired. STAs may also not utilize certain strategies because they lack knowledge about that strategy. Therefore, this research will identify many different issues to help STAs further reduce work zone congestion by providing information from other STAs' experiences and addressing the gaps in the literature. This research will assist STAs in managing their time and money resources when researching, identifying, and implementing strategies.

The literature review identified several gaps in the literature concerning work zone mobility, which are addressed in this research. One gap is the lack of literature describing the use of strategies on rural freeways. Further, there is a lack of literature describing some of the successful strategies implemented on urban freeways may not provide a benefit on rural freeways. Another gap in the literature is the discussion of what strategies would provide the most benefit for a project with a certain work intensity or duration. Many of the case studies highlight successful application of strategies; the literature does not mention strategies that have failed to meet congestion mitigation expectations. Finally, while many strategies are available to reduce or eliminate work zone congestion, documented experiences of strategy combinations are not prevalent in the literature.

As previously discussed, congestion mitigation strategies vary in usefulness based on project characteristics, such as type of work performed and facility location. This research will identify the differences in STA strategy selection based on different work intensity (reconstruction or resurfacing projects) and location (urban or rural setting). As an example, a large public awareness campaign is not necessary for freeway re-striping. While there is the benefit of public awareness about the striping, the cost of such a campaign would not make this a cost effective strategy. Another example would be the use of alternative routes. On a rural Interstate facility, detour route possibilities are often limited to two lane highways that detours traffic an unreasonable distance from the freeway. Urban facilities are often better suited to this strategy because an urban freeway likely has a parallel freeway or high speed/volume facility only a few miles away to handle traffic traveling longer distances. An alternate route is often not reasonable for a rural project, it has more benefit for an urban project, as conditions allow. While knowing what strategies are available is a beginning to effective congestion mitigation, being able to see and understand what other agencies have tried and their experiences is a next step in improving a STA's traffic management plans.

Other objectives of this research include identifying what strategies and possible combinations of strategies provide the greatest benefit based on various state transportation agency experience for different project types and location. There are three general components of strategy identification. The first component is to identify what strategies STAs are currently using to reduce congestion in and around work zones. Second, in order to learn from previous experiences, the past utilization of strategies will be identified and what the STAs' experiences were from this implementation. This includes those strategies that did not provide the benefits desired by the agency. Third, staff members at the agency will also have the opportunity to identify what strategies their agency is considering for future implementation and what strategies they believe should be considered in the future. This will provide insight to what strategies STAs are considering for the future and other agencies' experiences could be beneficial to these future considerations.

Another objective is to determine what states use for their work zone lane capacity values and if they utilize simulation programs to plan work zones. The research will determine if a work zone lane capacity has influence on the extent of strategies an STA would use. A relation between lane capacity values and strategies used can assist other STAs, with similar lane capacity values, in their strategy selection. The research will also determine if a more extensive work zone simulation analysis leads to a more extensive use of congestion mitigation strategies in the traffic control plans. Similarly, the research may indicate that utilizing work zone simulation tools may eliminate the use of strategies that provide minimal benefit.

The culmination of all research objectives will be recommendations to the Smart Work Zone Deployment Initiative for future research. This includes the fulfillment of the stated objectives to foster development of each STA's Safety and Mobility Policies. They will be able to view other STAs' experiences and determine areas they would like to research to benefit their policies. Utilizing the Smart Work Zone Deployment Initiative for future research fosters dissemination across states throughout the Midwest and provides a basis of consistency in similar traffic conditions.

CHAPTER 4 - METHODOLOGY

The purpose of this research is to assist State Transportation Agencies (STAs) in their selection of strategies for different project types and locations to reduce work zone congestion. In order to address the objectives identified in Chapter 3, a survey was developed to identify strategies STAs use to reduce or eliminate congestion in and around work zones. The survey consists of four different scenarios encompassing reconstruction and resurfacing projects occurring in both rural and urban locations. For each scenario, STA Engineers had the opportunity to identify strategies their agency would use for a project similar to the respective scenario. The questions focus on current practice, past experience, and future objectives or research of strategies the agency would like to use or do.

This chapter is presented in three sections. The first section is the survey components, including the predetermined list of work zone congestion mitigation strategies, four project scenarios, survey questions, and the survey review process. The second section describes the survey distribution process and identification of survey recipients. The final section identifies the methods of analysis of the survey information.

4.1 Survey Components

The survey consists of three components, the list of strategies, the scenarios and questions about each scenario. Each component is an integral part to the identification and analysis of what each STA is doing to mitigate work zone congestion.

4.1.1 Survey Strategies

Three questions in each survey scenario utilize a predetermined list of work zone congestion mitigation strategies to provide a consistent basis for comparison of strategy selection between STA respondents. The strategies selected in the predetermined list were those that appeared to have widespread use by agencies across the United States and represented all five strategy groups, shown in Table 6. Further discussion of the work zone congestion mitigation strategies is provided in the literature review.

4.1.2 Survey Scenarios

The scenarios developed for the survey include both a reconstruction project and resurfacing project for both an urban and rural facility. The objective of the reconstruction projects is to add capacity. The rural reconstruction project converts a four lane, median divided facility into a six lane median divided facility, three lanes in each direction. The urban reconstruction project reconstructs a six-lane facility into a barrier separated eight lane facility, four lanes in each direction. The current travel ways are adequate to maintain traffic through a work zone, but is part of the reconstruction and will be eventually replaced in the project. The duration of the lane closure(s) is several months, often utilizing the length of a construction season for only one direction or section of a multi-year project. A resurfacing or patching project is one that will resurface the current lanes

Table 6. Strategies Used in Survey

Traffic Management Strategies
• Smart Work Zones
• Dynamic Message Signs
• Travel Time and Delay Estimation System
• Advanced Speed Information System
• Traffic Conditions Displayed on Internet
• Narrowed Lanes
• Increased Incident Management Capabilities
• Increased Speed Enforcement
Demand Management Strategies
• Demand Side Traffic Management Strategies
• Alternative Route Improvements
• Improved Pre-Construction Traveler Information
• Mass Transit Improvements
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies
• Temporary Pavement
Alternative Project Scheduling Strategies
• Nighttime Construction Schedules
• Full Road Closures and Detour Routes
Alternative Contracting and Delivery Strategies to Accelerate Project Completion
• Design/build
• Lane Rental
• A+B and A+B+C Contracting
• Incentives/Disincentives to Reduce Construction Duration and Impacts
• Interim Completion Dates and Liquidated Damages

with an asphalt overlay. The current roadway is an asphalt wearing course that will be removed prior to overlay. The duration of the lane closure is most likely a couple of weeks, either continuous or intermittent to accommodate peak period traffic.

For the two rural Interstate projects, the location characteristics are similar to what the Iowa Department of Transportation would encounter when performing the activities on Interstate 80 between Davenport and Des Moines. The rural location is near an automated traffic recorder (ATR) location. High traffic volumes approach and exceed the Iowa DOT's work zone lane capacity for a single open lane, lane closure of 1,350 vehicles per hour per lane (vphpl) during the afternoons every day of the week, reaching the daily maximum hourly peak between 4-6 pm. Minimal commuter traffic is experienced at this location since it is along a rural segment of Interstate 80 between the Iowa City and Davenport urban areas There is the occurrence of peaks in traffic volumes due to events at the University of Iowa, especially during home football game Saturdays in the fall. The reconstruction project is most likely to coincide with football games because of the longer project duration. The resurfacing project is more flexible to avoid football weekends because resurfacing activities offer greater flexibility due to shorter lane occupancy durations. One unique characteristic of Interstate 80 is the high volumes of trucks. Thirty two percent of the volume at this location consists of trucks. Most traffic is likely to stay on the facility because alternate routes are distant; 60 to 80 miles out of the way travel. A summary of the characteristics for the urban location and the scenarios are displayed in Table 7.

Table 7. Summary of Rural Location Characteristics

Traffic Volume Characteristics and Issues with Congestion

- 36,000 AADT
- Minimal commuter traffic
- Volumes approach and exceed single lane capacity as afternoons progress (1350 vphpl)
- Volume spikes due to events at University of Iowa
- 32 percent trucks of total volume

Scenarios

- **Scenario 1. Rural Reconstruction Project**
    - Project Description: Reconstruct four lane Interstate to six lanes
    - Project Length: 10-15 miles
- **Scenario 2. Rural Resurfacing Project**
    - Project Description: Resurface four lane Interstate, one direction at a time
    - Project Length: 15 miles

For the urban Interstate projects, the location characteristics are similar to what the Iowa Department of Transportation would encounter when reconstructing or resurfacing a section of Interstate 235 in metropolitan Des Moines. The location selected is in the western suburbs of Des Moines, east of the Interstate 80 and 35 interchange. Commuter traffic is highly peaked, with directional volumes exceeding 1600 vphpl when all three lanes are open. The morning peak generally lasts two hours and has directional volumes that approach 2000 vphpl. Interstate 235 has a very low percentage of trucks, four percent of the total volume. Interstate 80 offers an alternative route for through traffic movements, but provides minimal benefit for commuters entering the Central Business District or commuters inside the urban core. Alternative route possibilities include arterials that run parallel to Interstate 235, but they do not have sufficient excess capacity to be used as a means for handling diverted traffic. A bus system is already in place to offer a mass transit option to and from downtown and the western suburbs. Stadiums, arenas and other event facilities are located downtown and may attract thousands of people in a short amount of time. Similarly, in the fall, the Interstate 235 is a major gateway to the Iowa State Fair that often draws over a million people in eleven days. Table 8 displays a summary of the characteristics for the urban location and the scenarios.

Table 8. Summary of Urban Location Characteristics

Traffic Volume Characteristics and Issues with Congestion

- 85,000 AADT
- High commuter traffic
- Volumes can range between 1600 and 1900 vphpl during peak periods
- Volume spikes due to events in downtown Des Moines
- 4 percent trucks of total volume

Scenarios

- **Scenario 3. Urban Reconstruction Project**
    - Project Description: Reconstruct urban Interstate
      6 lane facility to 8 lane facility by adding lane in each direction
    - Project Length: 5 miles
- **Scenario 4. Urban Resurfacing Project**
    - Project Description: Resurface four lane Interstate, one direction at a time
    - Project Length: 5 miles

4.1.3 Survey Questions

The survey questions were developed to determine the extent of STAs' work zone congestion mitigation strategy utilization for different projects. The questions focus on current practice, past experience, future strategy plans, and planning process components. An example of the survey instrument is presented in Appendix A. The questions are based on the following four topics:

- Work Zone Lane Capacities
- Work Zone Traffic Analysis
- Rural Scenarios
- Urban Scenarios

The first two questions are independent of the created scenarios. They are two components an agency may use to help determine the work zone strategies for a project. The first question allows the respondent to indicate if and what lane capacity values their agency uses in work zones. The second question allows the respondent to identify the tools their agency uses when analyzing work zone impacts on traffic during the project planning stages.

Work Zone Lane Capacities

- If your agency has an all inclusive work zone lane capacity that does not vary based on number of lanes open or closed, please enter the value in the following (vphpl):
- If your agency varies work zone lane capacity based on number of lanes open and closed, please enter the value in the following situations:
    - Three lanes open, one lane closed (vphpl)
    - Two lanes open, one lane closed (vphpl)
    - One lane open, one lane closed (vphpl)

Work Zone Traffic Analysis

- For work zone traffic management planning, does your agency use traffic simulation or highway capacity tools to analyze current traffic and expected work zone traffic conditions?

The questions dealing with the developed scenarios were categorized into three periods: current implementation, past experiences, and future strategy consideration. The first question in each period provides a predetermined list of strategies for the respondents to indicate what strategies their agency typically utilizes. For the past strategy experiences and future strategy implementation project questions, a follow-up question allows for short answer explanation by the respondent. The following questions were asked for all four scenarios.

Current Strategy Implementation

- Given the scenario, what congestion mitigation strategies would your State Transportation Agency typically use?

Past Strategy Implementation and Experiences

- Based on past experiences on similar projects, did any of the previously listed strategies not provide congestion mitigation benefits that were expected or acceptable to the agency?
- What work zone congestion mitigation strategies, if any, did your agency used to implement for a similar project but have since discontinued or replaced with other strategies?

Future Strategy Implementation

- Are there any strategies that your transportation agency has not typically utilized in similar rural reconstruction projects but is currently researching or looking to implementing for future projects?
- Are there any strategies that, in your opinion, should possibly be explored?

4.1.4 Survey Review Process

The survey went through an extensive review process. Several people were approached to provide input and review the survey, utilizing their experience in survey development and/or work zone congestion. The survey was reviewed by:

- Tom Maze – Iowa State University
- Kelly Strong – Iowa State University
- David Plazak – Iowa State University
- Kevin Heaslip – University of Florida (Post Doctoral Associate)
- Jerry Graham – Midwest Research Institute
- Mark Bortle – Iowa Department of Transportation
- Tom Nothbom – Wisconsin Department of Transportation
- Scott Stotlemeyer – Missouri Department of Transportation

4.2 Survey Distribution

The survey was distributed to all 50 State Transportation Agencies, encompassing a variety of positions within each agency. The following positions at the district and state level of each agency, as applicable to each respective agency, were identified as possible respondents to the survey:

- Project or Resident Engineers
- Traffic Engineers
- Operations and Management Engineers
- Any other Engineer that would have extensive knowledge of work zones

A variety of positions within an agency was chosen to obtain opinions from staff involved in different stages of a project on the benefits of each strategy that is implemented. The opinions may vary due to the exposure of the project conditions and characteristics, such as those that are in the field and observe the congestion first hand compared to someone that may only be a part of strategy selection and hears about the results through final reports or brief first hand experiences.

The survey was organized online and potential respondents were contacted via e-mail with a link to the survey website. The e-mail addresses of potential respondents were identified through multiple sources, including the following transportation committees:

- American Association of State Highway and Transportation Officials Highway Subcommittee on Systems Operations and Management
- American Association of State Highway and Transportation Officials Highway Subcommittee on Traffic Engineering
- Midwest Work Zone Roundtable

Other potential respondents were identified through a search of STA websites, recommendations from Center for Transportation Research and Education staff, contact with STA Engineers from previous projects, and referrals of those in the profession that are familiar with others that have knowledge of work zones.

4.3 Methods of Analysis

The analysis consists of seven components that address the objectives developed from the problem statement. Several methods of analysis are available to determine what strategies and combinations of strategies are best suited for various project locations and work intensity.

The first component of the analysis is determining what strategies STAs are currently using for four different project scenarios. This section displays the results for each scenario graphically, by strategy group and by frequency of response. The section also summarizes any comments provided by the respondents and any other strategies they indicated their agency may use on a similar project. The second component of the analysis uses the individual strategy responses for a comparison of strategies between scenarios by work intensity and project location. The next component of the research is the identification of STA past strategy experiences, regarding the predetermined list of strategies and other strategies the agency has utilized.

The fourth component is the analysis of strategy pairs provided by the STAs in their current implementation responses. This analysis consists of a strategy pair matrix and list of strategies that had frequent pairs in the responses. This analysis also identifies what strategies are paired with others frequently based on the strategy with the fewest total responses of the pair. This will identify what strategies STAs are frequently using if they use a certain strategy.

The next two components address the questions independent of the scenarios, work zone lane capacity values and traffic simulation and analysis tools used in the work zone planning process. The work zone lane capacity values are used to determine if there is a relationship between lane capacity values and the extent of strategy usage. Second, a list of work zone simulation and analysis tools is provided to provide insight of what STAs are currently using in the work zone planning process.

The final component is the identification of what strategies STAs are research or planning to utilize in the future. This component allows the respondents to provide their view of what strategies they would like to see considered for future implementation.

CHAPTER 5 – SURVEY ANALYSIS

Several objectives were identified in Chapter 3 to address gaps in the literature about work zone congestion mitigation strategies. This chapter provides the survey results and analysis of work zone congestion mitigation strategies identified by State Transportation Agencies (STAs). The purpose of this chapter is to address the gaps in the literature and assist STAs in their implementation of strategies to mitigate work zone induced congestion.

This chapter is presented in nine sections. Section 1 provides an overview of the survey respondents. Section 2 is the results of STAs' current strategy implementation in all four scenarios. Section 3 is the current implementation comparison of strategies between location and work intensity. Section 4 provides past experiences of STAs' strategy implementation. Section 5 consists of strategy combination matrices to determine strategy combinations that were frequently identified. Section 6 discusses the effects of lane capacity values may have on strategy selection. Section 7 discusses the STAs' current use of traffic simulation and planning tools to analyze the impact of work zones. Section 8 identifies strategies that STAs are research or planning to utilize in the future. Section 9 is the summary and conclusions of the analysis.

5.1 Survey Respondents

For this research, an e-mail was sent to Transportation Engineers at all 50 STAs in the United States with a link to a website with the survey. Forty-two surveys were completed online. The respondents were from at least 28 STAs, shown in Figure 15, and two respondents completed the survey anonymously. While the survey response was not as high as originally intended, those that responded provided great insight to what their agency does to reduce work zone congestion. Further, the representation of STAs, 28, provides a sufficient basis for comparison across the country.

One issue found when administering the survey was the lack of knowledge, or possible reluctance, of several potential respondents regarding what their agency does to reduce work zone congestion. This was particularly evident of many project managers and other district resident engineers. Several of the potential respondents contacted indicated that they lacked the knowledge to complete the survey and forwarded it to someone with more knowledge or experience. Because of this issue and the lack of surveys from both district and headquarters levels, this research did not accomplish an original objective of comparing responses from project managers and office personnel. It was also found that many STAs have Traffic Engineers at the District level and many Districts act more as a separate agency than originally thought. Further, the strategies utilized varied, some quite widely, between Districts within the same state. Because of these factors, each District within an agency was treated as a separate response in the response analyses.

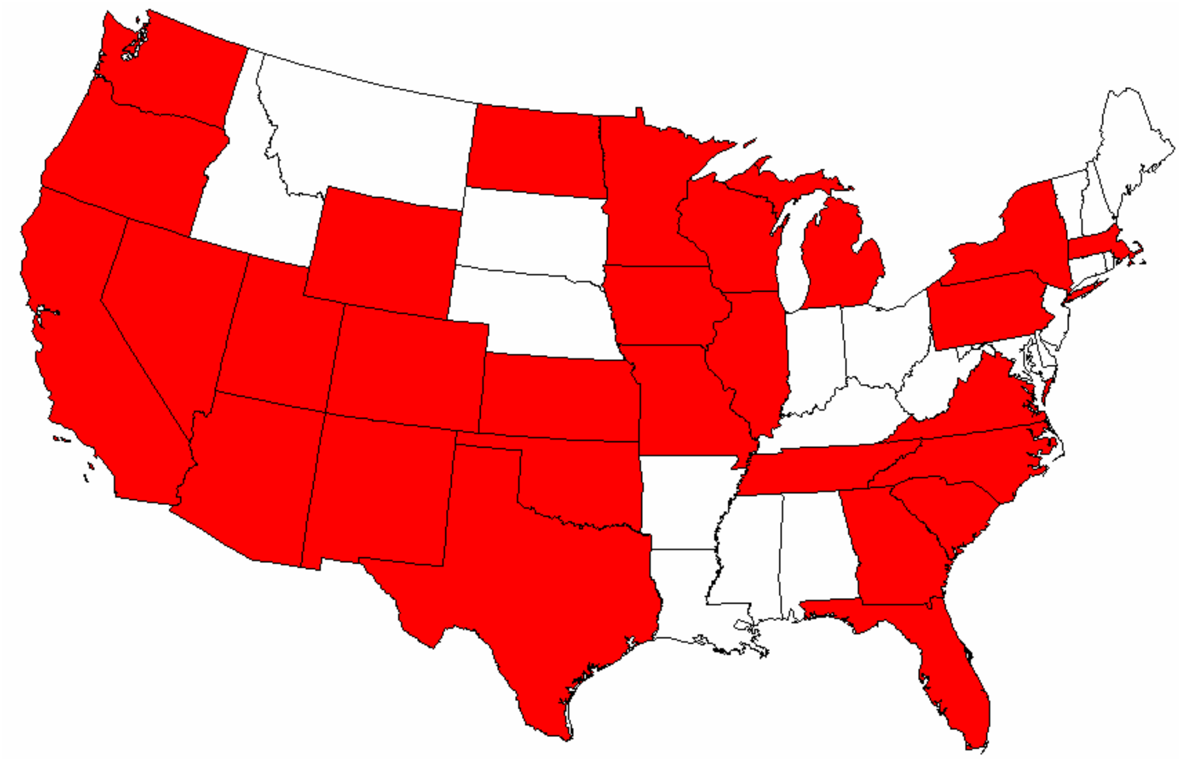

Figure 15. Survey Responses by State

5.2 Current Strategy Implementation

The STA responses regarding current strategy implementation to reduce work zone congestion varied based on work zone location and intensity of work performed. In order to provide an understandable means of delivering the results, the survey responses are presented in four components. The first component is a graphical view of the total responses for each strategy. The second is a table of the total responses for each strategy, organized by strategy group. The third component is a table of strategies, categorized by number of responses. The strategies are assigned to four categories, based on the number of responses for each strategy. The final component of each subsection is a list of other strategies and comments provided by the STA respondents.

5.2.1 Rural Reconstruction

The rural reconstruction scenario is a project where a four lane rural Interstate facility is reconstructed to a six-lane facility (three lanes in each direction). Section 4.1.2 details the project characteristics for this scenario. The overall objectives in this rural scenario are to maintain mobility of traffic through or around the work area and maintain adequate levels of safety. Each respondent identified strategies their STA would likely utilize in a similar project to fulfill the objectives. Figure 16 is a graphical view of the STA responses for each strategy.

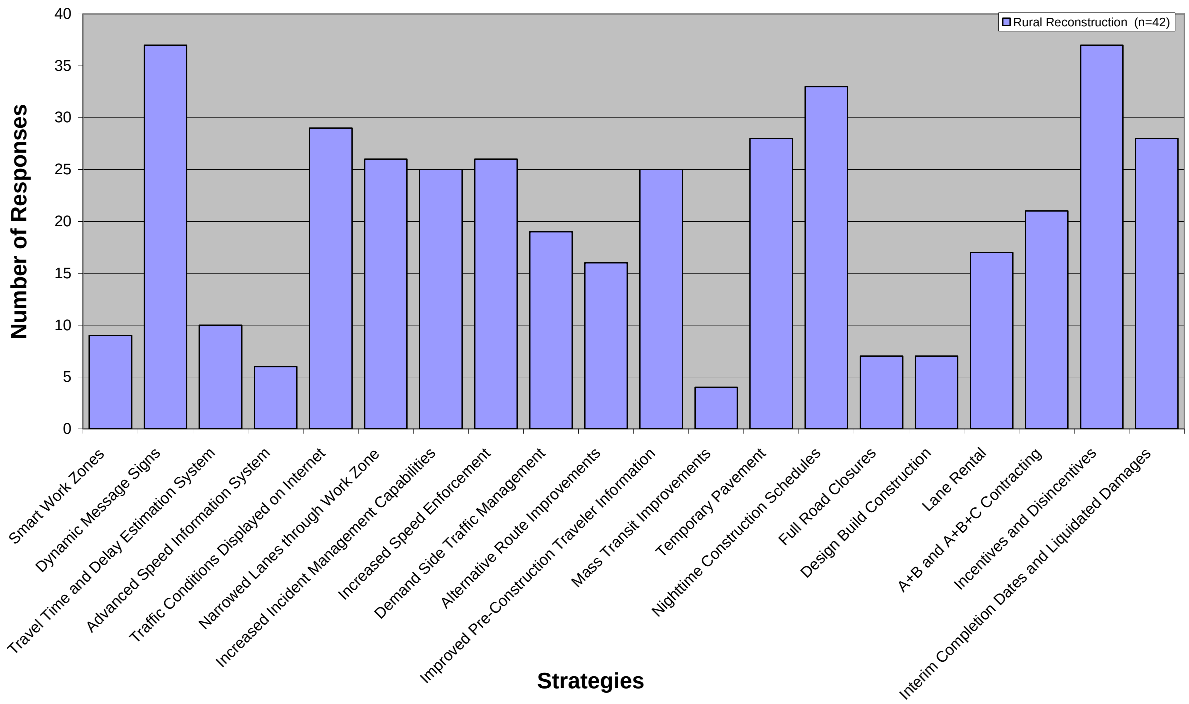

Figure 16. Rural Reconstruction Scenario Responses

Overall, the rural reconstruction project scenario had 42 respondents, whom indicated a total of 410 strategies used or 9.8 strategies per respondent. All strategies received at least four responses. As shown in Figure 16, there is a wide range in the number of responses for the strategies. Some strategies are used by many of the STAs while others are used by very few. Within the strategy groups results table, Table 9, a wide range of strategy responses is evident within each strategy group as well. As an example, in the alternative project scheduling strategy group, nighttime construction schedules was favored much more than full road closures, receiving 33 responses to 7 responses respectively. Table 10 shows the strategies broken into four categories based on the number of responses for a particular strategy.

Eleven of the 20 strategies in the survey had more than 50 percent of the respondents indicate they would use the respective strategy on a similar rural reconstruction project. Three of those strategies had a 75 percent or greater response rate: dynamic message signs, nighttime construction schedules, and incentives/disincentives. Each of these three strategies are categorized in a different strategy group, traffic management, alternative project scheduling, and alternative contracting and project delivery strategies, respectively. The eight strategies receiving between 50 and 75 percent of the responses were from four of the five strategy groups. From these results, it can be concluded that STAs are typically looking at different methods to reduce congestion, utilizing strategies from several strategy groups.

Table 9. Rural Reconstruction Scenario Responses by Strategy Group

Strategies	Responses
Traffic Management Strategies	
Smart Work Zones	9
Dynamic Message Signs	37
Travel Time and Delay Estimation System	10
Advanced Speed Information System	6
Traffic Conditions Displayed on Internet	29
Narrowed Lanes	26
Increased Incident Management Capabilities	25
Increased Speed Enforcement	26
Demand Management Strategies	
Demand Side Traffic Management Strategies	19
Alternative Route Improvements	16
Improved Pre-Construction Traveler Information	25
Mass Transit Improvements	4
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies	
Temporary Pavement	28
Alternative Project Scheduling Strategies	
Nighttime Construction Schedules	33
Full Road Closures and Detour Routes	7
Alternative Contracting and Delivery Strategies to Accelerate Project Completion	
Design/Build Construction	7
Lane Rental	17
A+B and A+B+C Contracting	21
Incentives/Disincentives to Reduce Construction Duration and Impacts	37
Interim Completion Dates and Liquidated Damages	28
Total Number of Respondents = 42	

While 11 strategies were identified by more than half of the respondents, nine were identified by less than half. Six of these nine strategies had fewer than 25 percent of the respondents indicate they would utilize that strategy. It is understandable why these six strategies are not often used in this situation. ITS costs and a lack of existing infrastructure are often prohibiting factors in rural locations. Mass transit improvements may not be applicable to many rural locations and are not applicable to this scenario. A full road closure may not be feasible due to a lack of nearby detour routes with adequate capacity.

Many respondents also provided other strategies they use to reduce or avoid work zone congestion on similar projects. Several STAs stated that they do not allow lane closures during peak travel periods. Examples of this are limiting work to just nights or simply avoiding the peak hours during the day. This may occur more frequently than stated in this survey since several respondents indicated that their STA would not consider the traffic volumes presented in the scenario a concern. A few respondents indicated that their agency would utilize other strategies not listed in the survey or variations of the listed strategies.

- Weekend full road closures
- Semi-permanent high mast lighting for nighttime construction
- Full closures on one side with traffic contra flow on other side
- Late merge signing

- Prohibiting work during peak hours
- Increased liquidated damages (when compared to other projects)

Table 10. Rural Reconstruction Strategies Categorized by Total Responses

75 % and Greater (32 Responses and Greater)	**74% – 50%** (21 – 31 Responses)	**49% – 25%** (11 – 20 Responses)	**Less than 25%** (10 Responses and Fewer)
• Dynamic Message Signs (37) • Incentives/Disincentives (37) • Nighttime Construction Schedules (33)	• Traffic Conditions Displayed on Internet (29) • Temporary Pavement (28) • Interim Completion Dates and Liquidated Damages (28) • Narrowed Lanes (26) • Increased Speed Enforcement (26) • Increased Incident Management Capabilities (25) • Improved Pre-Construction Traveler Information (25) • A+B and A+B+C Contracting (21)	• Demand Side Traffic Management (19) • Lane Rental (17) • Alternative Route Improvements (16)	• Travel Time and Delay Estimation System (10) • Smart Work Zones (9) • Full Road Closures (7) • Design/Build Construction (7) • Advanced Speed Information System (6) • Mass Transit Improvements (4)

One respondent provided insight to a project his agency completed with very similar project characteristics. The Oklahoma Department of Transportation utilized a smart work zone to inform motorists of congested traffic conditions and provided alternative routes for those driving to Dallas or other Texas destinations. However, as with many rural locations, the alternative routes were lengthy distances from the work zone and minimally used. Major work requiring lane closures ceased from October to December to maintain lanes in each direction through the holidays and the Oklahoma and Texas football game weekend.

5.2.2 Rural Resurfacing

The rural resurfacing scenario is a project where a four lane rural Interstate facility is resurfaced with an asphalt pavement. Section 4.1.2 details the project characteristics for this scenario. The overall objectives are to maintain mobility of traffic through or around the work area and maintain adequate levels of safety. Of all four scenarios, total road user costs are the least for a rural resurfacing project when utilizing a continuous lane closure. This is due to lower traffic volumes when compared to the urban scenario and a shorter project duration than that of a reconstruction project. Therefore, as expected, the rural resurfacing scenario had the fewest number of total strategy responses, 333, and the average number of responses per respondent, 8.1. Each respondent provided the strategies their STA would likely utilize to fulfill the objectives and Figure 17 displays their responses.

Within each strategy group, there is a large difference between the strategies that are widely used and those that are not. This is evident in Table 11. An example of this is between the two alternative project-scheduling strategies. Thirty STA respondents identified the use of nighttime construction schedules, while only six identified the implementation of full road closures and detour routes. Just over half of the respondents indicated they would use improved pre-construction traveler information, but few respondents indicated they

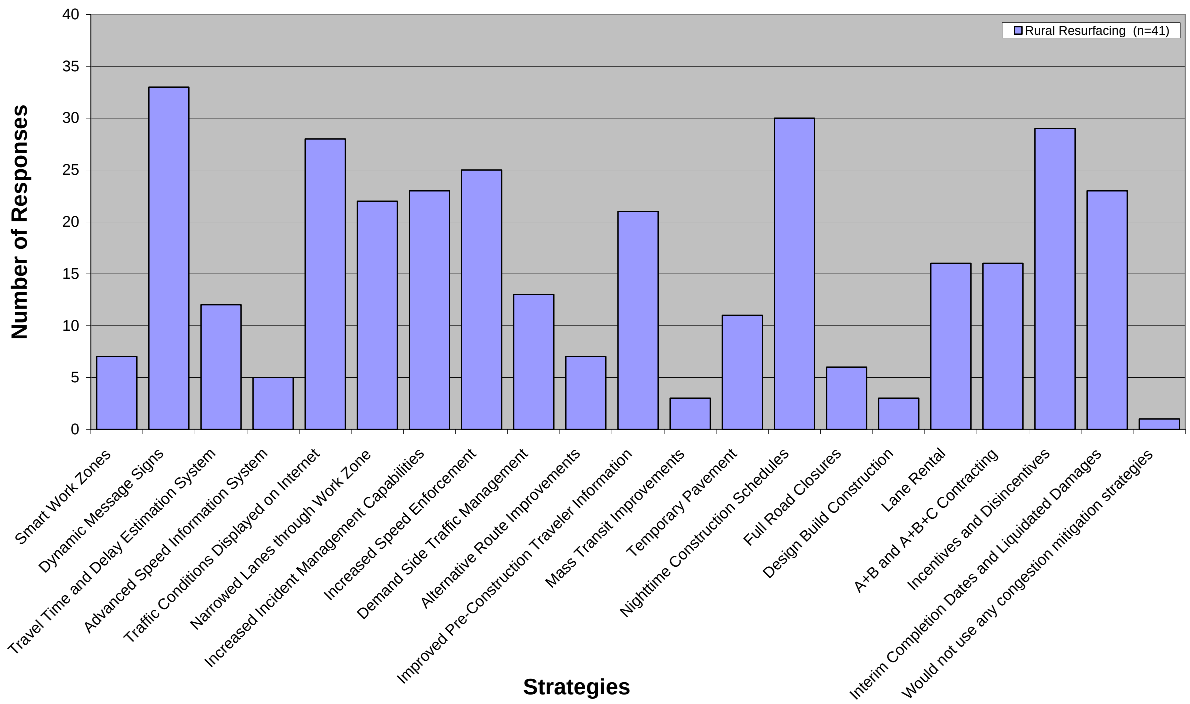

Figure 17. Rural Resurfacing Scenario Responses

Table 11. Rural Resurfacing Scenario Responses by Strategy Group

Strategies	Responses
Traffic Management Strategies	
Smart Work Zones	7
Dynamic Message Signs	33
Travel Time and Delay Estimation System	12
Advanced Speed Information System	5
Traffic Conditions Displayed on Internet	28
Narrowed Lanes	30
Increased Incident Management Capabilities	23
Increased Speed Enforcement	25
Demand Management Strategies	
Demand Side Traffic Management Strategies	13
Alternative Route Improvements	7
Improved Pre-Construction Traveler Information	21
Mass Transit Improvements	3
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies	
Temporary Pavement	11
Alternative Project Scheduling Strategies	
Nighttime Construction Schedules	30
Full Road Closures and Detour Routes	6
Alternative Contracting and Delivery Strategies to Accelerate Project Completion	
Design/build Construction	3
Lane Rental	16
A+B and A+B+C Contracting	16
Incentives/Disincentives to Reduce Construction Duration and Impacts	29
Interim Completion Dates and Liquidated Damages	23
Total Number of Respondents = 41	

would utilize any other demand management strategy. Traffic management strategies were the most frequently identified strategies.

The fewer number of strategies identified by STAs is also apparent in the assignment of strategies to categories based on number of responses, shown in Table 12. Only one, DMSs, of the 20 listed strategies had more than 31 responses. Eight of the 20 strategies received between 21 and 30 responses, representing four of the five strategy groups. While the total number of strategies identified may be fewer from many of the respondents, STAs are utilizing a variety of strategies from different strategy groups to reduce congestion. Even though nighttime construction schedules were not in the group with the most responses, 30 of 41 respondents indicated their agency would utilize this strategy. Because rural volumes are very low at night, compared to daytime volumes, utilizing this strategy can often eliminate any congestion by itself. Seven strategies had 10 or fewer responses, which represents less than 25 percent of the respondents indicating they would use a specific strategy.

Table 12. Rural Resurfacing Strategies

75 % and Greater (31 Responses and Greater)	**74% – 50%** (21 – 30 Responses)	**49% – 25%** (11 – 20 Responses)	**Less than 25%** (10 Responses and Fewer)
• Dynamic Message Signs (33)	• Narrowed Lanes (30) • Nighttime Construction Schedules (30) • Incentives/Disincentives (29) • Traffic Conditions Displayed on Internet (28) • Increased Speed Enforcement (25) • Increased Incident Management Capabilities (23) • Interim Completion Dates and Liquidated Damages (23) • Improved Pre-Construction Traveler Information (21)	• Lane Rental (16) • A+B and A+B+C Contracting (16) • Demand Side Traffic Management (13) • Travel Time and Delay Estimation System (12) • Temporary Pavement (11)	• Smart Work Zones (7) • Alternative Route Improvements (7) • Full Road Closures (6) • Advanced Speed Information System (5) • Design/Build Construction (3) • Mass Transit Improvements (3) • Would not use any strategies (1)

Similar to the rural reconstruction scenario, several respondents indicated their agency would not consider the peak traffic volumes an issue. Because congestion is not expected by these agencies, few strategies, if any, would be implemented for a lane closure. Three other respondents indicated they would only allow a lane closure during off peak hours where the permitted lane closure time and traffic volumes do not create congested conditions.

Many of the strategies with less than 25 percent response are not cost effective to utilize on this type of project, especially at the scenario traffic volumes. The reduction in road user costs would not outweigh the cost of implementation, partially because the work zone may only minimally affect road users. Other strategies are not relevant in the rural location, such as mass transit improvements or a full road closure with the absence of nearby detour routes. Detour routes are not necessary if one lane can be successfully closed during off peak hours to complete this type of project.

One respondent indicated that his agency would not currently utilize any strategies on this sort of project. Being a rural state, the agency had not experienced a project with similar traffic volumes to this scenario and the respondent was unsure what strategies they would use.

In addition to limiting work to off-peak hours, a few respondents also identified other strategies and techniques their agency would utilize on a similar rural resurfacing project.

- Similar to those in rural reconstruction, only less aggressive
- Utilize parallel routes and detour if convenient
- Daytime closures are allowed along with overnight drop-offs (overlays of 2 inches or less)
- Limit to lane closure to three miles
- Account for special events and holidays

5.2.3 Urban Reconstruction

The urban reconstruction scenario is a project where a four lane urban Interstate facility is reconstructed to a six-lane facility (three lanes in each direction). Section 4.1.2 details the project characteristics for this scenario. The overall objectives are to maintain mobility of traffic through or around the work area and maintain adequate levels of safety. The urban scenarios have the highest traffic volumes and the reconstruction scenarios have the longest duration. Coupling these two factors creates the highest total road user costs for a continuous lane closure of the four scenarios. Each respondent indicated strategies their STA would likely utilize to minimize the road user costs and fulfill the objectives. Figure 18 displays a graphical distribution of the agency responses.

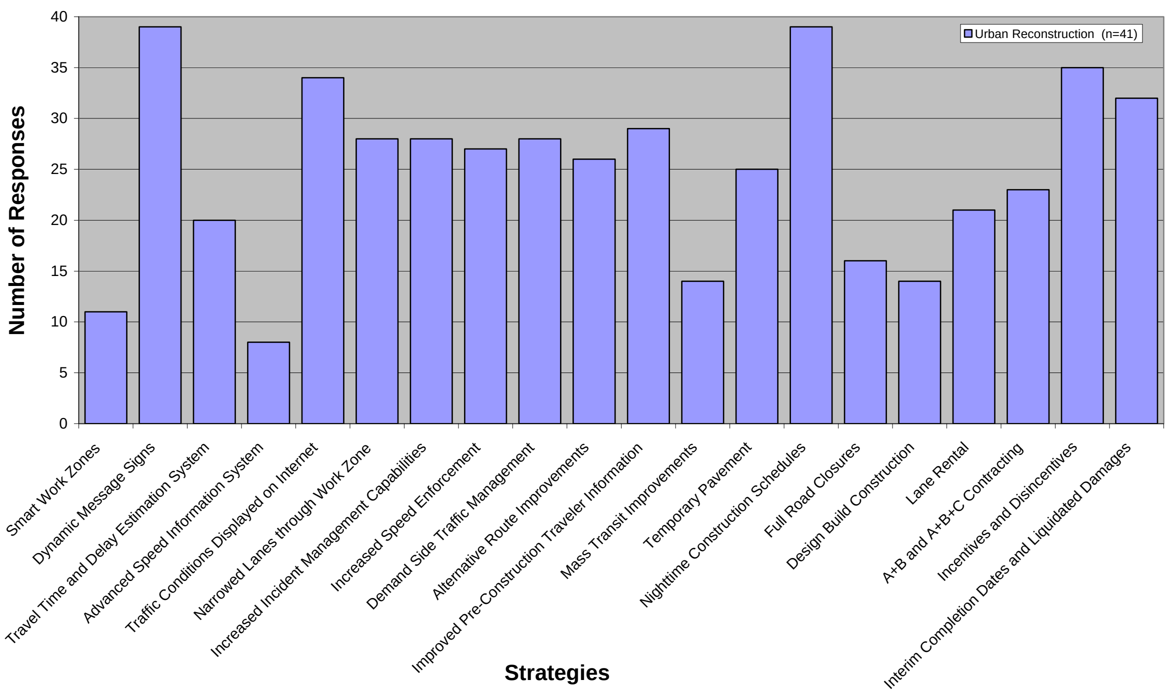

Figure 18. Urban Reconstruction Scenario Responses

Of the four scenarios, the urban reconstruction scenario had the highest number of total strategy responses, 497, and average number of responses per respondent, 12.1. Many strategies had over half of the respondents indicate they would use the respective strategy. Two strategies were identified by nearly all 41 respondents, dynamic message signs and nighttime construction schedules. Overall, many strategies received similar numbers of responses, regardless of strategy group. However, a few strategies are still favored more than others within the respective group.

Within each strategy group, shown in Table 13, more strategies received similar numbers of responses than in the other scenarios. An exception to this are the strategies smart work zones and advanced speed information system, receiving 11 and eight responses respectively. For demand management strategies, three of the four strategies received between 26 and 29 responses, while mass transit improvements received only 14 responses. For alternative project scheduling strategies, 39 of the 41 respondents indicated they would use nighttime construction schedules while only 16 stated they would utilize full road closures and detour routes. Incentives/disincentives, and interim completion dates and liquidated damages received the most responses for alternative contracting and delivery strategies with 35 and 32 respectively. The least was 14 for design/build construction.

Table 13. Urban Reconstruction Scenario Responses by Strategy Group

Strategies	Responses
Traffic Management Strategies	
Smart Work Zones	11
Dynamic Message Signs	39
Travel Time and Delay Estimation System	20
Advanced Speed Information System	8
Traffic Conditions Displayed on Internet	34
Narrowed Lanes	28
Increased Incident Management Capabilities	28
Increased Speed Enforcement	27
Demand Management Strategies	
Demand Side Traffic Management Strategies	28
Alternative Route Improvements	26
Improved Pre-Construction Traveler Information	29
Mass Transit Improvements	14
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies	
Temporary Pavement	25
Alternative Project Scheduling Strategies	
Nighttime Construction Schedules	39
Full Road Closures and Detour Routes	16
Alternative Contracting and Delivery Strategies to Accelerate Project Completion	
Design/Build Construction	14
Lane Rental	21
A+B and A+B+C Contracting	23
Incentives/Disincentives	35
Interim Completion Dates and Liquidated Damages	32
Total Number of Respondents = 41	

Overall, 14 of the 20 strategies had more than 50 percent of the respondents indicate their agency would utilize that strategy in a similar urban reconstruction project, shown in Table 14 . Of these 14 strategies, five received 31 or more responses. These five strategies represent three of the five strategy groups. All five strategy groups are represented in the 14 strategies receiving over 21 responses, or over 50 percent response. Similar to the previous scenarios, STAs are also trying to reduce work zone congestion through many different methods, encompassing different aspects of the project. The extent of the strategies being utilized is an indication of the commitment STAs have in attempting to reduce congestion created by work zone lane closures.

Only one strategy, advanced speed information system, received fewer than 10 responses. Five more strategies received less than 50 percent of the responses. However, a travel time and delay estimation system disseminates similar information to upstream motorists about downstream traffic conditions and an STA may prefer this type of traffic information. Another strategy, mass transit improvements, is not applicable to all areas due to the varying extent of existing mass transit infrastructure in other locations.

Table 14. Urban Reconstruction Strategies

75 % and Greater (31 Responses and Greater)	**74% – 50%** (21 – 30 Responses)	**49% – 25%** (11 – 20 Responses)	**Less than 25%** (10 Responses and Fewer)
• Dynamic Message Signs (39) • Nighttime Construction Schedules (39) • Incentives/Disincentives (35) • Traffic Conditions Displayed on Internet (34) • Interim Completion Dates and Liquidated Damages (32)	• Improved Pre-Construction Traveler Information (29) • Narrowed Lanes (28) • Increased Incident Management Capabilities (28) • Demand Side Traffic Management (28) • Increased Speed Enforcement (27) • Alternative Route Improvements (26) • Temporary Pavement (25) • A+B and A+B+C Contracting (23) • Lane Rental (21)	• Travel Time and Delay Estimation System (20) • Full Road Closures (16) • Mass Transit Improvements (14) • Design/Build Construction (14) • Smart Work Zones (11)	• Advanced Speed Information System (8)

Other strategies identified by the respondents include:

- Movable barriers on projects with highly directional traffic
- Semi-permanent high mast lighting for nighttime construction
- Avoid lane merge situations by utilizing lane drops at exit ramps
- Short term ramp closures
- Coordinate and communicate with area business groups, large employers, and traffic generators, etc.

5.2.4 Urban Resurfacing

The urban resurfacing scenario consists of a project where a six-lane urban Interstate facility is resurfaced with an asphalt pavement. Section 4.1.2 further details the project characteristics for this scenario. Significant congestion is possible in this scenario because it incorporates the higher traffic volumes of an urban facility, but a shorter duration than a reconstruction project. The overall objectives are to maintain mobility of traffic through or around the work area and maintain adequate levels of safety. Each respondent identified the strategies their STA would likely utilize to fulfill the objectives, graphically displayed in Figure 19.

Overall, the urban resurfacing scenario received fewer responses than the urban reconstruction scenario, but more than the two rural scenarios. The urban resurfacing project scenario had 41 respondents indicating a total number of 441 strategies used, or 10.8 strategies per respondent. Dynamic message signs and nighttime construction schedules were predominantly favored, but several other strategies were frequently identified as well.

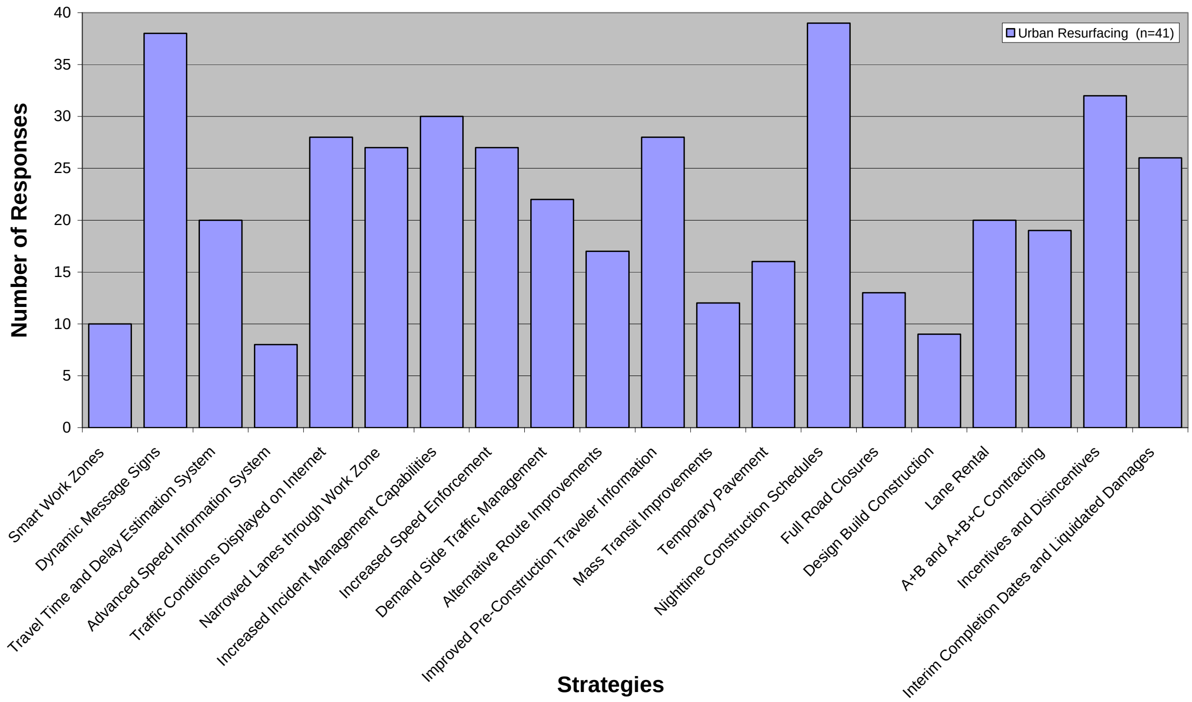

Figure 19. Urban Resurfacing Scenario Responses

Similar to the other scenarios, certain strategies were favored more than others within a respective strategy group. This is shown in Table 15. Within the traffic management strategies group, advanced speed information systems and smart work zones received the fewest responses. Four traffic management strategies received more than 27 responses, including the use of dynamic messages signs, which received 38 responses. Improved pre-construction traveler information received the most responses for demand management strategies, 28, while mass transit improvements and alternative route improvements received the fewest, 12 and 17 respectively.

The survey responses indicated a large difference in number of responses between the two alternative project-scheduling strategies. Many more agencies choose to utilize nighttime construction schedules, 39 of the 41 respondents, than utilize full road closures, 13 of 41. The nature of the work in this scenario is more conducive to using nighttime construction schedules because the work activity is flexible to be scheduled around peak periods. Therefore, the use of full road closures may only provide minimal additional benefit.

Finally, for alternative contracting and delivery strategies, incentives/disincentives, and interim completion dates and liquidated damages received the most responses with 32 and 26 respectively. Incentives/disincentives is an effective method to decrease the number of nights, if nighttime work is performed, or days needed to complete the project. While the work schedule would not likely be reduced as many days as in a reconstruction project, the incentives or disincentives can be adequately adjusted to represent road user cost impacts. Design/build construction received the fewest responses with only nine. Project design and construction durations may not be long enough to realize benefits from a design/build project delivery technique.

Table 15. Urban Resurfacing Scenario Responses by Strategy Group

Strategies	Responses
Traffic Management Strategies	
Smart Work Zones	10
Dynamic Message Signs	38
Travel Time and Delay Estimation System	20
Advanced Speed Information System	8
Traffic Conditions Displayed on Internet	28
Narrowed Lanes	27
Increased Incident Management Capabilities	30
Increased Speed Enforcement	27
Demand Management Strategies	
Demand Side Traffic Management Strategies	22
Alternative Route Improvements	17
Improved Pre-Construction Traveler Information	28
Mass Transit Improvements	12
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies	
Temporary Pavement	16
Alternative Project Scheduling Strategies	
Nighttime Construction Schedules	39
Full Road Closures and Detour Routes	13
Alternative Contracting and Delivery Strategies to Accelerate Project Completion	
Design/Build Construction	9
Lane Rental	20
A+B and A+B+C Contracting	19
Incentives/Disincentives	32
Interim Completion Dates and Liquidated Damages	26
Total Number of Respondents = 41	

Ten of the twenty strategies received more than 21 responses (over 50 percent of the total number of respondents) and are shown in Table 16. Three of these ten strategies received more than 75 percent response, dynamic message signs, nighttime construction schedules and the use of incentives/disincentives to reduce project duration. These three strategies are from three different strategy groups, including traffic management, alternative construction scheduling and alternative contracting and project delivery techniques. The other seven strategies receiving over 50 percent response are from three of the five strategy groups.

The other ten strategies all received fewer than 21 responses from the 41 total respondents. However, seven of these were in the 11 to 20 response category, indicating that several agencies still utilized these strategies. Only three strategies received 10 or fewer responses, including two traffic management strategies, smart work zones and advanced speed information systems, and one project delivery technique, design/build construction. A few of the respondents provided identified other strategies their agency utilizes in a similar urban reconstruction project.

- Off peak lane closures
- Daytime lane closures are allowed and overnight drop-offs are allowed if resurfacing projects are performed in 2 in. maximum lifts
- Single lane closures using MUTCD guidelines only
- Short term ramp closures
- Coordinate and communicate with area business groups, large employers, and traffic generators, etc.

Table 16. Urban Resurfacing Strategy Responses

75 % and Greater (31 Responses and Greater)	**74% – 50%** (21 – 30 Responses)	**49% – 25%** (11 – 20 Responses)	**Less than 25%** (10 Responses and Fewer)
• Nighttime Construction Schedules (39) • Dynamic Message Signs (38) • Incentives/Disincentives (32)	• Increased Incident Management Capabilities (30) • Traffic Conditions Displayed on Internet (28) • Improved Pre-Construction Traveler Information (28) • Narrowed Lanes (27) • Increased Speed Enforcement (27) • Interim Completion Dates and Liquidated Damages (26) • Demand Side Traffic Management (22)	• Travel Time and Delay Estimation System (20) • Lane Rental (20) • A+B and A+B+C Contracting (19) • Alternative Route Improvements (17) • Temporary Pavement (16) • Full Road Closures (13) • Mass Transit Improvements (12)	• Smart Work Zones (10) • Design/Build Construction (9) • Advanced Speed Information System (8)

5.2.5 Summary of Strategy Identification

The objective of this section is to present the strategies that STAs currently implement to mitigate work zone induced congestion. The strategies identified by the survey respondents are provided graphically and in tables for each of the four scenarios, with and without regard to each strategy's respective group. Overall, there were significant differences in the number of responses for the strategies that received several responses compared to those that only received a few.

Table 17 lists the strategies and number of responses where 75 percent of the STA respondents indicated they utilize the strategy for a similar project. When reviewing the strategies used for each of the four scenarios, over 75 percent of the respondents indicated their agency utilizes dynamic message signs for each project. Dynamic message signs are a very effective way to disseminate work zone information to motorists and the results show that STAs often use this strategy. Two other strategies had over 75 percent of the respondents indicate they would utilize them in three of the four scenarios: incentives/disincentives and nighttime construction schedules. The utilization of nighttime construction schedules is an alternative scheduling technique that fulfills the objective of minimizing traffic impacts by performing work during off peak hours at night. Incentives/disincentives is an effective strategy to minimize project duration by encouraging timely completion by the contractor. However, utilizing this strategy too frequently may instill an expectation from the contractor that they should receive some sort of compensation for completing a project in a timely manner.

Table 17. Summary of Strategies Receiving over 75 Percent Response

Rural Reconstruction	Rural Resurfacing	Urban Reconstruction	Urban Resurfacing
• Dynamic Message Signs (37) • Incentives/Disincentives (37) • Nighttime Construction Schedules (33)	• Dynamic Message Signs (33)	• Dynamic Message Signs (39) • Nighttime Construction Schedules (39) • Incentives/Disincentives (35) • Traffic Conditions Displayed on Internet (34) • Interim Completion Dates and Liquidated Damages (32)	• Nighttime Construction Schedules (39) • Dynamic Message Signs (38) • Incentives/Disincentives (32)

The results for each scenario also identified the strategies where between 25 and 75 percent of the respondents indicate their agency utilizes them in projects with similar characteristics. Each section presents these strategies in their respective scenario table. Even though these strategies did not receive the most responses, they should not be discarded from consideration. They are still used by several STAs and provide congestion mitigation benefits. The results section also lists several strategies that are not commonly utilized by STAs in similar projects. Table 18 displays the strategies that received 10 or fewer responses, or identified by less than 25 percent of the respondents.

Table 18. Summary of Strategies Receiving Less than 25 Percent Response

Rural Reconstruction	Rural Resurfacing	Urban Reconstruction	Urban Resurfacing
• Travel Time and Delay Estimation System (10) • Smart Work Zones (9) • Full Road Closures (7) • Design/Build Construction (7) • Advanced Speed Information System (6) • Mass Transit Improvements (4)	• Smart Work Zones (7) • Alternative Route Improvements (7) • Full Road Closures (6) • Advanced Speed Information System (5) • Design/Build Construction (3) • Mass Transit Improvements (3) • Would not use any strategies (1)	• Advanced Speed Information System (8)	• Smart Work Zones (10) • Design/Build Construction (9) • Advanced Speed Information System (8)

One of the strategies that received fewer than 10 responses for three of the four scenarios was smart work zones. As previously described in the literature review, a smart work zone is the utilization of ITS to provide motorists with timely, useful information. It is possible that the respondents that selected smart work zones are those where their agency calls this type of configuration a smart work zone. One issue with having several outputs of an Intelligent Transportation System is that many agencies may be using a similar system, but the output of the system varies. As an example, a smart work zone may contain a travel time and delay estimation system or an advanced speed information system. Both systems collect traffic speed data and report this to the upstream motorist, but they each utilize a different message and measure for dissemination. The advanced speed information system received fewer than 10 responses for all four scenarios. This system may also be utilized as a safety measure to alert motorists of unexpected queues over hills or around curves with limited sight distance. The output of a traffic characteristics message varies depending on the objectives of the respective agency.

Another strategy that appears in three of the four scenarios is design/build construction. This could be due to a couple of issues. One, design/build does not benefit projects that are relatively simple or short in duration, such as a resurfacing project. Two, many states do not utilize design/build or need it to be approved through their legislature before it is allowed. Three, with tight financial constraints placed on agencies, utilizing design/build may complete work too quickly for an agency to pay and still be able to afford other projects. Instead, agencies may opt to stage a large project over several years to allow for adequate funding of other necessary projects.

Two strategies that received fewer that 10 responses for both rural scenarios are full road closures and mass transit improvements. Mass transit improvements are likely not applicable to rural locations. Similarly, full road closures may not be applicable to rural locations because sufficient detour routes are likely unreasonable distances from the Interstate facility.

As stated in the discussions of the current strategies utilized in each scenario, there is a very diverse representation of strategies from the five strategy groups. Most of the five strategy groups are represented by strategies in the top 50 percent of strategy responses, or even top 75 percent for the urban reconstruction. This is a good indication that several agencies are trying to address work zone congestion by focusing on different aspects of the project, such as work activity, location and traffic characteristics.

5.3 Current Implementation Comparison of Strategies between Location and Work Intensity

One of the objectives of this research is to identify the strategies that are more commonly implemented on certain types of projects, based on location and work intensity. Therefore, four scenario comparisons were performed:

- Rural Reconstruction and Urban Reconstruction
- Rural Resurfacing and Urban Resurfacing
- Rural Resurfacing and Rural Reconstruction
- Urban Resurfacing and Urban Reconstruction

The comparison identified the strategies with a difference greater than seven total responses between the two scenarios. The cutoff point was seven responses. This is approximately 1/6 of the number of responses or a difference of 16.7 percent to 17 percent. Figure 20 displays a summary graph of the current strategy implementation responses for the four scenarios.

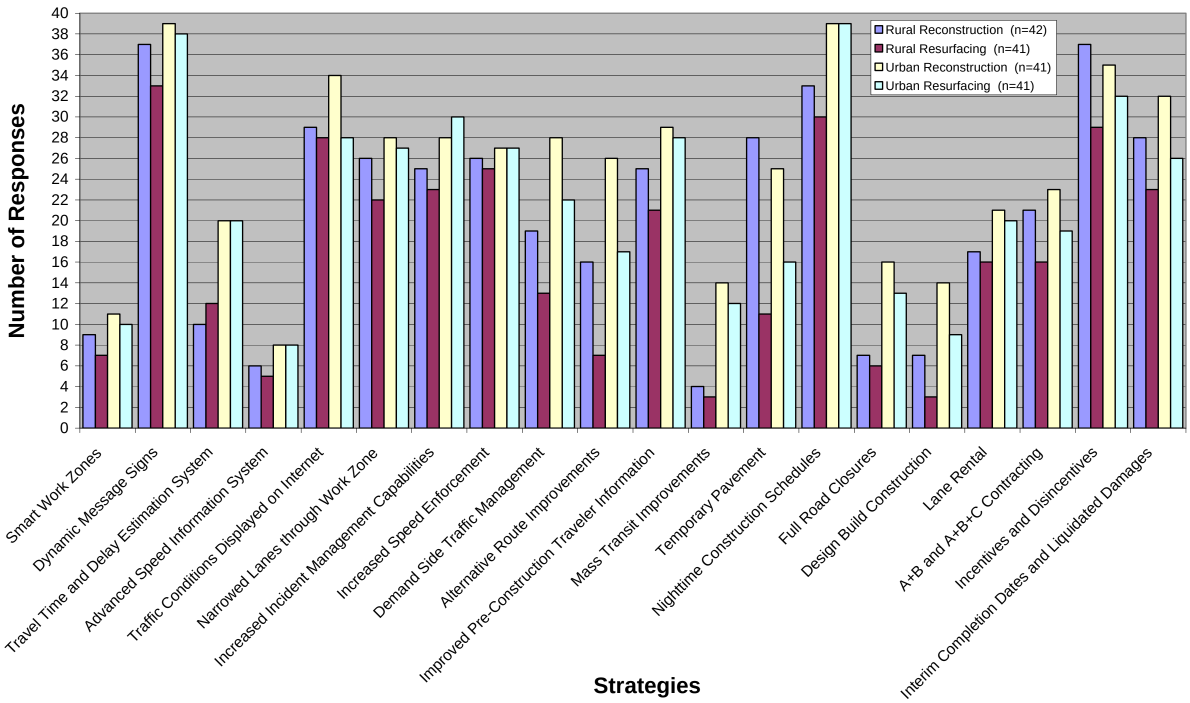

Figure 20. Summary of Current Strategy Responses

5.3.1 Comparison of Reconstruction Scenarios

The objective of this comparison is to identify what strategies had a large difference in the number of responses between rural and urban reconstruction projects. As stated in the previous section, the urban reconstruction scenario received the largest number of responses. Figure 21 displays the number of responses for each strategy for both rural and urban reconstruction scenarios. In this comparison, there were 42 respondents for the rural reconstruction scenario and 41 for the urban reconstruction scenario.

Figure 21 displays the survey responses for the rural reconstruction and urban reconstruction scenarios. For all but two strategies, respondents identified more strategies for the urban reconstruction project. The temporary pavements and incentives/disincentives strategies had more rural reconstruction responses, with differences of three and two respectively. Six strategies had a difference of seven or more responses (Urban Reconstruction – Rural Reconstruction)

- Travel time and delay estimation system (10)
- Demand side traffic management (9)
- Alternative route improvements (10)

- Mass transit improvements (10)
- Full road closures (9)
- Lane Rental (7)

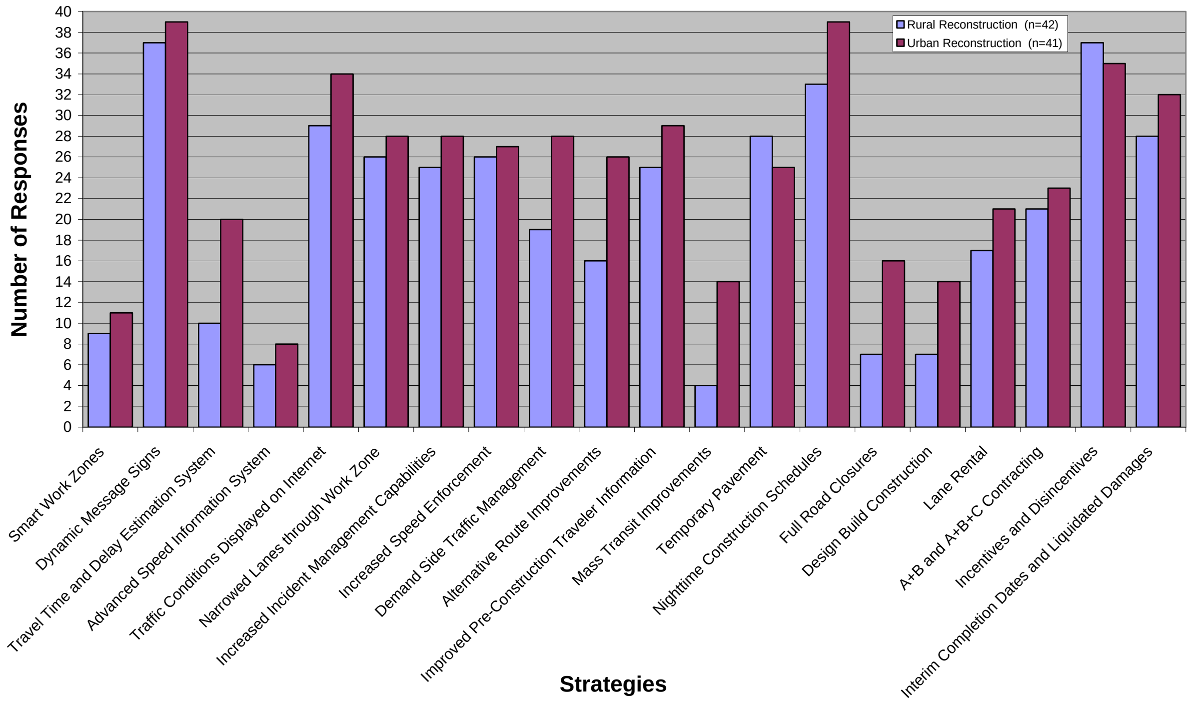

Figure 21. Rural and Urban Reconstruction Scenarios Comparison

Many of the strategies listed above are more conducive to urban locations. Three of the strategies identified with differences of seven or more responses are demand management strategies: demand side traffic management, alternative route improvements and mass transit improvements. Demand side traffic management strategies may be more successful in reducing peak period volumes on urban facilities because of the differing trip purposes. More mode and route alternatives are available in urban locations. The proximity of alternate routes to the Interstate facility in urban locations is usually much closer than potential alternative routes in rural locations. Therefore, alternative route improvements are utilized more often on urban locations, which assist the successful implementation of full road closures. Mass transit is more often located in urban locations and the mass transit improvements strategy is not applicable in many rural locations.

Another strategy that is more conducive to urban locations is travel time and delay estimation systems because adequate ITS infrastructure is already in place on many urban facilities. Similarly, providing a travel time or delay message on a rural facility may lack significance to a motorist because of the lack of acceptable, nearby alternative routes.

5.3.2 Comparison of Resurfacing Scenarios

The objective of this comparison is to identify what strategies have a difference greater than seven responses between the rural and urban resurfacing scenarios. This comparison incorporates the scenario with the fewest number of responses, rural resurfacing, and the scenario with the second most number of responses. Figure 22 displays the number of responses for each strategy for both rural and urban resurfacing scenarios.

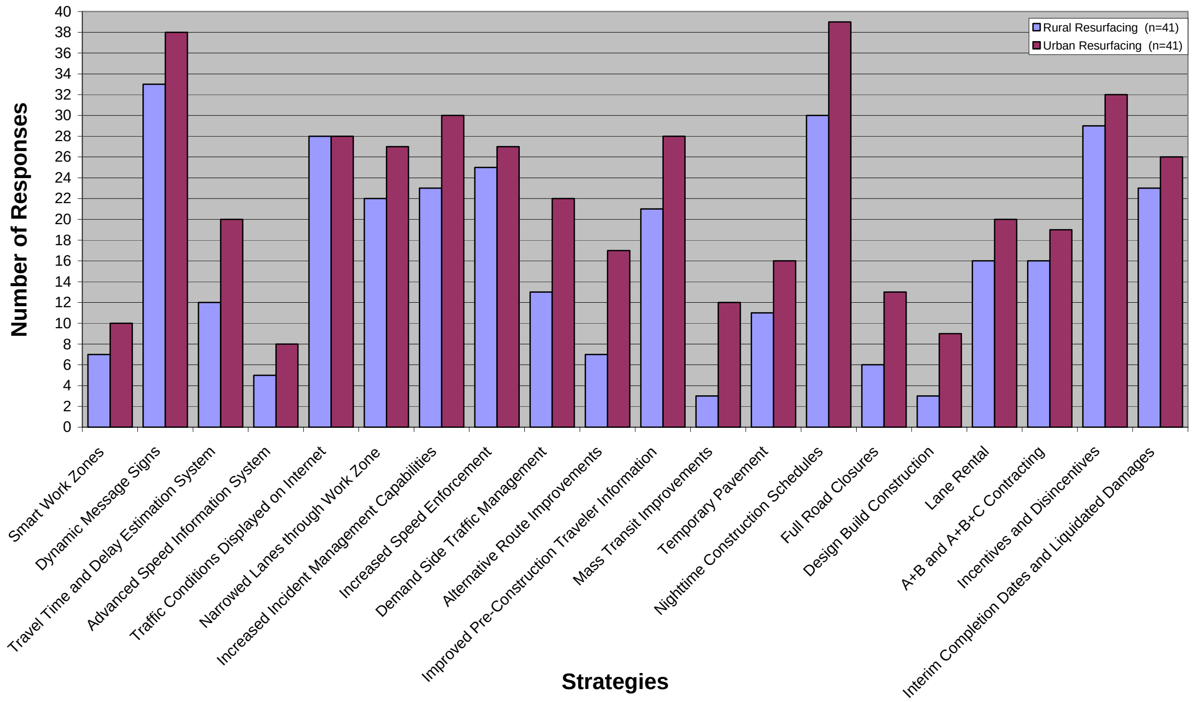

Figure 22. Rural and Urban Resurfacing Scenarios Comparison

Figure 22 displays the comparison of rural and urban resurfacing project responses. For all but one strategy, the urban resurfacing strategies received the most responses in the comparison. The lone exception is the traffic conditions displayed on the internet, which received an equal number for both scenarios. As expected, due to the large disparity in responses between the two scenarios, this comparison had the most strategies with a large difference in responses. Eight of the 20 strategies have a difference of more than seven responses (Urban Resurfacing – Rural Resurfacing).

- Travel time and delay estimation system (8)
- Increased incident management capabilities (7)
- Demand side traffic management (9)
- Alternative route improvements (10)
- Improved pre construction traveler information (7)
- Mass transit improvements (9)
- Nighttime construction schedules (9)
- Full road closures (7)

Four of the eight strategies with a difference greater than seven were demand management strategies. Demand side traffic management strategies are utilized to reduce facility traffic volumes by promoting promote changes in mode or route. This strategy may not be as effective in rural areas because adjusting travel characteristics may not be feasible. Mass transit improvements and alternative route improvements can also be successful methods to decrease volumes on the facility because an urban location offers alternatives to traveling on the facility with the work zone. Improved pre construction traveler information is an effective strategy to reduce high peak period commuter traffic volumes on urban facilities. Project information provided to motorists with ample time, in days, to make the necessary adjustments to avoid the peak periods reduces facility demand. This is of less importance to those drivers traveling longer distances, as they will likely accept the necessary delays because they are likely shorter in duration than the travel time of traversing an alternate route. With the prior statement, that is assuming a motorist even looks for work zones on their planned routes.

Nighttime construction schedules had nine more responses in the urban scenario than the rural scenario. A possible explanation to this large difference is the traffic volumes stated for each scenario. As previously mentioned, some STAs felt that the rural scenario traffic volumes were not of concern, would close lanes during any period of the day and disregard peak period traffic. This allows the STA to perform the resurfacing activities during daylight and not expose the drivers and workers to magnified safety issues during night work.

Out of the four scenario comparisons, the resurfacing scenario comparison had the most strategies with a difference in number of responses greater than seven. One issue that may factor into what strategies are selected for a rural or urban resurfacing project is the larger traffic volumes in the urban location. Congestion on the urban location is more likely to occur quicker and last for a longer duration than that in a rural location. During a lane closure, the volume to capacity ratio for the open lanes is much greater in the urban scenario than the rural scenario. Longer delays will be experienced at the urban location. Therefore, a more aggressive approach to reducing work zone congestion through strategy implementation is desired by the STA for the urban location.

5.3.3 Comparison of Rural Scenarios

The objective of this comparison is to identify what strategies had a large difference in the number of responses between the rural reconstruction and resurfacing scenarios. The main difference in these two scenarios is project duration and mobility constraints through the work zone. Figure 23 displays the number of responses for each strategy for both rural reconstruction and resurfacing scenarios. In this comparison, there were 42 respondents for the rural reconstruction scenario and 41 for the rural resurfacing scenario.

As shown in Figure 23, the rural reconstruction scenario received more responses for each strategy than the rural resurfacing scenario, except for one. Travel time and delay estimation system received two more responses in the rural resurfacing scenario. Overall, when comparing the same strategy utilization between scenarios, many differed by less than seven responses. Four strategies have a difference in number of responses of seven or greater (Rural Reconstruction – Rural Resurfacing):

- Demand side traffic management (7)
- Alternative route improvements (9)
- Temporary pavement (17)
- Incentives/disincentives (8)

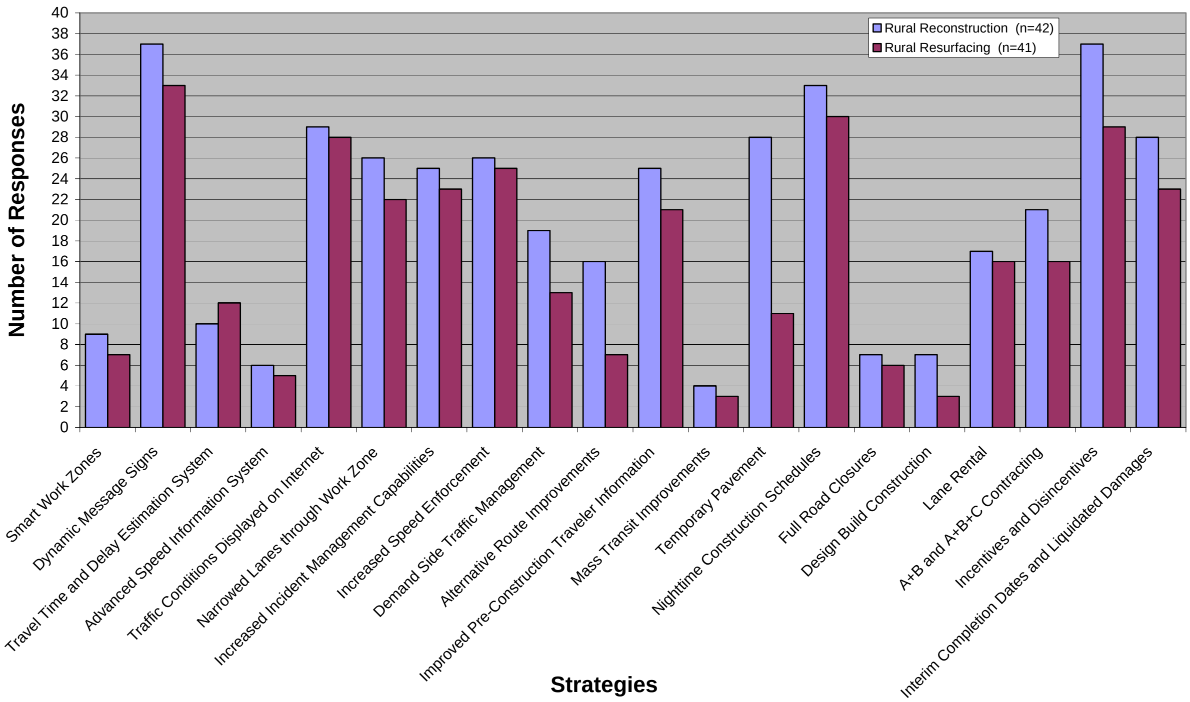

Figure 23. Rural Reconstruction and Rural Resurfacing Scenarios Comparison

Within this list, one strategy stands out because of the large difference in number of responses. The use of temporary pavement is much more prevalent in the rural reconstruction project. This is likely due to the longer duration of the rural reconstruction project. In addition, to provide a greater work area, temporary pavement is used to remove vehicles from the travel way and maintain the same number of travel lanes within the existing right-of-way. Temporary pavement is often cost prohibitive when resurfacing a roadway, especially with the short duration of asphalt pavement resurfacing activities.

The extended duration of the reconstruction project also likely influences STAs in their selection of the other three strategies. The overall road user costs will be less for the resurfacing project due to the short duration and possibility of performing work during off peak hours, more so than a reconstruction project. Incentives/disincentives may be less necessary, because completing a resurfacing project ahead of schedule may only save a couple of days. Similarly, if the monetary values are based on expected road user costs, the incentives are likely small and insignificant because minimal delay is expected by some agencies.

5.3.4 Comparison of Urban Scenarios

The objective of this comparison is to identify what strategies had a large difference in the number of responses between the urban reconstruction and resurfacing projects. As stated in the previous section, the urban reconstruction scenario received the most number of responses and the urban resurfacing received the second most. Figure 24 displays the number of responses for each strategy for both urban reconstruction and resurfacing scenarios.

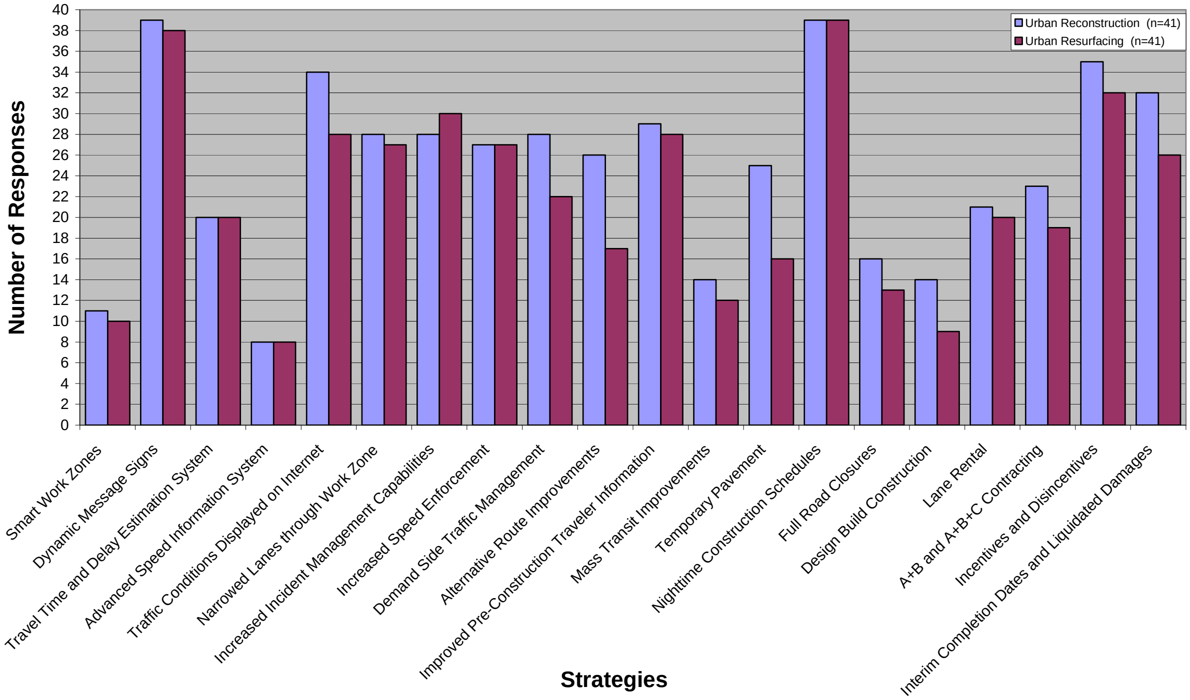

Figure 24. Urban Reconstruction and Urban Resurfacing Scenarios Comparison

Sixteen of the 20 strategies had more responses for the urban reconstruction scenario than the urban resurfacing scenario. Increased incident management had two more responses for the urban resurfacing scenario than the urban reconstruction scenario. Three strategies had the same number of responses, including travel time and delay estimation system, advanced speed information systems, use of nighttime construction schedules, and increased speed enforcement. For most of the strategies, however, the differences was only a few responses. Only two strategies had a difference of seven or greater responses (Urban Reconstruction – Urban Resurfacing).

- Alternative route improvements (9)
- Temporary pavement (9)

Many strategies have a similar number of responses for both urban reconstruction and resurfacing scenarios because closing a lane would be equally detrimental to mobility on the facility. Between the two scenarios, the project durations and flexibility in work schedules differ. Because of the varying project durations, a reconstruction project would extend the congestion over a longer period than a resurfacing project.

Nearly all respondents indicated that their agency would utilize dynamic message signs and nighttime construction schedules for these types of projects. Project duration likely influenced the difference in responses for alternative route improvements and temporary pavement strategies. The lower road user costs over the project duration of the rural reconstruction project may not offset the construction costs for the improvements and temporary pavement.

5.3.5 Summary of Strategy Comparisons

The comparison of strategies section identified the differences in strategy selection by agencies, based on project location and work activity. Table 19 and Table 20 display the summary of the four scenario comparisons presented in this section, based on location and work activity, respectively. The strategies listed in the table are those that had a total response difference of seven or more between the two compared scenarios.

Through the comparisons, it was evident that project characteristics, such as duration, location, and peak period traffic volumes, influence the respondents' selection of strategies. The comparisons based on location, as shown in Table 19, had the most strategies with a difference of seven or more responses. Further, both comparisons had five similar strategies identified. Several of these strategies with large differences are generally are more beneficial in urban locations. One the issue is the lack of nearby alternative routes in rural areas. Without alternative routes within a nearby proximity, several strategies are not applicable for implementation. These strategies include travel time and delay estimation systems (providing motorists with information to make a decision about an alternative route), alternative route improvements, and full road closures (alternative routes are necessary).

Table 19. Summary of Strategy Comparisons Based on Location

Reconstruction *(Urban Reconstruction – Rural Resurfacing)*	**Resurfacing** *(Urban Resurfacing – Rural Resurfacing)*
• Travel time and delay estimation system (10)	• Travel time and delay estimation system (8)
• Demand side traffic management (9)	• Demand side traffic management (9)
• Alternative route improvements (10)	• Alternative route improvements (10)
• Mass transit improvements (10)	• Mass transit improvements (9)
• Full road closures (9)	• Full road closures (7)
• Lane Rental (7)	• Increased incident management capabilities (7)
	• Improved pre construction traveler information (7)
	• Nighttime construction schedules (9)

Another issue when comparing strategies between urban and rural location implementation is the motorists' trip purpose. Generally, urban trips are shorter in length and peak periods are due to commuting motorists on urban facilities, while trips are longer and length on rural facilities. Utilizing strategies such as demand side traffic management strategies and improved pre-construction traveler information are not as beneficial to rural locations. Beyond providing project traveler information on the Internet, it is not feasible to apply extensive traveler information campaigns to the public several hundred miles from the project. Motorists making longer trips will likely accept and plan for the expected delay. The lack of alternative routes likely limits the choices a motorist can make to the time of day the motorist will traverse the work zone in an effort to avoid the possible delay. Demand side traffic management strategies are similar in that they are typically more beneficial to urban locations, where alternative routes and modes of transportation are available.

Lower traffic volumes and shorter duration peak periods on the rural facility are other considerations in strategy selection. The time between the peak traffic periods, especially at night, may be long enough to provide adequate and beneficial time to complete resurfacing activities without the use of more congestion mitigation strategies, if peak periods are a concern to the STA. The urban facility has a longer peak period and higher traffic volumes than the rural facility. When a lane is closed on this facility, the decrease in capacity cannot handle the demand, thus delays are quite extensive.

Table 20 displays the two strategy comparison results of scenarios based on work activity. The number of strategies identified varies greatly when compared to the location comparisons previously displayed. The different project durations and flexibility in scheduling lane closures are contributing factors to the selection of different strategies based on work activity. Concrete reconstruction activities require longer lane occupancy time due to the activities of a reconstruction and concrete cure time. The activities of an asphalt resurfacing project do not require extensive lane closures and a cure time is not needed after asphalt placement. The resurfacing project can likely be completed, if desired by the agency, during nighttime work hours to avoid peak commute periods.

Table 20. Summary of Strategy Comparisons Based on Work Activity

Rural *(Rural Reconstruction – Rural Resurfacing)*	**Urban** *(Urban Reconstruction – Urban Resurfacing)*
• Alternative route improvements (9) • Temporary pavement (17) • Demand side traffic management (7) • Incentives/Disincentives (8)	• Alternative route improvements (9) • Temporary pavement (9)

Two strategies shown in Table 20 were similar, alternative route improvements and temporary pavement. Both strategies may be very costly to implement, thus not feasible for a shorter duration resurfacing project. For the comparison of the rural scenarios, traffic volumes were likely small enough where extensive strategy implementation is not necessary for either project. The urban reconstruction and resurfacing scenarios comparison had the fewest strategies with a difference of seven or greater responses. While the project durations differed in the urban scenarios comparison, closing a lane during peak periods would be equally detrimental in both scenarios. Many of the work zone congestion mitigation strategies listed are applicable to both scenarios.

Through the comparison, it was found that project location affected the strategy selection more work activity. Several of the strategies are more applicable to urban locations than rural locations, due to proximity of alternative routes and trip purpose. For the comparisons based on work activity, similar strategies were selected and the differences in strategy selection were less.

5.4 Past Strategy Implementation and Experiences

Learning from STAs' unsuccessful strategy implementation experiences is beneficial to agencies that are developing Transportation Management Plans for similar project situations. A common cause of unsuccessful strategy implementation is a lack of understanding about the strategy, the components, and how it is implemented. As an example, new technology has the potential of delivering unparalleled benefits to reducing work zone congestion, but may require additional time and education to learn how to implement a strategy properly. The literature review indicated that there is a lack of literature about failed strategy implementation. The lessons learned by STAs from an unsuccessful strategy experience would be very beneficial to other agencies.

The objective of this section is to identify strategies that did not provide STAs with their expected congestion mitigation results. The STA respondents provided insight to some of the obstacles they have experienced with strategies to reduce work zone congestion. This objective allows STAs to learn of struggles others are experiencing with their strategy implementation. The STA responses ranged from failed expectations on one project to failed expectations on several projects.

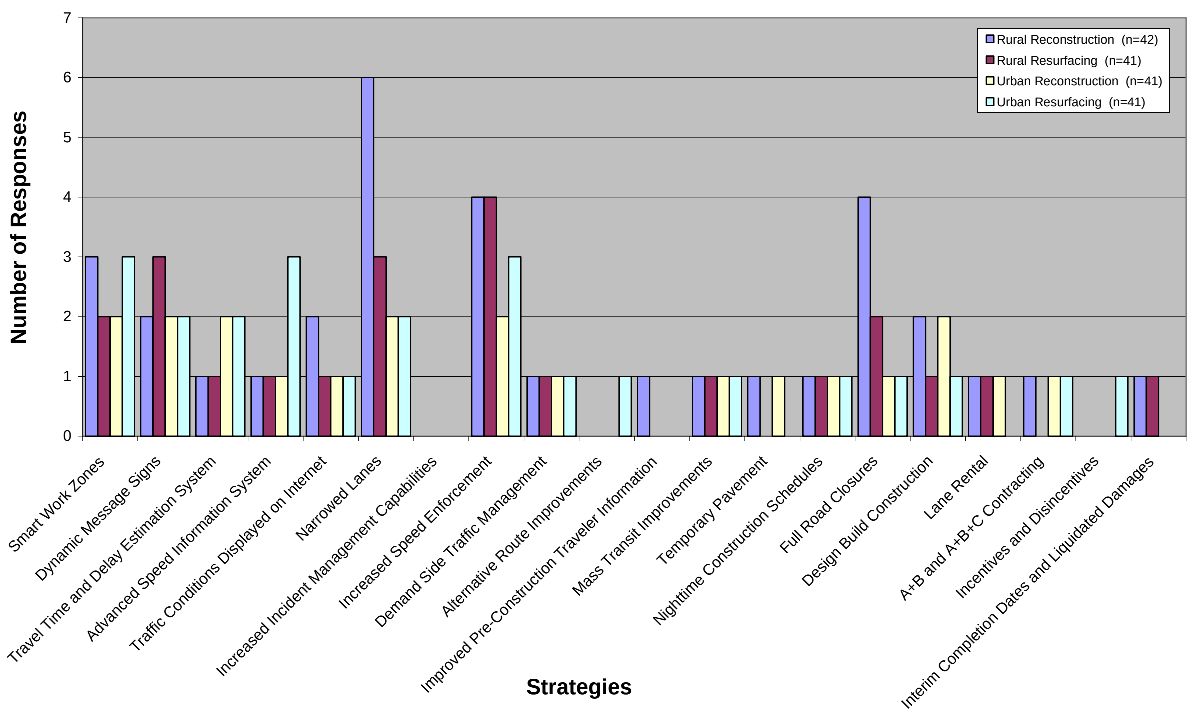

Figure 25. Past Strategy Experiences Summary

Figure 25 displays the strategies that respondents identified as failing to meet their agency's congestion reduction objectives. Many of the strategies received between one and three responses. Narrowed lanes for rural reconstruction projects received the most responses with six, followed by increased speed enforcement for both rural reconstruction and resurfacing projects and the use of a full road closure for a rural reconstruction project. As explained in the literature review, narrowed lanes is a strategy that may surprise agencies with the results. While the same number of lanes is maintained through the work zone, there is still a decrease in lane capacity. Motorist and worker safety is another issue with narrowed lanes. The absence of shoulders and vehicles striking cones or drums, which become projectiles into the work zone, are a couple of the concerns.

Many respondents did not identify any strategies for this question. While unlikely that an agency would be successful in every implementation of a strategy, the comments portion of this question provided an insight to the lack of responses. Five respondents indicated that they did not consider a strategy to fail if it provided any sort of congestion mitigation. While these agencies may consider a strategy successful, other agencies might consider it a failure, especially if only minor benefits were experiences compared to a high implementation cost. Three respondents indicated that all strategies are successful, if applied correctly, and any strategy could be unsuccessful or provide minimal benefit if not applied correctly. Several agencies are still relatively inexperienced to strategy implementation and experimenting with strategy application. If a strategy fails for these agencies, the implementation may not be considered a failure; rather it is a learning opportunity towards successful strategy application in the future. Another reason for the few responses may have been possible reluctance to indicate a strategy that failed to provide congestion mitigation benefits.

Several respondents indicated that their agency does not measure the performance of strategies, including both individual strategies within a combination and/or the combination of strategies used for a project. While it can be easily determined if congestion was or was not created by a work zone, the effectiveness of each strategy is unknown. Four respondents indicated that it is difficult to determine if any strategies previously utilized failed to meet expectation. They were particularly having difficulty assessing a single strategy when it is implemented within a group of strategies on a project. Other respondents indicated difficulty in measuring the total effectiveness of the strategy combination through a quantitative value. These issues are likely relevant to other agencies and should be addressed because it is an important component of strategy implementation. Understanding how the utilization of one strategy affects another is a good way to determine combinations of strategies to maximize the benefits while minimizing costs. A perception of implementing any strategy because it will at least provide some benefit may not be an efficient utilization of funds.

Several of the respondents expanded on their answer in the multiple selection portion of the question. The following is a list of the issues their agency encountered when they implemented certain strategies.

- Smart Work Zones
    - Agency unfamiliar with new technology
    - Contractor lacks knowledge to adequately implement system
- Dynamic Message Signs
    - Traffic condition messages old or incorrect of current conditions
    - Messages provide inaccurate or non-relevant messages
- Full Road Closures and Detour Routes
    - Detour routes on frontage roads
        - Roads not capable of handling detoured traffic

    - Congestion occurs even during non-peak hours
  - Distant detour routes
    - Not used even though detour route and original route arrive at same destination
- Liquidated Damages
  - Difficult to enforce
- Lane Rental Fees
  - Adjustment of fees specific to traffic conditions at work zone location
  - Fees are not significant to contractor, potential impacts are ignored and lane occupancy is not reduced or adjusted

One issue identified by STA respondents includes agency budget limitations. Agency budget limitations may reduce the extent of strategy implementation. One respondent indicated that congestion mitigation strategies are often value engineered out of their agency's projects. In addition, STAs with limited funds may not be able to implement the best possible strategy because they are limited to the least expensive strategies, which may provide less benefit. A limited staff may require the agency to contract out the strategy implementation, possibly resulting in an increase in implementation costs.

Another issue indicated by STA respondents is the implications of attempting to reduce traffic volumes and congestion to unrealistic levels. A common issue on urban facilities with recurring congestion is how to close a lane during the peak periods, such as what may be needed in a concrete reconstruction project. Overestimating the traffic volume reduction during these periods can lead to unexpected congested conditions, which the agency did not anticipate and is not prepared to handle. A couple of respondents indicated their agencies have attempted to close a lane during these periods. They believed that the congestion mitigation strategies would reduce the traffic volumes to a more manageable level so a lane closure could be implemented. However, the aggressive congestion mitigation attempts were highly unsuccessful due to their overestimation of strategy volume reductions and that the traffic volume reduction was unrealistic. The agencies have since avoided any attempts to close a lane during these periods.

Several STAs had experiences with strategies that failed to meet the expectations of reducing work zone congestion. There are several reasons why an agency may want to select a different strategy. One, a strategy may be providing continuously poor results and is replaced for a strategy that provides a benefit. Two, even though a strategy may provide a benefit to reducing congestion, there may be a different strategy that provides a greater benefit or similar benefit at a lower cost. Three, an STA may simply change their congestion mitigation objectives, utilizing different strategies. Several survey respondents provided insight to strategies that they do not readily use anymore and the reason for this action.

- Dynamic Merge Systems (DLM and DELM) – discontinued use
  - Issues included inconsistency to motorists, placement of merge locations, costs of implementation, and lack of benefit results in strategy being value engineered out of projects.
- Full road closures – discontinued use

- Nighttime construction schedules – replaced with flexible work windows or full closures when alternate routes available
- A+B+C contracting – replaced with incentives/disincentives
    - Incentives/disincentives has proven more successful at reducing work zone congestion
- Avoiding morning and evening peaks on select high volume roads– replaced with limiting work strictly to night or weekends
- Maintain all lanes and movements at all times – replaced with it is not always necessary to maintain lanes and movements if there is a reasonable congestion mitigation solution.
- Lane capacity specifications – replaced with restrictions based on volumes and peak periods
    - Issues included the contractor having difficulty knowing how to schedule work activities and the associated challenges with stopping work when the lane capacity threshold was met.

Three agencies identified strategies they are revisiting after they were previously discontinued or had provided poor results. Two of the three respondents provided similar responses for smart work zones.

- Highway Advisory Radio (HAR) – discontinued use but now revisiting application
    - Issues included technical problems with installation, high maintenance effort (equipment and message relevance), and low effectiveness in informing and diverting motorists
- Smart work zone – poor first results but now implementing strategy again
    - Issues were with contractor on the operation of the system and data collection, but now other vendors area available for implementation

5.5 Strategy Combination Matrices

The identification of strategy combinations from the STA current implementation responses is an objective of this research. This section displays the results of strategy pair analyses, which identifies the frequency of respondents including two strategies in their responses. The analysis consists of two components. The first component looks at the strategy pairs with the most responses. The second component looks at all strategy pairs and compares them to the number of individual strategy responses identified in Section 5.2. In this section, the term “individual responses” refers to the total responses for a strategy displayed in Section 5.2, Current Strategy Implementation.

5.5.1 Total Strategy Pairs Matrices

The first section identifies strategy pairs that frequently occurred in the survey respondents’ strategy selection. The strategy pairs were categorized into three ranges based on the number of pair responses. In the following matrices, the combinations with more than 25 responses are indicated by the red (darker) highlight. In addition to the strategy pair matrix, each scenario has a summary table of these strategy pairs. Other strategy pairs that were identified less frequently, between 20 and 24 pairs, are highlighted by yellow. The strategies with 19 and fewer pairs are in white boxes.

The rural reconstruction strategy responses indicated several strategy pairs that received over 20 and 25 pairs, graphically displayed in Table 23. Section 5.2.1 stated that three strategies had more than 75 percent of the respondents identify the strategy as one their agency would utilize in a project similar to this scenario: dynamic message signs, incentives/disincentives and nighttime construction schedules. Interestingly, dynamic message signs and incentives/disincentives had more than 25 pair responses with several other strategies, while nighttime construction schedules only had more than 25 pair responses with three other strategies. Several more strategies were identified with nighttime construction schedules at a lesser degree, between 20 and 25 responses. Traffic conditions displayed on the internet was the only strategy paired with the three common strategies mentioned above. The strategies with over 25 pairs are summarized in Table 21.

Table 21. Rural Reconstruction Strategy Combination Summary

Incentives/Disincentives • Dynamic message signs • Traffic conditions displayed on internet • Nighttime construction schedules • Interim completion dates and liquidated damages • Improved pre-construction traveler information • Increased incident management • Temporary pavement • Narrowed lanes	**Dynamic message signs** • Traffic conditions displayed on internet • Nighttime construction schedules • Incentives/Disincentives • Interim completion dates and liquidated damages • Narrowed lanes • Temporary pavement
Traffic conditions displayed on internet • Dynamic message signs • Nighttime construction • Incentives/Disincentives	**Nighttime construction schedules** • Dynamic message signs • Traffic conditions displayed on internet • Incentives/Disincentives
Narrowed lanes • Dynamic message signs • Incentives/Disincentives	**Increased incident management** • Incentives/Disincentives
Interim completion dates and liquidated damages • Dynamic message signs • Incentives/Disincentives	**Temporary pavement** • Dynamic message signs • Incentives/Disincentives
Improved pre-construction traveler information • Incentives/Disincentives	

The results of rural resurfacing strategy pair analysis, shown in Table 24, again show that many agencies are using only a few strategies for a rural resurfacing project to mitigate possible work zone congestion. The only strategy pair that received more than 25 pair responses was DMSs and incentives/disincentives. Ten other strategy pairs had between 20 and 25 responses. One interesting result from this is that there were two strategies that received 30 individual responses individually, but were not paired with any other strategy more than 25 times, nighttime construction schedules and narrowed lanes. Further, DMSs and incentives/disincentives both received 33 and 29 responses, respectively. This shows that the STA combinations of strategies are not consistent across all agencies.

Table 22. Rural Resurfacing Strategy Combination Summary

Dynamic message signs • Incentives/Disincentives	**Incentives/Disincentives** • Dynamic message signs

Table 23. Total Pair Matrix, Rural Reconstruction Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Smart Work Zones		9	6	3	7	7	2	2	3	6	8	6	7	1	5	7	5	9	7	9
Dynamic Message Signs	9		10	6	26	29	6	7	17	20	34	25	24	4	18	23	23	26	15	25
Travel Time and Delay Estimation System	6	10		3	7	7	2	2	5	7	8	6	6	1	5	6	5	7	5	9
Advanced Speed Information System	3	6	3		5	5	1	1	2	4	5	3	5	2	2	3	3	4	2	4
Traffic Conditions Displayed on Internet	7	26	7	5		25	5	6	11	16	26	20	18	4	18	19	18	18	11	21
Nighttime Construction Schedules	7	29	7	5	25		7	6	13	16	31	22	21	4	19	20	21	21	14	23
Full Road Closures	2	6	2	1	5	7		3	4	3	7	6	6	2	6	5	6	6	4	6
Design Build Construction	2	7	2	1	6	6	3		3	3	6	7	5	2	6	3	3	5	3	5
Lane Rental	3	17	5	2	11	13	4	3		12	16	10	13	1	9	10	10	10	8	10
A+B and A+B+C Contracting	6	20	7	4	16	16	3	3	12		20	14	15	3	10	14	12	15	12	18
Incentives and Disincentives	8	34	8	5	26	31	7	6	16	20		27	25	4	18	25	23	25	16	26
Interim Completion Dates and Liquidated Damages	6	25	6	3	20	22	6	7	10	14	27		18	3	13	19	20	19	12	21
Improved Pre-Construction Traveler Information	7	24	6	5	18	21	6	5	13	15	25	18		4	14	20	17	19	14	18
Mass Transit Improvements	1	4	1	2	4	4	2	2	1	3	4	3	4		4	3	2	3	3	3
Demand Side Traffic Management	5	18	5	2	18	19	6	6	9	10	18	13	14	4		12	13	15	9	15
Increased Incident Management Capabilities	7	23	6	3	19	20	5	3	10	14	25	19	20	3	12		18	18	14	21
Increased Speed Enforcement	5	23	5	3	18	21	6	3	10	12	23	20	17	2	13	18		17	11	19
Narrowed Lanes	9	26	7	4	18	21	6	5	10	15	25	19	19	3	15	18	17		11	22
Alternative Route Improvements	7	15	5	2	11	14	4	3	8	12	16	12	14	3	9	14	11	11		14
Temporary Pavement	9	25	9	4	21	23	6	5	10	18	26	21	18	3	15	21	19	22	14	

Table 24. Total Pair Matrix, Rural Resurfacing Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Smart Work Zones		7	4	1	5	6	0	0	4	4	3	4	3	0	2	4	6	3	2	4
Dynamic Message Signs	7		11	5	23	24	6	2	14	14	25	20	17	3	12	20	21	20	5	10
Travel Time and Delay Estimation System	4	11		2	10	9	2	1	8	6	10	8	7	1	6	6	8	8	2	5
Advanced Speed Information System	1	5	2		5	5	2	0	2	1	4	2	4	1	1	4	3	2	0	2
Traffic Conditions Displayed on Internet	5	23	10	5		23	5	3	11	12	22	16	15	3	13	19	17	15	6	9
Nighttime Construction Schedules	6	24	9	5	23		4	3	12	12	21	15	17	2	10	16	19	16	4	10
Full Road Closures	0	6	2	2	5	4		1	3	4	6	4	6	3	4	5	5	5	2	3
Design Build Construction	0	2	1	0	3	3	1		1	1	2	2	1	1	3	1	2	2	1	1
Lane Rental	4	14	8	2	11	12	3	1		10	12	10	10	1	6	9	10	11	4	6
A+B and A+B+C Contracting	4	14	6	1	12	12	4	1	10		13	9	9	3	8	9	9	8	6	6
Incentives and Disincentives	3	25	10	4	22	21	6	2	12	13		20	18	3	11	17	18	17	5	9
Interim Completion Dates and Liquidated Damages	4	20	8	2	16	15	4	2	10	9	20		14	2	8	14	18	14	5	8
Improved Pre-Construction Traveler Information	3	17	7	4	15	17	6	1	10	9	18	14		3	8	14	16	13	5	7
Mass Transit Improvements	0	3	1	1	3	2	3	1	1	3	3	2	3		3	2	2	2	2	1
Demand Side Traffic Management	2	12	6	1	13	10	4	3	6	8	11	8	8	3		9	8	9	5	5
Increased Incident Management Capabilities	4	20	6	4	19	16	5	1	9	9	17	14	14	2	9		16	16	7	10
Increased Speed Enforcement	6	21	8	3	17	19	5	2	10	9	18	18	16	2	8	16		14	5	9
Narrowed Lanes	3	20	8	2	15	16	5	2	11	8	17	14	13	2	9	16	14		4	8
Alternative Route Improvements	2	5	2	0	6	4	2	1	4	6	5	5	5	2	5	7	5	4		4
Temporary Pavement	4	10	5	2	9	10	3	1	6	6	9	8	7	1	5	10	9	8	4	

Of the four scenarios, the urban reconstruction scenario had the most strategy pairs with more than 20 responses. This is evident in the matrix, Table 26, and in the summary of strategies with pairs greater than 25 responses, Table 25. As previously stated, the urban reconstruction scenario received the most STA responses of current strategy implementation. Eleven of the 12 strategies that received more 25 or more individual responses were paired with at least one other strategy by more than 25 respondents. Several of the strategy combinations, have more than 20 pairs. The three most frequently paired strategies were nighttime construction schedules and dynamic message signs, and incentives/disincentives to reduce project duration.

Table 25. Urban Reconstruction Strategy Combination Summary

Nighttime construction schedules
- Dynamic message signs
- Traffic conditions displayed on internet
- Incentives/Disincentives
- Interim completion dates and liquidated damages
- Improve pre-construction traveler information
- Demand side traffic management
- Increased incident management capabilities
- Increased speed enforcement
- Narrowed lanes
- Alternative route improvements

Dynamic message signs
- Traffic conditions displayed on internet
- Nighttime construction schedules
- Incentives/Disincentives
- Interim completion dates and liquidated damages
- Improved pre-construction traveler information
- Demand side traffic management
- Increased incident management capabilities
- Increased speed enforcement
- Narrowed lanes

Incentives/Disincentives
- Dynamic message signs
- Traffic conditions displayed on internet
- Nighttime construction schedules
- Interim completion dates and liquidated damages
- Improved pre-construction traveler information
- Increased incident management capabilities
- Narrowed lanes

Traffic conditions displayed on Internet
- Dynamic message signs
- Nighttime construction schedules
- Incentives/Disincentives
- Interim completion dates and liquidated damages

Interim completion dates and liquidated damages
- Dynamic message signs
- Traffic conditions displayed on internet
- Nighttime construction schedules
- Incentives/Disincentives

Improved pre-construction traveler information
- Dynamic message signs
- Nighttime construction schedules
- Incentives/Disincentives

Increased incident management capabilities
- Dynamic message signs
- Nighttime construction schedules
- Incentives/Disincentives

Narrowed lanes
- Dynamic message signs
- Nighttime construction schedules
- Incentives/Disincentives

Demand side traffic management
- Dynamic message signs
- Nighttime construction schedules

Increased speed enforcement
- Dynamic message signs
- Nighttime construction schedules

Alternative route improvements
- Nighttime construction schedules

Table 26. Total Pair Matrix, Urban Reconstruction Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Smart Work Zones		11	9	6	10	10	5	5	6	7	10	9	9	4	7	8	7	9	6	9
Dynamic Message Signs	11		19	8	32	36	14	14	19	21	33	30	27	14	27	26	25	27	24	23
Travel Time and Delay Estimation System	9	19		6	18	19	7	9	13	14	17	16	16	8	15	13	12	14	13	13
Advanced Speed Information System	6	8	6		8	8	5	4	5	5	8	7	8	5	6	6	6	7	5	7
Traffic Conditions Displayed on Internet	10	32	18	8		31	13	13	15	19	29	27	24	13	24	23	22	23	21	22
Nighttime Construction Schedules	10	36	19	8	31		14	14	19	21	33	30	27	14	27	26	25	26	25	23
Full Road Closures	5	14	7	5	13	14		6	10	8	12	12	13	4	9	12	12	11	12	13
Design Build Construction	5	14	9	4	13	14	6		6	9	11	11	10	8	12	10	8	11	12	10
Lane Rental	6	19	13	5	15	19	10	6		16	18	16	17	8	14	13	12	15	13	14
A+B and A+B+C Contracting	7	21	14	5	19	21	8	9	16		21	17	19	11	17	15	13	17	15	16
Incentives and Disincentives	10	33	17	8	29	33	12	11	18	21		27	26	13	24	26	24	26	22	23
Interim Completion Dates and Liquidated Damages	9	30	16	7	27	30	12	11	16	17	27		24	12	22	23	23	23	20	21
Improved Pre-Construction Traveler Information	9	27	16	8	24	27	13	10	17	19	26	24		13	20	22	20	21	19	20
Mass Transit Improvements	4	14	8	5	13	14	4	8	8	11	13	12	13		14	11	10	11	11	9
Demand Side Traffic Management	7	27	15	6	24	27	9	12	14	17	24	22	20	14		21	19	22	21	17
Increased Incident Management Capabilities	8	26	13	6	23	26	12	10	13	15	26	23	22	11	21		21	24	21	20
Increased Speed Enforcement	7	25	12	6	22	25	12	8	12	13	24	23	20	10	19	21		18	19	18
Narrowed Lanes	9	27	14	7	23	26	11	11	15	17	26	23	21	11	22	24	18		19	20
Alternative Route Improvements	6	24	13	5	21	25	12	12	13	15	22	20	19	11	21	21	19	19		18
Temporary Pavement	9	23	13	7	22	23	13	10	14	16	23	21	20	9	17	20	18	20	18	

Most of the strategy pairs for the urban resurfacing scenario involved dynamic message signs and nighttime construction schedules, highlighted in Table 28. They each received 39 and 38 individual responses, respectively. One interesting combination was narrowed lanes to keep lanes open through a work zone and increased incident management capabilities. This pair had 26 respondents indicate that they utilize these strategies together, but individually, narrowed lanes only received 27 responses and increased incident management capabilities received 30. Overall, the strategy pairs resembled the strategy pairs from the urban reconstruction scenario, only with fewer strategies receiving more than 20 and 25 pairs. The summary of strategy pairs is shown in Table 27

Table 27. Urban Resurfacing Strategy Combination Summary

Nighttime construction schedules
- Dynamic message signs
- Traffic conditions displayed on internet
- Incentives/Disincentives
- Interim completion dates and liquidated damages
- Improved pre-construction traveler information
- Increased incident management capabilities
- Increased speed enforcement
- Narrowed lanes

Dynamic message signs
- Traffic conditions displayed on internet
- Nighttime construction schedules
- Incentives/Disincentives
- Improved pre-construction traveler information
- Increased incident management capabilities
- Narrowed lanes

Increased incident management
- Dynamic message signs
- Nighttime construction schedules
- Incentives/Disincentives
- Narrowed lanes

Incentives/Disincentives
- Dynamic message signs
- Nighttime construction schedules
- Increased incident management

Narrowed lanes
- Dynamic message signs
- Nighttime construction schedules
- Increased incident management capabilities

Traffic conditions displayed on internet
- Dynamic message signs
- Nighttime construction schedules

Improved pre-construction traveler information
- Dynamic message signs
- Nighttime Construction Schedules

Increased speed enforcement
- Nighttime construction schedules

Interim completion dates and liquidated damages
- Nighttime construction schedules

Table 28. Total Pair Matrix, Urban Resurfacing Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Smart Work Zones		10	9	5	9	10	5	3	7	6	8	9	9	4	6	9	8	10	7	8
Dynamic Message Signs	10		20	8	27	37	13	9	20	18	30	24	26	12	22	29	24	26	16	15
Travel Time and Delay Estimation System	9	20		7	17	20	8	5	12	12	16	14	17	8	14	17	13	14	11	11
Advanced Speed Information System	5	8	7		8	8	4	2	5	4	8	7	8	4	5	7	5	6	4	4
Traffic Conditions Displayed on Internet	9	27	17	8		27	12	8	13	16	24	20	22	11	19	24	19	20	15	14
Nighttime Construction Schedules	10	37	20	8	27		12	9	20	19	32	25	27	12	21	30	25	27	17	15
Full Road Closures	5	13	8	4	12	12		4	7	8	11	10	13	5	8	11	10	11	7	7
Design Build Construction	3	9	5	2	8	9	4		3	5	8	6	7	6	8	8	6	8	8	6
Lane Rental	7	20	12	5	13	20	7	3		12	15	12	16	6	9	13	10	14	7	9
A+B and A+B+C Contracting	6	18	12	4	16	19	8	5	12		16	11	15	9	12	15	11	15	10	10
Incentives and Disincentives	8	30	16	8	24	32	11	8	15	16		23	24	12	19	27	22	23	16	12
Interim Completion Dates and Liquidated Damages	9	24	14	7	20	25	10	6	12	11	23		22	9	16	24	20	21	15	12
Improved Pre-Construction Traveler Information	9	26	17	8	22	27	13	7	16	15	24	22		11	16	23	20	21	15	13
Mass Transit Improvements	4	12	8	4	11	12	5	6	6	9	12	9	11		11	11	9	10	9	6
Demand Side Traffic Management	6	22	14	5	19	21	8	8	9	12	19	16	16	11		21	16	18	14	12
Increased Incident Management Capabilities	9	29	17	7	24	30	11	8	13	15	27	24	23	11	21		23	26	15	14
Increased Speed Enforcement	8	24	13	5	19	25	10	6	10	11	22	20	20	9	16	23		21	16	12
Narrowed Lanes	10	26	14	6	20	27	11	8	14	15	23	21	21	10	18	26	21		17	14
Alternative Route Improvements	7	16	11	4	15	17	7	8	7	10	16	15	15	9	14	15	16	17		11
Temporary Pavement	8	15	11	4	14	15	7	6	9	10	12	12	13	6	12	14	12	14	11	

5.5.2 Strategy Pair and Individual Response Comparison

The second component of the strategy combination analysis utilizes the same strategy pair matrices as the previous subsection. However, in this analysis, the total pairs are compared with the total number of individual strategy responses, from Section 5.2, to determine what other strategies the respondents are selecting for their combinations when they select a specific strategy.

The following scenario matrices highlight the strategies used together at least 90 percent of the time when indicated by a respondent. The strategies pairs are compared with the number of responses in the row "Total Individual Strategy Responses" and highlighted if the number of pairs is within 90 percent of the total individual responses. As an example, the demand side traffic management strategy in the rural reconstruction scenario table, Table 29, is read: Nineteen respondents indicated their agency would use demand side traffic management strategies on a project similar to the rural reconstruction scenario. All 19 of those respondents also indicated that they would utilize nighttime construction schedules.

A benefit to this analysis is the identification of strategy pairs of the less frequently selected strategies. Several strategies are used in successful TMPs that are not selected by several agencies. The agencies utilizing these strategies may have determined other strategies that work collectively to provide the desired benefits. By identifying less often-used strategy pairs, the matrices can assist agencies in their strategy combination development for their TMPs. As an example, an STA identified a few specific strategies they want to use in their TMP, but they also would like to apply other strategies in addition to build a comprehensive strategy combination. These matrices will provide the strategies frequently used by other agencies when they selected the same strategies as the agency identify the other strategies that are frequently utilized by other STAs.

The rural reconstruction matrix, shown in Table 29, displays the highlighted strategy pairs frequently identified by respondents in conjunction with the implementation of a specific strategy. Dynamic message signs and incentives/disincentives were commonly identified by over 90 percent of the respondents indicating another strategy. This was expected because each strategy received 37 individual responses and both are likely paired with other strategies when the others are implemented.

Only a few other strategy pairs were highlighted in the rural reconstruction matrix and most were less than 10 pairs. However, these pairs still provide insight to what other strategies these STAs utilize in their TMPs. As an example, demand side traffic management strategies were paired with four other strategies over 90 percent of the time they were selected, DMSs, traffic conditions displayed on the Internet, nighttime construction schedules, and incentives/disincentives. These four strategies are each from a different strategy group and compliment each other when included in a transportation management plan. The respondents indicating use of smart work zones also identified three other strategies in the same strategy combination: DMSs, narrowed lanes, and temporary pavement. DMSs are used in a smart work zone as a way to disseminate traffic information to enroute motorists. Implementing a smart work zone on projects utilizing narrowed lanes or temporary pavement is beneficial to upstream motorists, preparing them to alter their downstream facility expectations. This likely has beneficial effects on mobility and safety of motorists approaching and through a work zone.

STA strategy responses varied widely in the rural resurfacing scenario matrix. Table 30 shows the only strategies highlighted were those that had few respondents identify the strategies individually. The 13 pairs of demand side traffic management and traffic conditions displayed on the Internet was the most pairs of all qualifying, highlighted pairs. These two strategies compliment each other in helping motorists choosing their travel mode, route and trip departure time.

Three strategies paired with temporary pavement all received 10 pair responses in the rural resurfacing matrix. Ten of 11 respondents indicating the use of temporary pavement also selected DMSs, nighttime construction schedules, and increased incident management capabilities. Each of these three strategies provides added mobility and safety benefits to the use of temporary pavement. Otherwise, the remaining strategy pairs are seven responses or less. Because very few strategy pairs are consistently included in the respondents' strategy combinations, this table also shows that the more frequently identified strategies have inconsistent pairing of strategies within an STA's transportation management plan.

Another strategy combination identified in the rural resurfacing matrix involves full road closures. All six respondents that indicated their agency would utilize a full road closure also identified three other strategies, DMSs, incentives/disincentives, and improved pre-construction traveler information. All three of these strategies are beneficial to the implementation of a full road closure by informing motorists, both pre-trip and enroute, and by attempting to reduce the length of the full closure as much as possible with incentives/disincentives.

Table 29. Strategy Pair and Individual Response Comparison, Rural Reconstruction Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Total Individual Strategy Responses	**9**	**37**	**10**	**6**	**29**	**33**	**7**	**7**	**17**	**21**	**37**	**28**	**25**	**4**	**19**	**25**	**26**	**26**	**16**	**28**
Smart Work Zones		9	6	3	7	7	2	2	3	6	8	6	7	1	5	7	5	9	7	9
Dynamic Message Signs	9		10	6	26	29	6	7	17	20	34	25	24	4	18	23	23	26	15	25
Travel Time and Delay Estimation System	6	10		3	7	7	2	2	5	7	8	6	6	1	5	6	5	7	5	9
Advanced Speed Information System	3	6	3		5	5	1	1	2	4	5	3	5	2	2	3	3	4	2	4
Traffic Conditions Displayed on Internet	7	26	7	5		25	5	6	11	16	26	20	18	4	18	19	18	18	11	21
Nighttime Construction Schedules	7	29	7	5	25		7	6	13	16	31	22	21	4	19	20	21	21	14	23
Full Road Closures	2	6	2	1	5	7		3	4	3	7	6	6	2	6	5	6	6	4	6
Design Build Construction	2	7	2	1	6	6	3		3	3	6	7	5	2	6	3	3	5	3	5
Lane Rental	3	17	5	2	11	13	4	3		12	16	10	13	1	9	10	10	10	8	10
A+B and A+B+C Contracting	6	20	7	4	16	16	3	3	12		20	14	15	3	10	14	12	15	12	18
Incentives and Disincentives	8	34	8	5	26	31	7	6	16	20		27	25	4	18	25	23	25	16	26
Interim Completion Dates and Liquidated Damages	6	25	6	3	20	22	6	7	10	14	27		18	3	13	19	20	19	12	21
Improved Pre-Construction Traveler Information	7	24	6	5	18	21	6	5	13	15	25	18		4	14	20	17	19	14	18
Mass Transit Improvements	1	4	1	2	4	4	2	2	1	3	4	3	4		4	3	2	3	3	3
Demand Side Traffic Management	5	18	5	2	18	19	6	6	9	10	18	13	14	4		12	13	15	9	15
Increased Incident Management Capabilities	7	23	6	3	19	20	5	3	10	14	25	19	20	3	12		18	18	14	21
Increased Speed Enforcement	5	23	5	3	18	21	6	3	10	12	23	20	17	2	13	18		17	11	19
Narrowed Lanes	9	26	7	4	18	21	6	5	10	15	25	19	19	3	15	18	17		11	22
Alternative Route Improvements	7	15	5	2	11	14	4	3	8	12	16	12	14	3	9	14	11	11		14
Temporary Pavement	9	25	9	4	21	23	6	5	10	18	26	21	18	3	15	21	19	22	14	

Table 30. Strategy Pair and Individual Response Comparison, Rural Resurfacing Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Total Individual Strategy Responses	**7**	**33**	**12**	**5**	**28**	**30**	**6**	**3**	**16**	**16**	**29**	**23**	**21**	**3**	**13**	**23**	**25**	**30**	**7**	**11**
Smart Work Zones		7	4	1	5	6	0	0	4	4	3	4	3	0	2	4	6	3	2	4
Dynamic Message Signs	7		11	5	23	24	6	2	14	14	25	20	17	3	12	20	21	20	5	10
Travel Time and Delay Estimation System	4	11		2	10	9	2	1	8	6	10	8	7	1	6	6	8	8	2	5
Advanced Speed Information System	1	5	2		5	5	2	0	2	1	4	2	4	1	1	4	3	2	0	2
Traffic Conditions Displayed on Internet	5	23	10	5		23	5	3	11	12	22	16	15	3	13	19	17	15	6	9
Nighttime Construction Schedules	6	24	9	5	23		4	3	12	12	21	15	17	2	10	16	19	16	4	10
Full Road Closures	0	6	2	2	5	4		1	3	4	6	4	6	3	4	5	5	5	2	3
Design Build Construction	0	2	1	0	3	3	1		1	1	2	2	1	1	3	1	2	2	1	1
Lane Rental	4	14	8	2	11	12	3	1		10	12	10	10	1	6	9	10	11	4	6
A+B and A+B+C Contracting	4	14	6	1	12	12	4	1	10		13	9	9	3	8	9	9	8	6	6
Incentives and Disincentives	3	25	10	4	22	21	6	2	12	13		20	18	3	11	17	18	17	5	9
Interim Completion Dates and Liquidated Damages	4	20	8	2	16	15	4	2	10	9	20		14	2	8	14	18	14	5	8
Improved Pre-Construction Traveler Information	3	17	7	4	15	17	6	1	10	9	18	14		3	8	14	16	13	5	7
Mass Transit Improvements	0	3	1	1	3	2	3	1	1	3	3	2	3		3	2	2	2	2	1
Demand Side Traffic Management	2	12	6	1	13	10	4	3	6	8	11	8	8	3		9	8	9	5	5
Increased Incident Management Capabilities	4	20	6	4	19	16	5	1	9	9	17	14	14	2	9		16	16	7	10
Increased Speed Enforcement	6	21	8	3	17	19	5	2	10	9	18	18	16	2	8	16		14	5	9
Narrowed Lanes	3	20	8	2	15	16	5	2	11	8	17	14	13	2	9	16	14		4	8
Alternative Route Improvements	2	5	2	0	6	4	2	1	4	6	5	5	5	2	5	7	5	4		4
Temporary Pavement	4	10	5	2	9	10	3	1	6	6	9	8	7	1	5	10	9	8	4	

In the urban reconstruction matrix, shown in Table 31, DMSs and nighttime construction schedules were identified in conjunction with 18 strategies by over 90 percent of the respondents that indicated use of the other 19 strategies. Individually, both DMSs and nighttime construction schedules were identified by 39 of the 41 respondents, thus are usually implemented in combination with the other strategies. Traffic conditions displayed on the Internet was identified by at least 90 percent of the respondents indicating the use of five other strategies and incentives/disincentives was frequently identified when seven other strategies were identified.

The urban reconstruction matrix provides an example of strategies frequently used with mass transit improvements. Over 90 percent of the 14 respondents that indicated their agency would utilize mass transit improvements also indicated they would use six other strategies, among others, within their transportation management plan. Demand side traffic management encourages mass transit ridership and promotes the improvements to the mass transit system and network. By providing the public with improved pre-construction traveler information, the demand management strategies are promoted and motorists understand the alternative travel modes and the benefits of alternative modes or routes. Traffic conditions on the Internet provide motorists information on determining alternative routes or modes, directing the motorist to the demand management strategies, mass transit via the public information.

The urban resurfacing matrix, shown in Table 32, is similar to that in the urban reconstruction scenario in that many of the highlighted strategy pairs include dynamic message signs and nighttime construction schedules. All strategies were paired with nighttime construction schedules by over 90 percent of the respondents and all strategies but one were paired with dynamic message signs. This was in part due to the individual responses of DMSs and nighttime construction schedules, receiving 38 and 39 responses respectively.

Of the four scenarios, the urban resurfacing scenario had the most highlighted strategies in the respective matrix. This is in part due to the common pairs incorporating DMSs and nighttime construction schedules, but several other strategies not involving those two also were common pairs. The matrix provides informative examples of what strategies are used in conjunction with a specific strategy, several of which were not frequently identified individually. Examples of these strategies and their highlighted pair include smart work zones and eight other strategies, advanced speed information systems with 5 other strategies, mass transit improvements with seven other strategies, and alternative route improvements with five other strategies.

Table 31. Strategy Pair and Individual Response Comparison, Urban Reconstruction Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Total Individual Strategy Responses	**11**	**39**	**20**	**8**	**34**	**39**	**16**	**14**	**21**	**23**	**35**	**32**	**29**	**14**	**28**	**28**	**27**	**28**	**26**	**25**
Smart Work Zones		11	9	6	10	10	5	5	6	7	10	9	9	4	7	8	7	9	6	9
Dynamic Message Signs	11		19	8	32	36	14	14	19	21	33	30	27	14	27	26	25	27	24	23
Travel Time and Delay Estimation System	9	19		6	18	19	7	9	13	14	17	16	16	8	15	13	12	14	13	13
Advanced Speed Information System	6	8	6		8	8	5	4	5	5	8	7	8	5	6	6	6	7	5	7
Traffic Conditions Displayed on Internet	10	32	18	8		31	13	13	15	19	29	27	24	13	24	23	22	23	21	22
Nighttime Construction Schedules	10	36	19	8	31		14	14	19	21	33	30	27	14	27	26	25	26	25	23
Full Road Closures	5	14	7	5	13	14		6	10	8	12	12	13	4	9	12	12	11	12	13
Design Build Construction	5	14	9	4	13	14	6		6	9	11	11	10	8	12	10	8	11	12	10
Lane Rental	6	19	13	5	15	19	10	6		16	18	16	17	8	14	13	12	15	13	14
A+B and A+B+C Contracting	7	21	14	5	19	21	8	9	16		21	17	19	11	17	15	13	17	15	16
Incentives and Disincentives	10	33	17	8	29	33	12	11	18	21		27	26	13	24	26	24	26	22	23
Interim Completion Dates and Liquidated Damages	9	30	16	7	27	30	12	11	16	17	27		24	12	22	23	23	23	20	21
Improved Pre-Construction Traveler Information	9	27	16	8	24	27	13	10	17	19	26	24		13	20	22	20	21	19	20
Mass Transit Improvements	4	14	8	5	13	14	4	8	8	11	13	12	13		14	11	10	11	11	9
Demand Side Traffic Management	7	27	15	6	24	27	9	12	14	17	24	22	20	14		21	19	22	21	17
Increased Incident Management Capabilities	8	26	13	6	23	26	12	10	13	15	26	23	22	11	21		21	24	21	20
Increased Speed Enforcement	7	25	12	6	22	25	12	8	12	13	24	23	20	10	19	21		18	19	18
Narrowed Lanes	9	27	14	7	23	26	11	11	15	17	26	23	21	11	22	24	18		19	20
Alternative Route Improvements	6	24	13	5	21	25	12	12	13	15	22	20	19	11	21	21	19	19		18
Temporary Pavement	9	23	13	7	22	23	13	10	14	16	23	21	20	9	17	20	18	20	18	

Table 32. Strategy Pair and Individual Response Comparison, Urban Resurfacing Strategies

	Smart Work Zones	Dynamic Message Signs	Travel Time and Delay Estimation System	Advanced Speed Information System	Traffic Conditions Displayed on Internet	Nighttime Construction Schedules	Full Road Closures	Design Build Construction	Lane Rental	A+B and A+B+C Contracting	Incentives and Disincentives	Interim Completion Dates and Liquidated Damages	Improved Pre-Construction Traveler Information	Mass Transit Improvements	Demand Side Traffic Management	Increased Incident Management Capabilities	Increased Speed Enforcement	Narrowed Lanes	Alternative Route Improvements	Temporary Pavement
Total Individual Strategy Responses	**10**	**38**	**20**	**8**	**28**	**39**	**13**	**9**	**20**	**19**	**32**	**26**	**28**	**12**	**22**	**30**	**27**	**27**	**17**	**16**
Smart Work Zones		10	9	5	9	10	5	3	7	6	8	9	9	4	6	9	8	10	7	8
Dynamic Message Signs	10		20	8	27	37	13	9	20	18	30	24	26	12	22	29	24	26	16	15
Travel Time and Delay Estimation System	9	20		7	17	20	8	5	12	12	16	14	17	8	14	17	13	14	11	11
Advanced Speed Information System	5	8	7		8	8	4	2	5	4	8	7	8	4	5	7	5	6	4	4
Traffic Conditions Displayed on Internet	9	27	17	8		27	12	8	13	16	24	20	22	11	19	24	19	20	15	14
Nighttime Construction Schedules	10	37	20	8	27		12	9	20	19	32	25	27	12	21	30	25	27	17	15
Full Road Closures	5	13	8	4	12	12		4	7	8	11	10	13	5	8	11	10	11	7	7
Design Build Construction	3	9	5	2	8	9	4		3	5	8	6	7	6	8	8	6	8	8	6
Lane Rental	7	20	12	5	13	20	7	3		12	15	12	16	6	9	13	10	14	7	9
A+B and A+B+C Contracting	6	18	12	4	16	19	8	5	12		16	11	15	9	12	15	11	15	10	10
Incentives and Disincentives	8	30	16	8	24	32	11	8	15	16		23	24	12	19	27	22	23	16	12
Interim Completion Dates and Liquidated Damages	9	24	14	7	20	25	10	6	12	11	23		22	9	16	24	20	21	15	12
Improved Pre-Construction Traveler Information	9	26	17	8	22	27	13	7	16	15	24	22		11	16	23	20	21	15	13
Mass Transit Improvements	4	12	8	4	11	12	5	6	6	9	12	9	11		11	11	9	10	9	6
Demand Side Traffic Management	6	22	14	5	19	21	8	8	9	12	19	16	16	11		21	16	18	14	12
Increased Incident Management Capabilities	9	29	17	7	24	30	11	8	13	15	27	24	23	11	21		23	26	15	14
Increased Speed Enforcement	8	24	13	5	19	25	10	6	10	11	22	20	20	9	16	23		21	16	12
Narrowed Lanes	10	26	14	6	20	27	11	8	14	15	23	21	21	10	18	26	21		17	14
Alternative Route Improvements	7	16	11	4	15	17	7	8	7	10	16	15	15	9	14	15	16	17		11
Temporary Pavement	8	15	11	4	14	15	7	6	9	10	12	12	13	6	12	14	12	14	11	

5.5.3 Strategy Pairs Summary

This section identifies pairs of strategies that were common in STAs' responses for each scenario. Two objectives were met, 1) identify the pairs that were most frequently identified by respondents and 2) identify strategy pairs that were frequently selected by the respondents based on the total number of responses for a specific strategy. The matrices are an effective tool to first identify what strategies other STAs are most frequently utilizing and then identify what strategies are being most frequently utilized in conjunction with a specific individual strategy.

The analysis of total strategy pairs identified strategies that were frequently paired together. A summary table in each subsection provides the pairs with more than 25 responses. As expected, the most pairs were in the urban reconstruction, followed by the urban resurfacing, rural reconstruction and rural resurfacing scenario. The rural resurfacing scenario only had one strategy pair that received more than 25 responses, while the urban reconstruction had 24.

The second component of this analysis is a set of matrices that facilitates the building of strategy combinations for a project. These matrices allow someone to identify what strategies other STAs are commonly utilizing with a certain strategy, regardless of total number of responses the strategy received. For all scenarios but the rural resurfacing scenario, a few strategies were frequently identified with several other strategies (dynamic message signs, nighttime construction, and incentives/disincentives). The rural resurfacing scenario showed a wide variety of strategies selected by STAs, with minimal consistency across the agencies.

5.6 Work Zone Lane Capacity Values

The literature review discussed the issue of STAs using different values for work zone lane capacities. The lane capacity values vary widely due to many location specific variables, such as driver characteristics, facility design, terrain, and the tool used to calculate the value. One of the objectives of this research is to investigate the possible influence of a high or low lane capacity value may have on an STA in their decision to utilize various strategies to reduce work zone congestion. A benefit to this objective is that it also provides examples of strategy implementation based on work zone lane capacity values.

The survey allowed the respondents to provide Interstate work zone lane capacity values their agency uses for all lane configurations. However, many respondents indicated that they did not know what their agency used or their agency did not have any statewide lane capacity values. Others indicated their agency does not use lane capacity values as a threshold value; rather they use a delay or queue length estimation from a simulation of the work zone. Even though a lane capacity is needed as an input to determine vehicle queue or delay, they were not identified by these agencies.

Because of the few responses, the analysis incorporates the lane capacity values identified in the survey and the values displayed in Table 3 from the literature review for STAs that submitted a survey but did not provide lane capacity values. The analysis uses 18 lane capacity values, which are categorized into three ranges shown in Table 33. The lane closure configurations are one lane open, one lane closed for the rural facilities and two lanes open, one lane closed for the urban facilities. A few STAs that did respond provided a range of values. As a basis for consistency, the upper value was used for this application because the terrain at each scenario location was relatively flat and the facilities lack any unexpected situations.

Table 33. Number of Respondents with Agency Lane Capacity Category Ranges

Rural Facilities *one lane open and one lane closed*			
1200 vphpl and less	**1201 – 1400 vphpl**	**1401 – 1600 vphpl**	**1601+ vphpl**
5	7	6	0
Urban Facilities *two lanes open and one lane closed*			
1200 vphpl and less	**1201 – 1400 vphpl**	**1401 – 1600 vphpl**	**1601+ vphpl**
5	6	5	2

The work zone lane capacity values differed greatly across the 18 agencies. The agencies with the higher lane capacity values are generally in more urban locations. Achieving these higher capacity values without experiencing congestion is debatable, especially those greater than 1600 vphpl. Generally, the lane capacity values in the lower and middle categories, less than 1400 vphpl, are more accurate to a typical work zone in most locations. One issue to account for in this analysis is that a facility deemed rural by one STA may be different than in another. As an example, rural Wyoming is much less populated than rural New York. This is similar in urban locations as well. The population density in New York City is different from that in Des Moines, Iowa.

5.6.1 Analysis Components

In the discussion of strategies, the lane capacity categories displayed in Table 33 for the rural scenarios are identified by the following:

- Lower Category: 1200 vphpl and less
- Middle Category: 1201 – 1400 vphpl
- Upper Category: 1401 – 1600 vphpl

For the urban scenarios, the two agencies with the lane capacity values greater than 1600 vphpl were combined with the agencies having lane capacities between 1401 and 1600 vphpl. This was done to create a larger category of seven agencies for comparison. The lane capacity categories for the urban scenario are as follows:

- Lower Category: 1200 vphpl and less
- Middle Category: 1201 – 1400 vphpl
- Upper Category: 1401 vphpl and greater

In the scenario tables, each column represents an STA respondent and their strategy responses. A strategy that was selected by a respondent is indicated by the filled, red boxes. The bottom of the table allows for the notes portion. Respondents that indicated any other strategies they use in a similar situation are indicated in the "Other Strategies" row and detailed in the "notes" section.

5.6.2 Rural Reconstruction Scenario

The rural reconstruction project utilizes a one lane open, one lane closed configuration for categorizing the lane capacity values provided by STAs. Table 34 displays the strategies identified by respondents, shown in the filled boxes, based on their STA's work zone lane capacity values.

Most strategies within the traffic management strategies group had varied responses between the three lane capacity value ranges. The use of ITS technologies increased with respondents that identified increasing values for lane capacity. Only two of the six respondents in the upper range indicated use of traffic conditions displayed on the internet. The other two lane capacity categories combined had 11 of 12 respondents indicate their STA displays traffic conditions on the internet for a rural reconstruction project. Another strategy that had varied responses was increased speed enforcement, with the fewest responses in the middle lane capacity category. The narrowed lanes strategy was predominant in the largest lane capacity value category, as the other two categories did not indicate this strategy as frequently.

A few strategies displayed a trend in response across the three STA lane capacity ranges for the other four strategy groups. The demand management strategies received similar responses for all strategies except demand side traffic management strategies, where the middle lane capacity category received more responses than the other two categories combined. All STAs in the category with the smallest work zone lane capacity values identified the use of nighttime construction schedules and the frequency of response decreased as the lane capacity value groups increased. For alternative contracting and project delivery strategies, A+B and A+B+C contracting was more frequently identified in the middle category than the other two. The use of incentives/disincentives was unanimous for the bottom two categories and all but one respondent identified this strategy in the top category.

An interesting response in this table is from the respondent in the far right column. This agency has a work zone lane capacity value between 1401 and 1600 vphpl, but only indicated they would utilize nighttime construction schedules and avoid the peak periods for lane closures. It would be interesting to investigate the success of only using this one strategy and simply avoiding peak periods. If utilizing off peak hour work, specifically at night, is all that is needed, the other agencies utilizing several strategies may be using too many that are unnecessary. Another possibility is that congestion still exists and the levels are deemed acceptable to the agency. If congestion exists, another possibility is that other strategies may not be used due to a number of factors, such as agency financial and staffing constraints. The rural facilities in the state may not have large traffic volumes and the work zone lane capacity value may not be specifically accurate to the rural facilities.

Table 34. Rural Reconstruction Scenario Strategies Based on Lane Capacity Values

	Lower Category					*Middle Category*							*Upper Category*					
	1200 vphpl and less					**1201 – 1400 vhphl**							**1401 – 1600 vphpl**					
Smart Work Zone		■												■	■			
Dynamic Message Signs	■	■			■	■	■		■	■	■	■	■	■	■	■	■	
Travel Time and Delay Estimation System											■			■	■			
Advanced Speed Information System					■						■							
Traffic Conditions on Internet		■	■	■	■	■	■	■	■	■	■	■	■		■			
Narrowed Lanes		■							■	■		■	■	■	■	■	■	
Increased Incident Management	■	■		■	■		■	■	■	■		■	■	■	■	■	■	
Increased Speed Enforcement	■	■	■	■	■	■		■					■	■		■	■	
Demand Side Traffic Management		■						■	■	■	■		■					
Alternative Route Improvement	■	■		■			■		■				■	■				
Improved Pre-Construction Traveler Information	■	■		■	■		■		■	■	■		■	■	■	■	■	
Mass Transit Improvements									■		■		■					
Temporary Pavement		■	■	■				■	■	■		■	■	■	■	■		
Nighttime Construction Schedules	■	■	■	■	■	■		■	■		■	■	■	■				■
Full Road Closures								■					■	■				
Design/Build Construction									■						■			
Lane Rental	■					■	■			■	■			■			■	
A+B and A+B+C Contracting				■		■	■		■	■	■		■	■	■			
Incentives/Disincentives	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Interim Completion Dates and Liquidated Damages		■	■	■		■	■	■	■			■	■	■	■	■	■	
Other Strategies	■ 1							■ 2								■ 3	■ 4	■ 5

Notes:
1. Use of late merge signing during lane closures
2.Partial (weekend only) full closure a possibility
3.Off-peak construction only
4.Off-peak construction only
5. Off -peak construction eliminating work during the highest 2-3 hour peak demand daily

5.6.3 Rural Resurfacing Scenario

The rural resurfacing project utilizes a one lane open, one lane closed configuration for categorizing the lane capacity values provided by STAs. Table 35 displays the strategies identified by respondents, represented by the filled boxes, based on their STA's work zone lane capacity values.

Three strategies in the traffic management strategies group had differing response rates across the three lane capacity value categories. ITS technologies increased as the lane capacity categories increased. Dynamic message signs were widely used across the two categories with the largest work zone lane capacity values. As in the rural reconstruction scenario, the same two STAs in the bottom category indicated they would not use dynamic message signs. The STAs with the lane capacity values in the highest category identified traffic conditions displayed on the internet the least of the three categories. Increased speed enforcement was more common in the largest and smallest lane capacity value categories, while less than half of the respondents indicated that their STA would utilize this strategy in the middle lane capacity category.

Table 35. Rural Resurfacing Strategies Based on Lane Capacity Values

	Lower Category					*Middle Category*							*Upper Category*					
	1200 vphpl and less					**1201 – 1400 vphpl**							**1401 to 1600 vphpl**					
Smart Work Zone		■												■		■		
Dynamic Message Signs	■	■			■	■	■	■		■	■	■	■	■		■	■	■
Travel Time and Delay Estimation System												■		■		■		
Advanced Speed Information System					■							■						
Traffic Conditions on Internet		■	■	■	■	■	■	■	■	■	■	■	■					
Narrowed Lanes	■	■					■			■	■		■	■				■
Increased Incident Management	■	■		■	■		■		■	■	■		■				■	■
Increased Speed Enforcement	■	■	■	■	■	■			■	■			■	■		■	■	■
Demand Side Traffic Management										■	■	■	■					
Alternative Route Improvement				■						■			■					
Improved Pre-Construction Traveler Information	■		■	■	■			■		■		■	■	■	■		■	■
Mass Transit Improvements										■		■	■					
Temporary Pavement	■	■		■						■	■			■				
Nighttime Construction Schedules	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■		
Full Road Closures	■									■		■	■					
Design/Build Construction										■								
Lane Rental	■					■	■				■	■		■				■
A+B and A+B+C Contracting	■			■		■		■		■	■	■	■	■		■		
Incentives/Disincentives	■		■	■	■	■	■	■		■	■	■	■	■		■	■	■
Interim Completion Dates and Liquidated Damages	■		■	■		■	■			■			■	■			■	■
Other Strategies					1												■ 2	

Notes:
1. Similar strategies are used for rural reconstruction project, but less aggressively.
2. Lane closures during off peak times

Demand management strategies were similar across all three lane capacity value categories except for improved pre-construction traveler information. Improved pre-construction traveler information responses were more frequent in the categories with the largest and smallest lane capacity values. Similar to the responses in the rural reconstruction scenario, nighttime work schedules were common in the bottom two categories, but only received three responses from six respondents in the top group. Alternative contracting and project delivery techniques appear to be similar across all categories.

A couple of agencies represented in the middle category appear to have a very aggressive use of strategies because of their selection of many strategies for this scenario. Many of the strategies they indicated appear to be the exception, and not the norm, when compared to agencies in the other two categories. Examples include demand side traffic management and mass transit improvements.

As previously shown in the Current Implementation Results, Section 5.2, this scenario had the fewest number of responses. Compared to the other tables in this section, fewer strategies are identified across all three categories in this scenario.

5.6.4 Urban Reconstruction Scenario

The urban reconstruction project utilizes a two lanes open, one lane closed configuration for categorizing the lane capacity values provided by STAs. For this lane closure configuration, two respondents indicated that they have a lane capacity value of greater than 1601 vphpl. When discussing the lane capacity values for this scenario, these two STAs are combined with the five STAs in the 1401-1600 vphpl to form one category. Table 36 displays the strategies identified by respondents, represented by the filled boxes, based on their STA's work zone lane capacity values. As described in the Current Strategy Implementation, Section 5.2, the urban reconstruction scenario had the largest number of responses. This is evident in the table below as most STAs identified several more strategies for this project.

The STAs' use of ITS technologies is common for the urban reconstruction project scenario. Across all categories, all but one respondent indicated that their respective agency would utilize dynamic message signs. Travel time and delay estimation systems were identified by five of the seven STA respondents with lane capacity values greater than 1401 vphpl. The category with the smallest lane capacity values had fewer responses than the other two categories for both narrowed lanes and increased incident management. However, the lowest lane capacity category had all respondents indicate they would use increased speed enforcement.

Three strategy trends were identified within the demand management strategy group. Demand side traffic management responses decreased for the upper lane capacity value category and were unanimous in selection by respondents in the middle category. For alternative route improvements, the number of responses also decreased as lane capacity value categories increased. Improved pre-construction traveler information increased across the three strategies and culminated by all seven respondents with a lane capacity greater than 1401selecting the strategy.

Nighttime construction schedules are widely used by STAs across all lane capacity categories, while full road closures received very few responses. Few trends were evident in the alternative contracting strategy group. Only one of the five respondents in the lowest lane capacity range selected lane rental. It was selected by four of six in the middle range and by four of seven in the upper range. Every respondent in the top two categories and four of five in the smallest category indicated they utilize incentives/disincentives

Table 36. Urban Reconstruction Strategies Based on Lane Capacity Values

	Lower Category					*Middle Category*						*Upper Category*						
	1200 vphpl and fewer					**1201 – 1400 vphpl**						**1401 – 1600 vphpl**					**1601+ vphpl**	
Smart Work Zone		■											■				■	
Dynamic Message Signs	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■
Travel Time and Delay Estimation System		■	■								■		■	■		■	■	■
Advanced Speed Information System		■									■							
Traffic Conditions on Internet	■	■	■	■	■	■	■	■		■	■	■	■	■		■	■	
Narrowed Lanes		■			■	■	■	■	■	■		■	■		■	■	■	
Increased Incident Management		■		■	■	■	■	■	■	■		■	■	■	■		■	
Increased Speed Enforcement	■	■	■	■	■	■	■	■				■		■	■		■	■
Demand Side Traffic Management	■	■	■		■	■	■	■	■	■	■	■		■	■		■	
Alternative Route Improvement	■	■		■	■	■	■	■	■	■				■	■		■	■
Improved Pre-Construction Traveler Information		■		■			■	■	■		■	■	■	■	■	■	■	■
Mass Transit Improvements	■	■			■			■			■	■		■	■			
Temporary Pavement	■	■		■		■	■	■		■			■				■	■
Nighttime Construction Schedules	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
Full Road Closures						■	■	■									■	■
Design/Build Construction	■	■			■			■					■					
Lane Rental	■					■	■		■		■				■	■	■	■
A+B and A+B+C Contracting	■	■		■		■		■	■		■	■	■		■	■	■	■
Incentives/Disincentives	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Interim Completion Dates and Liquidated Damages	■	■	■	■		■	■	■		■		■	■	■	■	■	■	
Other Strategies							■ 1			■ 2								

Notes:
1. Movable barriers for facilities with highly directional traffic
2. Avoid lane merge situations. Utilize lane drops at exit ramps instead

5.6.5 Urban Resurfacing

The urban resurfacing project utilizes a two lane open, one lane closed configuration, for categorizing the lane capacity values provided by STAs. Table 37 displays the strategies identified by respondents based on their STA's work zone lane capacity values, represented by the filled boxes.

Table 37. Urban Resurfacing Strategies Based on Lane Capacity Values

	Lower Category					*Middle Category*						*Upper Category*						
	1200 vphpl and fewer					**1201 – 1400 vphpl**						**1401 to 1600 vphpl**					**1601+ vhphl**	
Smart Work Zone		■															■	
Dynamic Message Signs	■	■	■		■	■	■	■	■	■	■	■		■	■	■	■	■
Travel Time and Delay Estimation System		■	■								■	■		■			■	■
Advanced Speed Information System		■	■								■							
Traffic Conditions on Internet		■	■	■	■	■	■		■	■	■	■		■			■	
Narrowed Lanes	■	■			■			■	■	■		■	■		■		■	
Increased Incident Management	■	■		■	■			■	■	■		■	■	■	■		■	
Increased Speed Enforcement	■	■	■	■	■	■		■	■			■	■	■	■		■	■
Demand Side Traffic Management	■	■	■		■				■	■	■	■		■	■			
Alternative Route Improvement				■	■				■					■	■		■	
Improved Pre-Construction Traveler Information		■	■	■					■		■	■	■	■	■	■	■	■
Mass Transit Improvements		■			■				■		■	■		■	■			
Temporary Pavement				■					■	■							■	■
Nighttime Construction Schedules	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Full Road Closures									■		■	■					■	
Design/Build Construction		■			■				■									
Lane Rental	■						■			■	■				■	■	■	■
A+B and A+B+C Contracting		■		■		■			■	■	■	■			■	■	■	
Incentives/Disincentives	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	
Interim Completion Dates and Liquidated Damages	■	■	■	■			■		■				■	■	■		■	
Others														■ 1	■ 2			

Notes:
1. Lane closures in off-peak hours. Communication with area business groups, large traffic generators, etc. Selected use of short term ramp closures.
2. Off-peak lane closure

The responses for traffic management strategies varied across the three lane capacity categories in the urban resurfacing scenario project. The use of ITS strategies generally remained similar across the three categories, except travel time and delay estimation systems. Four of the seven respondents in the top lane capacity category indicated their agency would utilize this system. However, only three of the seven respondents in the same category indicated their agency would display traffic conditions on the internet. This was a dramatic decrease from the other two categories. Increased speed enforcement was unanimous in the category with the smallest lane capacity values and six of seven indicated this strategy in the top category.

The other four strategy groups had few strategies that varied in response across the three lane capacity categories. Improved pre-construction traveler information was unanimous in the top group and not identified as frequently in the other two categories. Every respondent in this table indicated their agency would utilize nighttime construction schedules. The alternative contracting and project delivery techniques received similar rates of response across the five groups, with emphasis on incentives/disincentives. Interim completion dates and liquidated damages and A+B and A+B+C contracting also had frequent response, but slightly less than incentives/disincentives. Only two of the six respondents in the middle category indicated their agency would utilize interim completion dates and liquidated damages.

5.6.6 Work Zone Lane Capacity Values Conclusions

This section displays the strategy combinations of STAs that identified their agency's work zone lane capacity values for the four scenarios. The objective of this analysis was to determine if there is any relationship between lane capacity values and strategies used by the respective STAs. Eighteen respondents were used and categorized into three lane capacity value ranges.

For about 75 percent of the strategies, it was difficult to determine any sort of trend across the three lane capacity ranges. For these strategies, the responses were similar across all three lane capacity categories, such as strategies being identified either frequently, infrequently, or having around half of the respondents in each category signify implementation. One issue that contributed to this difficulty was the lack of possible respondents, 18 over three categories. If only a couple of respondents indicated their agency did not utilize a strategy, it would appear that the respective strategy is not used by agencies categorized that range.

In the other 25 percent of the strategies in each scenario, the responses displayed a trend in use across the three lane capacity categories, as shown in Table 38. The trend is based on going from the agencies in the lower lane capacity category (1200 vphpl and less), across the middle category to the upper category of agencies with the largest lane capacity values. Three trends were identified in the summary table. The frequency of respondents indicating the use of a specific strategy either linearly increased or decreased across the three categories. Another possibility was the respondents in the middle category identifying a specific strategy most or least frequently, displaying more of a parabolic identification distribution. The other trend identified was where the upper or lower category received more or less responses than the other two categories. For example, this is distinguished by "decrease for upper category only".

The term "ITS Technologies" incorporates the strategies smart work zones, DMSs, travel time and delay estimation systems, advanced speed information systems, and traffic conditions displayed on the Internet, unless otherwise identified. For most of these strategies, the strategy responses individually were not numerous enough to identify a significant trend. However, when all ITS strategies were combined together and viewed as a group, trends were often evident. The ITS strategies that received enough responses to identify a trend individually are also shown in the summary table.

Table 38. Summary of Lane Capacity and Strategy Trends

Strategies	**Trend Across Lane Capacity Categories** *Response frequency increases or decreases as lane capacity value ranges increase -or- One category differs from other two categories*
Rural Reconstruction	
ITS Technologies	Increases
Narrowed lanes	Increases
Increased speed enforcement	Decrease for upper category only
Demand side traffic management	Highest for middle
Traffic conditions displayed on Internet	Decreases
Nighttime construction schedules	Highest for middle
A+B and A+B+C contracting	Lowest for middle
Rural Resurfacing	
ITS Technologies	Increases
Traffic conditions displayed on Internet	Decrease for upper category only
Increased speed enforcement	Lowest for middle
Improved preconstruction traveler information	Lowest for middle
Nighttime construction schedules	Decrease for upper category only
Urban Reconstruction	
ITS Technologies	Increases
Travel time and delay estimation system	Increase
Demand side traffic management	Decreases
Alternative route improvements	Decreases
Improved pre-construction traveler information	Increases
Lane rental	Increases
Urban Resurfacing	
Traffic conditions displayed on internet	Decrease for upper category only
Increased speed enforcement	Lowest for middle
Nighttime construction schedules	Unanimous across all three ranges
Improved pre-construction traveler information	Lowest for middle
Interim completion dates and liquidated damages	Lowest for middle

It is reasonable that the use of the Intelligent Transportation System strategies increases as the work zone lane capacity range categories increases. In states that have more populated rural areas, the facilities have greater traffic volumes and the likelihood is greater that ITS technology is currently in place for easy implementation. Similarly, the availability of alternative routes is greater, thus improving the effectiveness of disseminating traffic condition information to motorists and them choosing an alternative route. However, the traffic conditions displayed on the internet were least identified by the agencies in the highest category. While these agencies actively used other ITS technology, they did not use traffic information to display the information on the Internet. This strategy was identified the most by the STAs in the lower category, which are likely more rural, less populated states. In addition to traffic conditions displayed on the Internet, nighttime construction and increased speed enforcement were generally identified the most frequently in the lowest lane capacity category.

Similar to the rural scenarios, ITS technology use generally increased as the lane capacity categories increased towards the urban states in the upper category. The information collected and disseminated through ITS is very beneficial to motorists in congested areas, especially during peak periods, providing them with relevant and timely traffic information. The agencies in the upper category also identified improved pre-construction traveler information and lane rental more frequently or at a similar frequency than the other two agency categories. The lower lane capacity category, consisting of less populated states, indicated the use of demand side traffic management and alternative route improvement strategies in the urban reconstruction strategy. Most cities in the rural states typically do not have an extensive demand side traffic management program, with an exception being Des Moines. Therefore, implementation of this sort of strategy is incorporated with large projects, while larger urban areas typically use existing programs.

Generally, there is minimal trend and it is difficult to draw any conclusions based on the comparison using STA work zone lane capacity values. An alternative analysis to this could be one that looks at agencies by region or similar terrain and motorist characteristics. Many strategy trends are subject to interpretation, due to the few respondents in each category. The summary table identifies the more significant trends or differences across the three categories and is by no means all the trends possible in this type of analysis. A larger sample size would be necessary to determine differences among other strategies and to validate these strategy trends.

Another benefit of this section is the sample of strategy combinations STAs use at given lane capacity ranges. There may be some correlation between the lane capacity value of an STA and what strategies the others are using so they can model their TMPs after the other STAs' examples. However, this does provide a very good example of what other STAs are utilizing for strategies and what their lane capacity values are. An STA can relate between their lane capacity values and strategies used by other STAs to assist themselves in determining what strategies they are going to use in their transportation management plan.

5.7 Traffic Simulation and Work Zone Traffic Planning Tools

During the work zone planning process, many STAs utilize work zone impact analysis and simulation tools to estimate and analyze the impacts of a work zone lane closure on traffic. The respondents had the opportunity to identify all tools they utilize during the planning process. One objective of this question is to determine if the use of certain work zone traffic simulation or analysis tools affected the selection of congestion mitigation strategies. In addition, the list of tools provided by the respondents may be beneficial to STAs that are beginning to analyze work zone impacts.

Table 39 provides two columns of responses. The first is the "Totals" column that displays the number of responses each simulation or planning tool received. The survey respondents were neither limited to a predetermined list of tools nor limited to identifying only one strategy. Each respondent could indicate and discuss all work zone analysis tools utilized by their agency, regardless of the extent. Many respondents provided strategies that their agency uses on a limited basis, which are included in the "Totals" column and indicated in the "Limited Use" column. The most common examples of limited use were using simulation tools to analyze only major projects or only urban facilities. It should be noted that the "Limited Use" totals could be greater than displayed if all respondents described the extent they utilize each tool.

Table 39. Traffic Simulation and Planning Tools Summary

Traffic Simulation and Planning Tools	Totals	Limited Use
Highway Capacity Manual and Spreadsheets	22	2
CORSIM	9	4
Synchro/SimTraffic	10	4
QUEWZ	8	3
QuickZone	12	5
VISSIM	2	
MITSIM	1	
CO3	2	
Paramics	1	
Moskovitz Curve	1	
Consulting or Research Center	2	1
Do Not Use Simulation	4	
Starting or Planning to Use	5	
Did Not Respond	2	
Number of Respondents = 42		

The results in Table 39 indicate that the two most frequently identified tools were deterministic queuing tools. The use of Highway Capacity Spreadsheets or Highway Capacity Manual theory received the most responses with 22. This category includes the spreadsheets developed by STAs specific to their agency. QuickZone had the second most responses with 12. However, of these 12 respondents, five indicated that they only utilize QuickZone on a limited basis. The next two most frequently identified strategies were microscopic simulation tools. Synchro/SimTraffic and CORSIM received 10 and 9 responses respectively. Similar to QuickZone, a few of these respondents indicated they only use these two simulation tools on a limited basis. The other tool that received several responses, five, was the deterministic queuing tool QUEWZ. Overall, the responses indicated that many STAs use Highway Capacity Spreadsheets as their primary tool and are either beginning to implement other tools or already use them on a limited basis for more complex projects. The results in this survey were similar to those obtained in a survey administered by Edara, shown in Table 5 of the literature review (60).

Various other tools were identified by only one or two STAs. These mostly consisted of microscopic simulation tools with network trip distribution capabilities, such as VISSIM, MITSIM and Paramics. Four STA respondents indicated their agency does not currently use any simulation or analysis tools. However, these four STAs were also planning to use simulation and planning tools in conjunction with their updated safety and mobility policy.

An original objective of this question was to determine if the use of certain work zone traffic simulation or analysis tools affected the selection of congestion mitigation strategies. After reviewing the responses, it was difficult to determine the extent some STAs utilize each tool. Many of the STAs provided a complete list of tools they use or planning to use in the future. However, some respondents did not provide an all inclusive list, rather listed only a couple of strategies and alluded to more. Therefore, it would be difficult to investigate the effect of extensive work zone analysis has on the selection of congestion mitigation strategies with these responses. Follow up with each agency would be needed to understand the full extent of their analysis during the planning stages.

The literature review provides a summary of two research evaluations of various analysis tools. Both evaluations found that the estimated traffic conditions in a simulation program or analysis tool did not replicate actual field conditions. From the results in the literature review and survey results in this project, further research is needed. One, STAs are using many different tools. Standardizing the use of a simulation program that reflects actual conditions can help with determining strategies to reduce the expected impacts. Second, in order to do standardize the analysis tools across STAs, further research needs to be completed to determine what program adequately estimates the work zone impacts or determining what is needed to improve the programs.

5.8 Future Strategy Implementation Identification

An important aspect of improving safety and mobility through a work zone is the continuous research, development, and improvement of existing congestion mitigation strategies and technology. STA staff that deal with work zone issues on a daily basis and view conditions in the field often have good ideas of what needs to be accomplished. However, the transition from identifying what they would like to see done to research and development is sometimes lost. Research, development and education can greatly benefit STAs when implementing congestion mitigation strategies, especially when they are new to the agency. Failure to apply a strategy correctly can lead to unacceptable delays and queues that can cripple a facility or surrounding network.

Increasing traffic volumes on Interstate facilities nationwide is a reason more STAs are now looking at mobility impacts on facilities and project types they previously did not consider. An example of this is on rural facilities such as Interstate 80 in the rural states Iowa and Nebraska. During the peak periods on this facility, a lane closure can create long queues and delays as well as safety concerns. Mobility impacts on urban and rural resurfacing projects may not have been previously considered by some STAs because of the short duration and the ability to complete the project between daytime or nighttime peak periods. However, as traffic volumes increase and peak periods expand to longer durations, the open work window becomes smaller. This type of project will begin to impact traffic, whereas it did not in previous implementation.

The future strategy identification questions consist of two components. The first component consists of respondents identifying strategies that their agency is currently research or planning to apply in the future. Figure 26 graphically displays the respondents' strategy identification. The second component is the identification of strategies the respondents would like to see applied or researched in the future, based on their knowledge and experience of work zones.

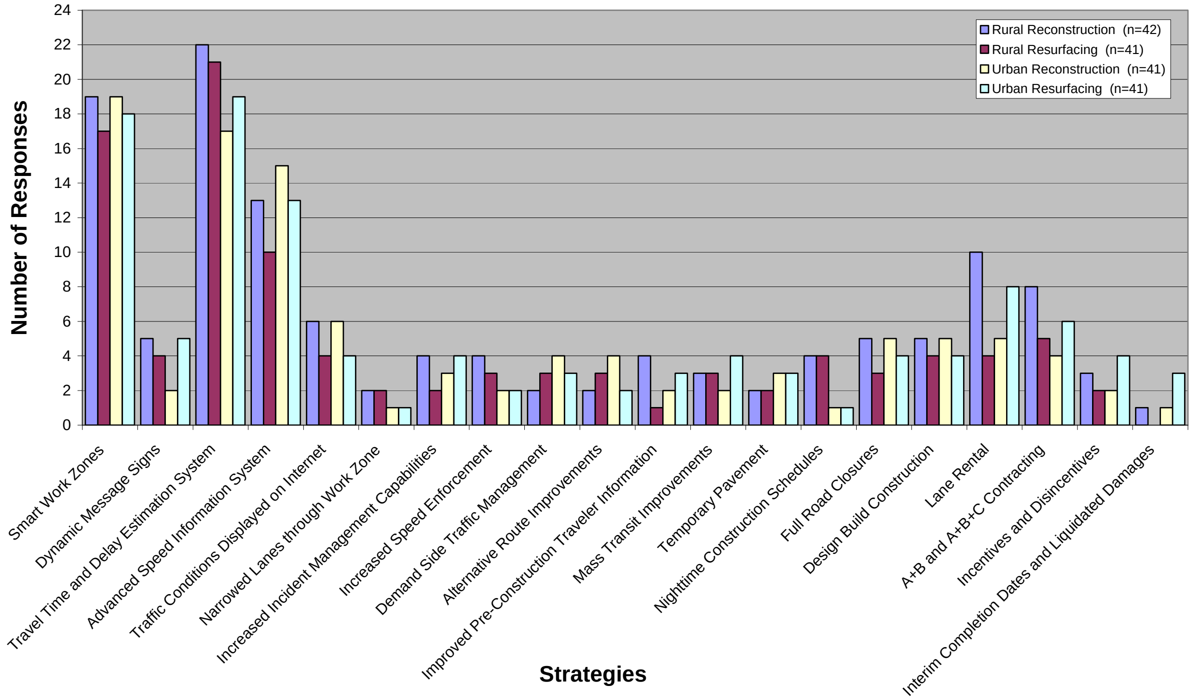

Figure 26. Future Strategy Implementation Summary

The STA respondents indicated that their agencies are looking into primarily utilizing traffic management strategies and, to a lesser extent, alternative contracting strategies in the future. The three strategies that received the most responses are all in the traffic management strategies group: smart work zones, travel time and delay estimation system, and advanced speed information systems. All three are possible components of an Intelligent Transportation System. As previous mentioned, a smart work zone is another name for the implementation of an Intelligent Transportation System, which may include a travel time and delay estimation system or an advanced speed information system. The component that disseminates the traffic information to enroute motorists, dynamic message signs, received very few responses because of its current widespread use.

Design/build, lane rental, and A+B and A+B+C contracting received more than five responses in several scenarios. Further, lane rental received 10 and 8 responses in the rural reconstruction and urban resurfacing scenarios, respectively. A+B and A+B+C contracting also received eight responses in the rural reconstruction scenario and six in the urban resurfacing scenario. The interest in alternative contracting and project delivery strategies is likely due to two factors. One, many agencies did not utilize these strategies on past projects, instead used traditional contracting techniques because there was little focus on mobility impacts and lane occupancy. Two, implementation of these strategies by STAs that have been utilizing them for a while has been successful.

Several alternative contracting and project delivery strategies received more than five responses in a scenario. Lane rental and A+B and A+B+C contracting received six or more responses for the rural reconstruction and urban resurfacing scenarios. Several agencies have not utilized these strategies in the past, but are now considering implementation to address mobility issues.

The comments portion of the future agency strategy implementation question allowed STAs to provide insight of their future strategy objectives to maintain safety and mobility through a work zone. Several respondents indicated that they would like to have a better understanding of work zone congestion strategies, how they are applied, and to what projects they maximize their benefits. Another common response was that their STA is currently beginning to look at congestion mitigation strategies. Therefore, all strategies are being considered for future projects and the ones identified in the multiple selection portion of the question are the strategies that are being more actively pursued. Other comments were geared specifically to strategies provided in the predetermined strategy list.

- Traffic conditions on the Internet
    - System improvements
    - Utilizing closed circuit cameras and a traffic center
- Full road closures
    - Future consideration on reconstruction projects
- Lane rentals and other disincentives
    - Increase use
    - Refine fee structures
- Design/build
    - Legislative action needed to implement on regular basis
- Continue with MUTCD guidelines on resurfacing projects

The comments portion of the question also allowed the respondents to identify other strategies that are not provided in the predetermined strategy list. The respondents indicated that these strategies could be potentially utilized for all scenarios.

- Reversible lanes
- Further advancement of ITS strategies
- Split merge designs, similar to Ohio Department of Transportation design
- Movable temporary rumble strips (had many rear end crashes due to queuing)
- 511 Traveler Information
- Traffic Management Center development and ITS integration

The second component of the future strategy implementation section is a question that allowed the respondent to identify what strategies they would like to see utilized. This question was independent of what strategies the respondent's agency was planning to use in the future, rather allowing them to provide their own thoughts on work zone congestion mitigation strategies. Table 40 lists the responses for the four project types used in the scenarios.

Table 40. Strategies for Future Consideration, Respondents' Suggestions

Rural Reconstruction	Rural Resurfacing
• Late merge • Alternate route improvements • Development of district's traffic center to coordinate with law enforcement	• Refine late merge concept • Utilizing manageable project lengths (try and keep it reasonable, short) • Temporary express lanes (no ramp connections) • Overbuilding project features to gain additional work zone mobility • Full closures • Continue to develop accurate lane rental fees
Urban Reconstruction	**Urban Resurfacing**
• Considering the transportation network • ITS/ traffic control center development	• Arterial DMS diversion route trailblazers • Traffic conditions on the internet • Travel time and delay systems • ITS/traffic control center development

One respondent indicated they would like to see more coordination between work zone ITS applications and permanent DMSs. Sometimes, there is a miscommunication or apprehension about using permanent devices for work zone information. In addition, the respondent feels that traffic management centers are crucial to this type of work. A few other survey respondents indicated the balance needed between project costs and maintaining mobility. In order to maximize benefits while minimizing costs, all strategies applicable to certain project should be considered to achieve a comprehensive solution. The extent of the congestion mitigation depends on the agency's objectives towards maintaining mobility through a work zone.

5.9 Survey Analysis Summary and Concluding Remarks

The urban reconstruction scenario received the most State Transportation Agency responses for strategies used to reduce work zone congestion, followed by the urban resurfacing, rural reconstruction and rural resurfacing scenarios. The urban reconstruction scenario combines two variables that result in higher road user costs, the high traffic volumes of an urban Interstate facility and the longer duration of a reconstruction project. Therefore, a more extensive Transportation Management Plan is necessary to reduce the work zone impacts. While traffic volumes are typically less on rural facilities, many are experiencing increases in traffic volumes to levels that require STAs to consider the mobility impacts of a lane closure. Many strategies used for urban facilities do not provide the same benefits for rural facilities, typically because of a different type of motorists' trip purpose. This research looked at what STAs are utilizing to maintain adequate levels of safety and mobility on rural and urban facilities, while looking at current implementation, past experiences and future objectives.

Through the identification of strategies that STAs utilize on projects similar to the four scenarios, it was found that agencies are typically looking at many different areas to try to mitigate work zone induced congestion. The following strategies received 75 percent or more respondents indicate their agency utilizes a strategy on projects similar to the scenarios (number of scenarios the strategy occurs, note):

- Dynamic message signs (4)
- Incentives/disincentives (3, all but rural resurfacing)
- Nighttime construction schedules (3, all but rural resurfacing)
- Traffic conditions displayed on the internet (1, urban reconstruction)
- Interim completion dates and liquidated damages (1, urban reconstruction)

These five strategies represent three work zone strategy groups: traffic management strategies, alternative project scheduling strategies, and alternative contracting and project delivery techniques. Upon further investigation, all scenarios, except rural resurfacing, had at least one strategy from each group receive more than 50 percent response.

The number of responses for many work zone congestion mitigation strategies differed across the four scenarios. The Current Strategy Implementation Comparison section identified strategies that had large differences in number of responses between the comparisons of two strategies. The objective of this analysis was to determine what strategies are commonly being used for one scenario, but not used as frequently in another. This provided insight to what types of projects the strategies are most suited and Table 19 summarizes the results.

The past strategy experiences identified strategies STAs previously implemented that failed to provide the expected benefits. While most strategies were identified by only one or zero respondents, a few strategies received more. The most frequently identified strategies were (scenario):

- Narrowed lanes (rural reconstruction)
- Increased speed enforcement (rural resurfacing and reconstruction)
- Full road closures (rural reconstruction)

As many as three respondents identified several strategies that utilize ITS technology. Several respondents did not indicate any strategies that failed to provide the expected benefits, but the comments portion of the question provided some insight to the lack of responses. A few agencies indicated that they either do not currently have any sort of performance measurement criteria or process to evaluate the effectiveness of work zone congestion strategies. Another response was that STAs have a hard time evaluating a single strategy implemented in a group.

Another question in this section identified strategies that STAs implemented regularly or a few times, but have since discontinued use and/or replaced them with another strategy. Overall, most of the strategies received at least one response that an agency did not have the expected results with a strategy. At minimum, the results show that no strategy is perfect; each may not always provide the expected benefits. The responses to this question were varied and there did not appear to be any trend among agencies of a certain strategy being commonly discontinued.

The strategy combination section identified strategy pairs that are present in each respondent's strategy selection for managing mobility and safety through a work zone. The first component was the identification of pairs that received more than 20 and 25 pair responses. These strategies are summarized in the tables within the section. As expected with the total individual responses for each scenario, the urban reconstruction scenario had the most strategy pairs with over 25 responses, while the rural resurfacing scenario only had one strategy pair with over 25 responses. The second component of this analysis is four matrices that facilitate the building of strategy combinations for a project similar to the survey scenarios. These matrices identify what strategies other STAs are commonly utilizing with a certain strategy, regardless of how many total responses the strategy received. For all but the rural resurfacing scenario, a few strategies were frequently identified with several other strategies, such as DMSs, nighttime construction schedules, and incentives/disincentives. The rural resurfacing scenario showed a wide variety of strategies selected by STAs, with minimal consistency across the agencies.

Overall, nearly 75 percent of the strategies for each scenario had responses that did not show any sort of trend across different work zone lane capacity ranges. The other 25 percent of the strategies showed either an increase, decrease, or the middle range was higher or lower than the other two ranges, in the number of respondents indicating they utilize a strategy. One issue was the small number of respondents used in this analysis, 18, and the subsequent few in each lane capacity range, between five and seven. Table 38 summarizes the strategies that showed a trend across the three lane capacity ranges for each of the four scenarios. The only strategy that was consistent across three of the four scenarios was the use of ITS technologies. The use of these technologies increased as the lane capacity ranges increased. Several other strategies showed a trend in multiple scenarios, but the trend varied in each of those. Because of the randomness of responses, it was difficulty to determine any trends across lane capacity ranges for many strategies. It appears that lane capacity does not make a difference on strategy selection across different agencies.

Thirty-six of the 42 respondents indicated their agency utilizes traffic simulation or planning tools to analyze work zone impacts on safety and mobility. The most frequently identified tool was a deterministic queuing tool, Highway Capacity Spreadsheets and theory, with 22 responses. Four other tools that received several responses were QuickZone (12), Synchro/SimTraffic (10), CORSIM (9), and QUEWZ (8). One issue identified through the analysis of responses was there are not any tools used by many STAs. Even in the 22 responses for the Highway Capacity Spreadsheets, several include spreadsheets developed by an STA, specific to their state.

The future strategy implementation section identified strategies that STAs are currently researching or planning to implement in the future. Each respondent was also asked to identify strategies they think would provide benefit to a project type. By understanding what strategies are likely to be used in the future by STAs, research is able to assist the agencies in implementation or provide recommendations on other strategies that may be suitable for a similar situation. The most commonly identified strategies, typically between 12 and 22 responses, were related to ITS: smart work zones, travel time and delay estimation systems, and advanced speed information systems. Between six and ten respondents identified the alternative contracting strategies lane rental and A+B and A+B+C contracting.

CHAPTER 6 – CONCLUSIONS AND RECOMENDATIONS

Overall, the Federal Highway Administration and State Transportation Agencies are actively trying to improve mobility and safety through and around the work zone. The extent of STA actions varies widely across the nation, due to different factors such as current congestion conditions and extent of addressing mobility concerns in the past. Several STAs have already been aggressively addressing the mobility and safety issues of work zones. Their utilization of work zone congestion mitigation strategies is very comprehensive, addressing many aspects of the a motorist's trip process. Other STAs are only now beginning to address the issue and lack the comprehensive knowledge of other agencies. The strategies being utilized to maintain adequate levels of safety and mobility vary widely between different project types (reconstruction or resurfacing) and location (urban or rural), as well as by STA. This research identified what strategies STAs are currently using and their experiences to provide a tool for all agencies in work zone congestion mitigation. This chapter consists of the survey analysis conclusions, the description of the strategy selection tables in Appendix B, and recommendations for future research.

6.1 Analysis Conclusions

The current strategy implementation results provided an insight to the strategies currently utilized by STAs to reduce work zone congestion. The strategies identified most frequently in the four scenarios consist of strategies from all five strategy groups. Each strategy group provides specific benefits to the final objective of reducing road user costs over the length of a project. Traffic management strategies work to increase mobility through a work zone by keeping traffic moving and maintaining adequate safety. Demand management strategies work to reduce motorist demand on the facility, which in turn reduces congestion. Design Alternatives to Minimize Life Cycle Congestion Cost Strategies maintains mobility on a facility not only during the current project, but will provide mobility benefits in future projects as well. Alternative scheduling strategies reduce road user costs by utilizing lane closures either during non-peak periods or reducing the overall road user costs by shortening the project duration. Finally, alternative contracting and project delivery strategies reduce total road user costs by shortening the project duration and lane occupancy durations. The successful application of strategies from all five strategy groups is an effective way to reduce congestion and minimize the road user costs imposed on motorists.

The results provide valuable information of what STAs are doing currently, their past strategy implementation experiences, and what they plan to do in the future. The sharing of both successful and unsuccessful experiences across agencies is important to improving work zone mobility and safety nationwide. Further, agencies that are now beginning to implement congestion mitigation strategies can view what similar agencies are doing for different projects, with different locations and work activities. Often, learning from experiences of unsuccessful implementation is just as important, if not more, than documentation of successful implementation. STAs are able to learn from mistakes and other issues that may arise and jeopardize the strategy's success.

6.2 Recommendations for Strategy Selection

The review of the literature and survey results indicated that agency objectives and attitude towards maintaining mobility facilitates successful Transportation Management Plans to reduce or eliminate work zone created congestion. Three recommendations on strategy selection and objectives were selected to promote successful strategy implementation. First, an agency needs to have a proactive view on reducing work zone congestion and implementing strategies to accomplish the objectives. Making work zone congestion a priority during the planning process will likely improve mobility through and around a work zone. Second, all strategies applicable to a project should be considered to achieve a comprehensive solution. Limiting strategy selection to a specific funding amount that eliminates the most beneficial strategies will likely result in more mobility issues during project implementation. While applying all strategies that an agency identifies may eliminate congestion to the largest possible extent, it is not financially feasible for agencies. An appropriate balance between mobility and funding should be found, and the extent of funding is likely tied to the work zone congestion objectives of the agency. Third, a diverse utilization of strategies from all five strategy groups is most beneficial. The strategy groups address congestion in a variety of different ways providing a comprehensive congestion mitigation solution.

Throughout the survey, many respondents indicated that more variables play a part in the selection of strategies than those provided in the scenarios. Because each project is unique, a selection of strategies to be applied for all projects within a give location and work activity, such as urban reconstruction, is not provided in this research. Rather, a table of strategies that are frequently used for a similar type of project is provided with additional information and strategies that can be used as suggestions and assistance in the strategy selection process. Appendix B consists of the strategy summary tables for all four scenarios. The tables identify the strategies that received over 50 percent response of implementation from the surveyed agencies, as shown in Section 5.2. For each strategy identified, further information is provided from the current implementation analysis in sections 5.3, 5.5 and past experiences identification in Section 5.4.

6.3 Recommendations for Future Research

The results showed that vast varieties of strategies are considered and being used by STAs across the United States. Aside from a few strategies, STAs tend to disagree on what strategies to use on certain types of projects. Dynamic message signs, incentives/disincentives, and nighttime construction schedules appear to be widely used for the different types of projects. However, beyond these three strategies, there generally lacks a consensus between STAs on what strategies should be used. Further research is necessary to complete a comprehensive combination of strategies that addresses all aspects of mobility and safety through and around work zones.

6.3.1 Areas of Emphasis

Throughout the analysis of the survey results, it was apparent that many STAs do not quantify the results of their strategy implementation. The reasons centered on STAs not knowing either how to quantify the results of all strategies used in combination or how to quantify the performance of individual strategies within the combination. By quantifying results, STAs will have a way to determine strategies that are successful and those that are not as successful and decide if another strategy should be explored as a replacement. STAs will also have quantitative results to justify the use of strategies, especially those with high costs. The following is the proposed research to address these issues.

- Develop performance measures and process to administer performance measures
    - For combinations of strategies
    - For individual strategies within a combination
- Perform a quantitative analysis of strategies to determine strategy groups
    - Benefit to cost analysis of individual strategies and combinations
    - Identification of components that go into strategy implementation and identify costs
    - Quantify variations of strategy interaction (effects on strategy performance due to implementation of a different strategy)
    - Build strategy combinations based on results
- Application of these issues to case studies

6.3.2 Strategy Combinations

One gap in the literature was the lack of discussion concerning strategy combinations uses on projects. Further research on all strategies in the TMP would benefit agencies when they are selecting strategies for similar projects.

- Identify the interaction of strategies when implemented together and the resulting implications
    - Positive or negative affects on another strategy
    - Expected results based on implementation with other strategies
    - Interaction of strategies within strategy groups and across strategy groups
- Expand the strategy pair identification to larger combinations, such as eight strategies for each project type

6.3.3 Individual Strategies

Further research of individual strategies would be very beneficial to improving the implementation and congestion mitigation potential of each strategy. One issue is the lack of a detailed explanation and implementation components of several of the strategies. Similarly, the determination and identification of the differing levels of benefit a strategy provides different project types and location.

- Identify how strategies benefit, and the extent, a specific type of project, based on varying location and work activities
- Investigation of strategy inclusion or exclusion by agencies that contradicted the survey respondents selections
    - Provide information on drawbacks or benefits of strategies not widely known
    - Determine why a couple of the strategies were not selected by all respondents
    - Note: no strategy was a unanimous selection in any survey scenario
- Analyze regional distributions of identified strategies for each project type (i.e. strategy implementation in Midwestern states may differ to those applied in East Coast states)

Most of the respondents did not describe any of the strategies that failed to meet their expectations. Therefore, the reasons why a strategy failed or the extent is unknown to this research. By providing other STA experiences, others may learn from their experiences and try to avoid similar results.

- Analyze the unsuccessful implementation of strategies

Through the identification of future strategy implementation by STAs and what agency staff feel could provide congestion mitigation benefits, opportunities are available for research institutions and groups to provide assistance. By providing the STA with as much information about implementation as possible reduces their risk of having a strategy fail and causing adverse congestion. The following four strategies were commonly identified for future use by the agencies and may benefit by further research.

- Smart Work Zones
- Travel Time and Delay Estimation Systems
- Advanced Speed Estimation Systems
- Lane Rental Fee Development

6.3.4 Case Studies

Many of the previously identified recommendations of future research involve output that can also be applied, and is very beneficial, to case studies.

- For the strategies that failed to meet expectations, follow up with those STAs and document their experience and why they feel it was unsuccessful
- Provide case studies of unsuccessful application of strategies.
- Include analysis of all strategies utilized on projects

6.3.5 Work Zone Simulation and Analysis Tools

Through the review of literature concerning work zone simulation and analysis tools, it appeared that there was minimal research on the accuracy of the analysis results compared to actual field conditions. The research that was available questioned the accuracy of the tools after the research determined many did not accurately portray actual field conditions. Another issue was the wide variety of tools that STAs utilize.

Highway Capacity Spreadsheets were the most widely used strategy, but only a little over half of the respondents indicated their agency uses the tool. Several other tools were identified by around 25 percent of the respondents.

- Evaluation of analysis tools and identification of benefits and drawbacks of each tool
- Determine the extent an STA uses an analysis tools, such as what tools they use for certain types of projects

APPENDIX A – SURVEY INSTRUMENT

The following is an example of the survey sent to potential respondents at State Transportation Agencies. The scenario survey questions are only presented once, for the rural reconstruction scenario, because they were the same for each scenario. Both rural and urban scenario information pages are provided. The online survey slightly deviates from this version because of formatting challenges the online tool provided. The content remained the same. A sample e-mail introduction is also included. The introductory e-mail sent to the respondents was personalized to account for the knowledge they would provide to the research, thus varied between recipients.

Introductory E-mail to Potential Respondents

Dear State Transportation Engineer,

The Center for Transportation Research and Education (CTRE) at Iowa State University is conducting a study on best practices for reducing traffic congestion in work zones. We could benefit greatly from your insight on this issue through your experience and knowledge with work zones. Your participation by providing what your agency does regarding work zone congestion in an online survey will be very beneficial to this project's objective of identifying what STAs are doing nationwide to reduce congestion in and around work zones.

We recognize that time is your most valuable asset, so we have designed the survey as concisely as possible. The questions should take between 15 and 45 minutes to complete, depending on the extent of your agency's use of congestion mitigation strategies. All data from the survey questions will be compiled anonymously, and your answers will remain confidential. The results of this survey will provide recommendations to the Smart Work Zone Deployment Initiative (SWZDI) by identifying which strategies would benefit from further research to provide quantitative results.

The survey is found on the following webpage:

http://www.surveymonkey.com/s.asp?u=431773489848

The closing date of the survey is April 14, 2007. If you are unable to complete the survey, please forward this to another staff member with knowledge of work zones.

We thank you in advance for your participation.

Jon Wiegand and Tom Maze

Center for Transportation Research and Education
Iowa State University

Instructions

- Read the short introduction that follows to familiarize yourself with the study
- Answer the General Organizational Questions on the first page of the survey.
- Read the scenarios that begin on the second page of the survey, and answer the questions that follow by checking the appropriate box.

- Use the comment boxes if there is anything else you would like to add, such as comments on a specific strategy, or another strategy that has been used successfully for a similar situation.

If you are uncertain of the definitions or classifications of any of the listed strategies, please refer to the Strategy Summaries listed at the end of the survey

Introduction

Congestion created or amplified by lane closures in work zones can create unacceptable delays to motorists if not adequately addressed. To manage or reduce this congestion, State Transportation Agencies (STAs) can use various congestion mitigation strategies. Generally, the strategies fall into the following five groups:

- Traffic Management Strategies
- Demand Management Strategies
- Alternative Project Scheduling and Phasing Strategies
- Design Alternatives to Minimize Life Cycle Congestion Cost Strategies
- Alternative Contracting and Delivery Strategies to Accelerate Project Completion

Various strategies that appear to have widespread use were selected for inclusion in this survey to provide consistent comparison. You will also have the opportunity to identify unique strategies that you might use for certain types of projects.

The purpose of this research is to determine what strategies are currently being utilized by STAs and their experiences, positive or negative, with a strategy and conclusions from usage. In addition to current practice, the questions also focus on past strategy experiences and future plans of what the agency would like to utilize. To help determine answers to these questions, four scenarios were developed:

- Rural: Interstate 80 between Iowa City and Davenport
    - Reconstruction
    - Resurfacing
- Urban: Interstate 235 in metropolitan Des Moines
    - Reconstruction
    - Resurfacing

The objective of the reconstruction project is to add capacity, thus one lane is being added in each direction. The current travel ways are adequate to maintain traffic through a work zone, but will eventually be replaced in the project. The rural reconstruction project converts a four lane, median divided facility into a six lane median divided facility, three lanes in each direction. The urban reconstruction project reconstructs a six lane facility into a barrier separated eight lane facility, four lanes in each direction. The duration of the lane closure(s) is several months, often utilizing the length of a construction season for only one direction or section of a multi-year project. A resurfacing or patching project is one that will resurface the current lanes with an asphalt overlay. The current roadway is an asphalt wearing course that will be removed prior to overlay. The duration of the lane closure is most likely a couple of weeks, either continuous or intermittent to accommodate peak period traffic.

General Organizational Questions

Name of Respondent:
Agency:
Position within Agency:
Telephone:
E-mail:

Interstate and Freeway Work Zone Lane Capacities

Please enter the work zone lane capacities in the box

If your agency has an all inclusive work zone lane capacity that does not vary based on number of lanes open or closed, please enter the value in the following:
Work Zone Lane Capacity vehicles per hour per lane (vphpl)

If your agency varies work zone lane capacity based on number of lanes open and closed, please enter the value in the following situations, if applicable:

Three lanes open, one lane closed
Work Zone Lane Capacity vehicles per hour per lane (vphpl)

Two lanes open, one lane closed
Work Zone Lane Capacity vphpl

One lane open, one lane closed
Work Zone Lane Capacity vphpl

Planning Tools

For work zone traffic management planning, does your agency use traffic simulation or highway capacity tools to analyze current traffic and expected work zone traffic conditions?

- *Please note any differences between state or district offices, rural or urban facility, or activity type (reconstruction, resurfacing or maintenance)*
- *Tool examples include: Highway Capacity Manual equations, spreadsheets, QuickZone, Quewz, CORSIM, Synchro/SimTraffic, VISSIM, etc.*

Rural Scenarios

For the two rural Interstate projects, the situation is similar to what the Iowa Department of Transportation would encounter when performing the activities on Interstate 80 between Davenport and Des Moines. The example rural project is located near an automated traffic recorder (ATR) location. High traffic volumes approach and exceed the Iowa DOT's work zone lane capacity for a single open lane, lane closure of 1,350 vehicles per hour per lane (vphpl) during the afternoons every day of the week, reaching the daily maximum hourly peak between 4-6 pm. Minimal commuter traffic is experienced at this location since it is along a rural segment of I-80. There is the occurrence of peaks in traffic volumes due to events at the University of Iowa, especially during home football game Saturdays in the fall. Only the reconstruction project is most likely to coincide with football games as resurfacing and maintenance activities offer flexibility due to shorter lane occupancy durations. One unique characteristic of Interstate 80 is the high volumes of trucks. Thirty two percent of the volume at this location consists of trucks. Most traffic is likely to stay on the facility as alternate routes are distant (60 to 80 miles out of the way travel).

Relevant Information Summary

AADT: 36000

Percent Trucks: 32 percent

Number of Lanes: 4 lanes
(2 in each direction)

Terrain: Rolling hills

Location Example: I-80 between Iowa City and Davenport

Peak Hours:
Weekdays: 1–6pm
Ranging between 1100-1550 vph
Exceeds 1350 vph: 3–6pm
Weekends: Sundays 11am–7pm

Ranging between 1100 – 1500 vph

Minimal Commuter Traffic
University of Iowa Event Traffic

Considerations:

Scenario 1. Rural Reconstruction Project
Conversion of median divided four-lane Interstate to six lanes over 10 miles

1. Current Strategy Implementation
Given the scenario, what congestion mitigation strategies would your State Transportation Agency typically use? *Please check all that apply.*

Use of ITS Technologies
☐ Dynamic Message Signs
☐ Travel Time and Delay Estimation System
☐ Advanced Speed Information System
☐ Traffic Conditions Displayed on Internet
☐ Other ITS:

Alternative Project Scheduling Strategies
☐ Use of Nighttime Construction Schedules
☐ Use of Full Road Closures

Demand Management Strategies
☐ Improved Pre-Construction Traveler Information
☐ Mass Transit Improvements (Bus, rail, etc.)
☐ Encourage Alternative Modes, Carpooling, Telecommuting, Transit Fare Reductions, etc.

Contracting and Project Delivery Strategies
☐ Design Build Construction
☐ Lane Rental
☐ A+B and A+B+C Contracting
☐ Incentives and Disincentives to Reduce Construction Duration and Impacts
☐ Interim Completion Dates and Liquidated Damages

Other Strategies
☐ Increased Incident Management Capabilities
☐ Increased Speed Enforcement
☐ Narrowed Lanes through Work Zone
☐ Alternative Route Improvements
☐ Use of Temporary Pavement
☐ **Others**:

Comments and further information:

2. Past Experiences
Based on past experiences on similar projects, did any of the previously listed strategies fail to provide congestion mitigation benefits that were expected or acceptable to the agency?

- *As an example, congestion was not noticeably reduced*
- *If other strategies have been tried but failed to provide expected congestion reduction, please list*

Use of ITS Technologies
☐ Dynamic Message Signs
☐ Travel Time and Delay Estimation System
☐ Advanced Speed Information System
☐ Traffic Conditions Displayed on Internet
☐ Other ITS:

Alternative Project Scheduling Strategies
☐ Use of Nighttime Construction Schedules
☐ Use of Full Road Closures

Demand Management Strategies
☐ Improved Pre-Construction Traveler Information
☐ Mass Transit Improvements (Bus, rail, etc.)
☐ Encourage Alternative Modes, Carpooling, Telecommuting, Transit Fare Reductions, etc.

Contracting and Project Delivery Strategies
☐ Design Build Construction
☐ Lane Rental
☐ A+B and A+B+C Contracting
☐ Incentives and Disincentives to Reduce Construction Duration and Impacts
☐ Interim Completion Dates and Liquidated Damages

Other Strategies
☐ Increased Incident Management Capabilities
☐ Increased Speed Enforcement
☐ Narrowed Lanes through Work Zone
☐ Alternative Route Improvements
☐ Use of Temporary Pavement
☐ **Others**:

Comments and further information:

What work zone congestion mitigation strategies, if any, has your agency utilized in the past for a similar project but have since discontinued or replaced with other strategies?

- *The strategies could be both successful and unsuccessful in mitigating work zone congestion.*
- *One reason for replacing a successful strategy is using an alternative strategy that further reduces congestion and/or agency costs.*
- *Please list the strategies that were replaced, any strategies that directly replaced them, and reason why a strategy is no longer used. The strategies can be both those on the list provided in the survey and those not listed.*

3. Future Projects

Are there any strategies that your transportation agency has not typically utilized in similar rural reconstruction projects but is currently researching or looking to implement for future projects? *Please check all that apply.*

Use of ITS Technologies

☐ Dynamic Message Signs
☐ Travel Time and Delay Estimation System
☐ Advanced Speed Information System
☐ Traffic Conditions Displayed on Internet
☐ Other ITS:

Alternative Project Scheduling Strategies

☐ Use of Nighttime Construction Schedules
☐ Use of Full Road Closures

Demand Management Strategies

☐ Improved Pre-Construction Traveler Information
☐ Mass Transit Improvements (Bus, rail, etc.)
☐ Encourage Alternative Modes, Carpooling, Telecommuting, Transit Fare Reductions, etc.

Contracting and Project Delivery Strategies

☐ Design Build Construction
☐ Lane Rental
☐ A+B and A+B+C Contracting
☐ Incentives and Disincentives to Reduce Construction Duration and Impacts
☐ Interim Completion Dates and Liquidated Damages

Other Strategies

☐ Increased Incident Management Capabilities
☐ Increased Speed Enforcement
☐ Narrowed Lanes through Work Zone
☐ Alternative Route Improvements
☐ Use of Temporary Pavement
☐ **Others**:

Comments and further information:

Are there any other strategies that, in your opinion, should possibly be explored?
Please list any strategies and state why or what benefit the strategy may contribute to congestion mitigation.

Urban Scenarios

For the urban Interstate projects, the situation is similar to what the Iowa Department of Transportation would encounter when reconstructing, resurfacing, or performing maintenance on Interstate 235 in metropolitan Des Moines. The location selected is in the western suburbs of Des Moines, east of the Interstate 80 and 35 interchange Commuter traffic is highly peaked, with directional volumes exceeding 1600 vphpl when all three lanes are open. The morning peak generally lasts two hours and has directional volumes that approach 2000 vphpl. I-235 has a very low percentage of trucks, four percent. Interstate 80 offers an alternative route for through traffic movements, but provides minimal benefit for commuters entering the Central Business District or commuters inside the urban core. Alternative route possibilities include arterials that run parallel to Interstate 235, but they do not have sufficient excess capacity to be used as a means for handling diverted traffic. A bus system is already in place to offer a mass transit option to and from downtown and the western suburbs. Stadiums, arenas and other event locations are located downtown which may attract thousands of people in a short amount of time. Similarly, in the fall, the Interstate 235 is a major gateway to the Iowa State Fair which often draws over a million people in eleven days.

Relevant Information Summary

AADT: 85000

Percent Trucks: 4 percent

Number of Lanes: 6 through lanes
3 lanes eastbound
3 lanes westbound

Terrain: level

Location Example: I-235 in Des Moines metro

Considerations:
High commuter volumes
Downtown special events

Weekend: Peak directional hourly volumes around 2400 in afternoon

Peak Hours:
Weekday Hourly volumes

	Eastbound		Westbound	
	Volume (vehicles)	**Vehicles per lane***	**Volume (vehicles)**	**Vehicles per lane***
6am	3421	1711	1851	926
7am	5784	2892	3068	1534
8am	4128	2064	2483	1242
9am	2630	1315	2019	1010
10am	2141	1071	2199	1100
11am	2273	1137	2519	1260
12noon	2643	1322	2723	1362
1pm	2615	1308	2491	1246
2pm	2823	1412	2696	1348
3pm	3205	1603	3944	1972
4pm	3557	1779	4893	2447
5pm	3319	1660	4814	2407
6pm	2213	1107	2662	1331
7pm	1540	770	1644	822
8pm	1257	629	1187	594

*** Vehicles per lane with 2 lanes open and one closed**

APPENDIX B – STRATEGY SELECTION TABLES

The following is a set of tables that summarize the survey results of Section 5.2, 5.3, 5.4, and 5.5. This table was developed to provide relevant information and assist STAs, or other agencies seeking to mitigate work zone congestion, in making decisions on what strategies they would like to utilize for different projects. The strategies are listed in decreasing order by total number of individual responses, as shown in Section 5.2. The strategies were limited to those receiving 50 percent or more identification from the STA respondents. Below is a description of what sections the information is analyzed and originally presented.

Strategy Response Percent - Section 5.2	
Strategy	*Strategy Group*
Total Pair Responses • Section 5.5.1	Frequently Paired Strategies • Section 5.5.2
Notes: Section 5.3 and Section 5.4	

Rural Reconstruction Strategy Summary

75 Percent Response	
Dynamic Message Signs	*Traffic Management Strategy*
Total Pair Responses • Traffic conditions displayed on internet • Nighttime construction schedules • Incentives/disincentives • Interim completion dates and liquidated damages • Narrowed lanes • Temporary pavement	Frequently Paired Strategies • Incentives/disincentives
Notes: Respondents noted that strategy loses effectiveness from irrelevant messages	
Incentives/Disincentives	*Alternative Contracting and Project Delivery Strategies*
Total Pair Responses • Dynamic message signs • Traffic conditions displayed on internet • Nighttime construction schedules • Interim completion dates and liquidated damages • Improved pre-construction traveler information • Increased incident management • Temporary pavement • Narrowed lanes	Frequently Paired Strategies • Dynamic message signs
Notes: 8 more responses for rural reconstruction than rural resurfacing scenario	
Nighttime Construction Schedules	*Alternative Project Scheduling Strategies*
Total Pair Responses • Dynamic message signs • Traffic conditions displayed on internet • Incentives/disincentives	Frequently Paired Strategies • Incentives/disincentives
Notes:	

50 Percent Response

Traffic Conditions Displayed on Internet
Traffic Management Strategies

Total Pair Responses	Frequently Paired Strategies
• Dynamic message signs • Nighttime construction • Incentives/disincentives	

Notes:

Temporary Pavement
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies

Total Pair Responses	Frequently Paired Strategies
• Dynamic message signs • Incentives/disincentives	• Incentives/disincentives

Notes: 17 more responses for rural reconstruction than rural resurfacing scenario

Interim Completion Dates and Liquidated Damages
Alternative Contracting and Project Delivery Strategies

Total Pair Responses	Frequently Paired Strategies
• Dynamic message signs • Incentives/disincentives	• Incentives/disincentives

Notes: Possible difficulty in enforcing damages

Increased Speed Enforcement
Traffic Management Strategies

Total Pair Responses	Frequently Paired Strategies

Notes: 4 respondents indicated past experiences did not meet expectations

Narrowed Lanes
Traffic Management Strategies

Total Pair Responses	Frequently Paired Strategies
• Dynamic message signs • Incentives/disincentives	• Dynamic message signs • Incentives/disincentives

Notes: 6 respondents indicated past experiences did not meet expectations

Increased Incident Management Capabilities
Traffic Management Strategies

Total Pair Responses	Frequently Paired Strategies
• Incentives/disincentives	• Dynamic message signs • Incentives/disincentives

Notes:

Improved Pre-Construction Traveler Information
Demand Management Strategies

Total Pair Responses	Frequently Paired Strategies
• Incentives/disincentives	• Dynamic message signs • Incentives/disincentives

Notes:

A+B and A+B+C Contracting
Alternative Contracting and Project Delivery Strategies

Total Pair Responses	Frequently Paired Strategies
	• Dynamic message signs • Incentives/disincentives

Notes:

Rural Resurfacing Strategy Summary

75 Percent Response

Dynamic Message Signs	*Traffic Management Strategy*
Total Pair Responses • Incentives/disincentives	Frequently Paired Strategies • Incentives/disincentives
Notes: Respondents noted that strategy loses effectiveness from irrelevant messages	

50 Percent Response

Narrowed Lanes	*Traffic Management Strategies*
Total Pair Responses	Frequently Paired Strategies
Notes:	
Nighttime Construction Schedules	*Alternative Project Scheduling Strategies*
Total Pair Responses	Frequently Paired Strategies
Notes: 9 fewer responses for rural resurfacing than urban resurfacing scenario 8 fewer responses for rural resurfacing than rural reconstruction scenario	
Incentives/Disincentives	*Alternative Contracting and Project Delivery Strategies*
Total Pair Responses • Dynamic message signs	Frequently Paired Strategies
Notes: 8 fewer responses for rural resurfacing than rural reconstruction scenario	
Traffic Conditions Displayed on Internet	*Traffic Management Strategies*
Total Pair Responses	Frequently Paired Strategies
Notes:	
Increased Speed Enforcement	*Traffic Management Strategies*
Total Pair Responses	Frequently Paired Strategies
Notes: 4 respondents indicated past experiences did not meet expectations	
Increased Incident Management Capabilities	*Traffic Management Strategies*
Total Pair Responses	Frequently Paired Strategies
Notes: 8 fewer responses for rural resurfacing than urban resurfacing scenario	
Interim Completion Dates and Liquidated Damages	*Alternative Contracting and Project Delivery Strategies*
Total Pair Responses	Frequently Paired Strategies
Notes: Damages can be difficult to enforce	
Improved Pre-Construction Traveler Information	*Demand Management Strategies*
Total Pair Responses	Frequently Paired Strategies
Notes: 7 fewer responses for rural resurfacing than urban resurfacing scenario	

Urban Reconstruction Strategy Summary

75 Percent Response

Dynamic Message Signs

Traffic Management Strategies

Total Pair Responses
- Traffic conditions displayed on internet
- Nighttime construction schedules
- Incentives/disincentives
- Interim completion dates and liquidated damages
- Improved pre-construction traveler information
- Demand side traffic management
- Increased incident management capabilities
- Increased speed enforcement
- Narrowed lanes

Frequently Paired Strategies
- Nighttime construction schedules

Notes: Respondents noted that strategy loses effectiveness from irrelevant messages

Nighttime Construction Schedules

Alternative Contracting and Project Delivery Strategies

Total Pair Responses
- Dynamic message signs
- Traffic conditions displayed on internet
- Incentives/disincentives
- Interim completion dates and liquidated damages
- Improve pre-construction traveler information
- Demand side traffic management
- Increased incident management capabilities
- Increased speed enforcement
- Narrowed lanes
- Alternative route improvements

Frequently Paired Strategies
- Dynamic message signs

Notes: 17 more responses for rural reconstruction than rural resurfacing scenario

Incentives/Disincentives

Alternative Contracting and Project Delivery Strategies

Total Pair Responses
- Dynamic message signs
- Traffic conditions displayed on internet
- Nighttime construction schedules
- Interim completion dates and liquidated damages
- Improved pre-construction traveler information
- Increased incident management capabilities
- Narrowed lanes

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes:

Traffic Conditions Displayed on Internet

Demand Management Strategies

Total Pair Responses
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives
- Interim completion dates and liquidated damages

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes:

Interim Completion Dates and Liquidated Damages

Alternative Contracting and Project Delivery Strategies

Total Pair Responses
- Dynamic message signs
- Traffic conditions displayed on internet
- Nighttime construction schedules
- Incentives/disincentives

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes: Damages can be difficult to enforce

50 Percent Response

Improved Pre-Construction Traveler Information
Demand Management Strategies

Total Pair Responses
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes:

Increased Incident Management Capabilities
Traffic Management Strategies

Total Pair Responses
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives

Notes: 17 more responses for rural reconstruction than rural resurfacing scenario

Narrowed Lanes
Traffic Management Strategies

Total Pair Responses
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives

Notes:

Demand Side Traffic Management
Demand Management Strategies

Total Pair Responses
- Dynamic message signs
- Nighttime construction schedules

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes: 9 more responses for urban reconstruction than rural reconstruction scenario

Increased Speed Enforcement
Traffic Management Strategies

Total Pair Responses
- Dynamic message signs
- Nighttime construction schedules

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes:

Alternative Route Improvements
Demand Management Strategies

Total Pair Responses
- Nighttime construction schedules

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes: 10 more responses for urban reconstruction than rural reconstruction scenario
9 more responses for urban reconstruction than urban resurfacing scenario

Temporary Pavement
Design Alternatives to Minimize Life Cycle Congestion Cost Strategies

Total Pair Responses

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives

Notes: 9 more responses for urban reconstruction than urban resurfacing scenario

A+B and A+B+C Contracting
Alternative Contracting and Project Delivery Strategies

Total Pair Responses

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules
- Incentives/disincentives

Notes:

Lane Rental
Alternative Contracting and Project Delivery Strategies

Total Pair Responses

Frequently Paired Strategies
- Dynamic message signs
- Nighttime construction schedules

Notes: 7 more responses for urban reconstruction than rural reconstruction
Applicable fees specific to project necessary

Urban Resurfacing Strategy Summary

75 Percent Response

Nighttime Construction Schedules	*Alternative Project Scheduling Strategies*
Total Pair Responses • Dynamic message signs • Traffic conditions displayed on internet • Incentives/disincentives • Interim completion dates and liquidated damages • Improved pre-construction traveler information • Increased incident management capabilities • Increased speed enforcement • Narrowed lanes	Frequently Paired Strategies • Dynamic message signs
Notes: 9 more responses for urban resurfacing than rural resurfacing scenario	

Dynamic Message Signs	*Traffic Management Strategies*
Total Pair Responses • Traffic conditions displayed on internet • Nighttime construction schedules • Incentives/disincentives • Improved pre-construction traveler information • Increased incident management capabilities • Narrowed lanes	Frequently Paired Strategies • Nighttime construction schedules
Notes: 8 more responses for urban resurfacing than rural resurfacing scenario Respondents noted that strategy loses effectiveness from irrelevant messages	

Incentives/Disincentives	*Alternative Contracting and Delivery Strategies*
Total Pair Responses • Dynamic message signs • Nighttime construction schedules • Increased incident management	Frequently Paired Strategies • Dynamic message signs • Nighttime construction schedules
Notes:	

50 Percent Response

Increased Incident Management Capabilities	*Traffic Management Strategies*
Total Pair Responses • Dynamic message signs • Nighttime construction schedules • Incentives/disincentives • Narrowed lanes	Frequently Paired Strategies • Dynamic message signs • Nighttime construction schedules • Incentives/disincentives
Notes: 7 more responses for urban resurfacing than rural resurfacing scenario	
Traffic Conditions Displayed on Internet	***Traffic Management Strategies***
Total Pair Responses • Dynamic message signs • Nighttime construction schedules	Frequently Paired Strategies • Dynamic message signs • Nighttime construction schedules
Notes:	
Improved Pre-Construction Traveler Information	*Demand Management Strategies*
Total Pair Responses • Dynamic message signs • Nighttime Construction Schedules	Frequently Paired Strategies • Dynamic message signs • Nighttime construction schedules
Notes: 7 more responses for urban resurfacing than rural resurfacing scenario	
Increased Speed Enforcement	*Traffic Management Strategies*
Total Pair Responses • Nighttime construction schedules	Frequently Paired Strategies • Nighttime construction schedules
Notes:	
Narrowed Lanes	*Traffic Management Strategies*
Total Pair Responses • Dynamic message signs • Nighttime construction schedules • Increased incident management capabilities	Frequently Paired Strategies • Dynamic message signs • Nighttime construction schedules • Increased incident management capabilities
Notes:	
Interim Completion Dates and Liquidated Damages	*Alternative Contracting and Delivery Strategies*
Total Pair Responses • Nighttime construction schedules	Frequently Paired Strategies • Dynamic message signs • Nighttime construction schedules • Increased incident management capabilities
Notes:	
Demand Side Traffic Management	*Demand Management Strategies*
Total Pair Responses	Frequently Paired Strategies • Dynamic message signs • Nighttime construction schedules • Increased incident management capabilities
Notes: 9 more responses for urban resurfacing than rural resurfacing scenario	

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